BARR

Sugar Creek Lake Source Water Protection Plan

Prepared for
City of Moberly

City of Moberly!

June 2019

DRAFT

1001 Diamond Ridge, Suite 1100
Jefferson City, MO 65109
573.638.5000
www.barr.com

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Abbreviations

BMP	best management practice
DBPs	disinfection byproducts
DO	dissolved oxygen
GeoSTRAT	Geosciences Technical Resources Assessment Tool
HAA	haloacetic acids
ISS	inorganic suspended solids
LMVP	Lakes of Missouri Volunteer Program
MDC	Missouri Department of Conservation
MDNR	Missouri Department of Natural Resources
NLCD	National Land Cover Dataset
NRCS	Natural Resources Conservation Service
QAPP	Quality Assurance Project Plan
SPI	Stream Power Index
SWCD	soil and water conservation district
THM	trihalomethanes
THPWD	Thomas-Hill Public Water Supply District
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
WTP	water treatment plant

1.0 Introduction

Sugar Creek Lake (lake) is a 330 acre reservoir on Sugar Creek located approximately 4 miles northwest of the City of Moberly (City) and serves as the City's sole drinking water source (Large Figure 1 and Large Figure 2). The City owns the lake and 269 acres adjacent to the shoreline (Large Figure 3). Although the lake's primary use is drinking water supply for the City, the lake is also used frequently for recreation. Stakeholder interest in the lake's water quality and quantity include, but are not limited to drinking water consumers, recreationists, and landowners within the Sugar Creek Lake watershed (watershed). Over the previous two decades, increased water quality stressors, regulatory drivers, and City population growth have stimulated increased stakeholder interest in the protection of the lake. This Source Water Protection Plan (Plan) sets forth strategies and provides guidance to stakeholders for the protection of the lake and its watershed, in order to provide sustainable, reliable, and high quality drinking water supply for the City and its customers.

1.1 Background

This Plan is a comprehensive update to the City's original Source Water Protection Plan (2004 Plan). The purpose of the 2004 Plan was to establish a document that identified major resource issues and strategies to address the issues to improve the lake's water quality and plan for the longevity of the lake as a drinking water source for the City. The goals of the 2004 Plan included the following:

- Goal 1: Reduce levels of trihalomethanes (THM) and haloacetic acids (HAA), both of which are disinfection byproducts (DBPs), in the City's finished water so that quarterly tests are always below allowable levels
- Goal 2: Ensure there will be enough water to meet the City of Moberly's needs for population and business growth for the next 200 years

Two primary objectives of each of the 2004 Plan's goals were to reduce disinfection byproducts (DBPs) and to seek out additional sources of water supply to supplement the lake's supply, respectively. The goal to reduce DBPs in the City's produced water has been largely met; however, the City has not yet obtained an additional water supply source. Due to observed free ammonia spikes in the lake and the other nutrient sample results, and the City's concerns about long–term water supply, the City determined in 2017 that the Plan needed to be updated and expanded. The City applied for grant funding to complete an update of the Plan through the Missouri Department of Natural Resources' (MDNR) Public Drinking Water Branch, Source Water Protection Grant, and was subsequently awarded a grant that would partially fund this project. MDNR partnered in this Plan through the grant and by conducting an updated lake yield study (Appendix A). The City's partnership with the U.S. Geological Survey (USGS) also contributed to the lake yield study by providing funding and technical expertise in conducting a bathymetric survey of the lake and providing a change analysis with this data.

1.2 Purpose

The purpose of this updated and expanded Plan is to identify goals, objectives, and strategies for the lake and provide a guidance to stakeholders for the long-term protection of the lake as a drinking water source for the City. During the planning process, discussed in Section 2.0, stakeholders developed the following purpose statement to guide this Plan's development:

"To develop a voluntary program that results in best management practices (BMPs) for activities on Sugar Creek Lake and its watershed."

This Plan is also designed to achieve the following objectives:

- describe the planning process used develop the goals, objectives, and strategies for the lake (Section 2.0)
- outline the specific goals, objectives, and strategies for this Plan and include existing and proposed implementation timelines (Section 3.0)
- identify potential watershed-wide sources of pollution that may reasonably be expected to affect the lake's water quality (Section 4.0)
- describe water quality data for the lake with respect to Missouri Water Quality Standards (Section 5.0)
- discuss historic water treatment challenges and long-term water supply (Section 6.0)
- propose steps toward future implementation of goals, objectives, and strategies identified in this Plan (Section 7.0)

2.0 Planning Process

This section presents the City's planning process for this Plan. The City believes that it was critical to include stakeholder and public engagement in the planning process to maximize the benefits of the process and achieve the goals of this Plan. The City developed a stakeholder engagement plan and included broad outreach to the public with many opportunities to provide input regarding the content of this Plan and the needs of the lake and the watershed. This approach included three tiers of planning teams and meetings: the Planning Team, the Core Planning Committee, and the Citizen's Cabinet. These groups included stakeholders that represent a wide variety of needs and perspectives in the watershed. The approach and meeting content is described in Sections 2.1 and 2.2. Section 2.3 provides a summary of key topics discussed at the meetings, as well as summarizing concerns and questions of the stakeholders.

2.1 Approach

The planning process was conducted using a three-tier approach with three groups of stakeholders. The stakeholders groups worked together to assemble information and input for the planning process. The three tiers of the planning process included the following:

- Planning Team
- Core Planning Committee
- Citizen's Cabinet

The first tier of the planning process began with the Planning Team, which consisted of staff from the City staff, MU Extension, Boone Consulting, and Barr Engineering Co. The following individuals were members of this team:

- Mary West-Calcagno, Director of Public Utilities, City of Moberly
- Matt Everts, Chief Operator, City of Moberly
- Tony Boone, Boone Consulting
- Tish Johnson, University of Missouri, Extension
- Andrea Collier, Barr Engineering Co.

The Planning Team met in person and via conference calls to develop an initial framework that resulted in the next two tiers of public engagement. In addition, this team coordinated and facilitated for public meetings, which included content development, data presentation, guest speaker coordination, meeting summaries, and documentation of the public engagement process.

The Planning Team identified that a second tier of planning was needed and would be called the Core Planning Committee. The Core Planning Committee members consisted of all of the members of the Planning Team, and the following stakeholders:

- Eric Breusch, Randolph County Health Department
- Dhruba Dhakal, University of Missouri, Extension
- Todd Walker, City of Moberly Parks & Recreation Department
- John Kirchhoff, Randolph County Soil and Water Conservation District
- Brian Todd, Missouri Department of Conservation (MDC)
- Bob Riley, community resident and volunteer

The Core Planning Committee was convened to determine how to design and facilitate the larger public engagement process, or third tier of stakeholder meetings. This third tier of the planning process was named the Citizen's Committee. Attendees of the Citizen's Committee meetings included all of the Planning Team members and the Core Planning Committee members, the public, and stakeholders representing the following sectors:

- Lake watershed residents and land owners
- Agricultural producers and land owners
- Business and industry
- Non-profit organizations
- Education
- Lake recreation
- Newspaper and radio media
- City government
- County government
- State government
- Federal government

2.2 Meetings

The Planning Team met in person or conducted conference calls to coordinate and plan meetings with stakeholders and the public. The Planning Team developed content for the meetings and engaged as participants. Provided below are the meeting dates for all of the meetings the City hosted with the Core

Planning Committee and the Citizen's Cabinet. These in-person meetings provided key input to developing Plan content and examining existing data and information for the lake and watershed. The Core Planning Committee met in person on the following dates:

- June 12, 2018
- June 28, 2018
- July 20, 2018

The goals and content of the Core Planning Committee meetings included determining all of the categories of stakeholders that should be notified about the Citizen's Cabinet meetings, key topics to discuss in the meetings, and important data and information to present in the meetings. The Core Planning Committee assisted the Planning Team in making decisions about and prioritizing meeting content for the Citizen's Cabinet meetings. The Citizen's Cabinet included a broad range of stakeholders and was open to the public. These public meetings convened after the Core Planning Committee met three times. The Citizen's Cabinet met in person on the following dates:

- August 23, 2018
- September 25, 2018
- November 29, 2018
- December 11, 2018
- January 10, 2019
- January 29, 2019

The goals and content of these meetings included reviewing watershed characteristics, reviewing available data and information regarding the lake and watershed, identifying goals for the lake and watershed, identifying key concerns of stakeholders, and providing a forum for discussion and input to be provided to the City. These meeting topics are summarized in Section 2.3.

2.3 Public Participation and Input

The input provided by stakeholders in the Core Committee and Citizen's Cabinet meetings was very broad and many of the topics were discussed at several meetings; this input is summarized below. In addition, multiple newspaper articles were written about the planning process by the Moberly Monitor-Index.

During the planning meetings, stakeholders developed the following statements to cast vision for the planning process and this Plan:

Community Representation Statement

"We endeavor to represent diverse community interests, to educate and motivate citizens to protect all water uses at Sugar Creek Lake for present and future generations."

Source Water Protection Plan Purpose Statement

"To develop a voluntary program that results in best management practices (BMPs) for activities on Sugar Creek Lake and its watershed."

2.3.1 Meeting Topics and Key Issues

Topics that were discussed in the meetings included, but were not limited to the following:

- Watershed characteristics
- Defined the lake as City infrastructure that must be operated and maintained
- Available quantity of the lake's raw water supply
- Lake water sample data and pollutant loads in the lake
- Lake bottom sediment and resuspension of nutrients
- Operation of the Water Treatment Plant (WTP) and treatment challenges
- Algae bloom control
- Property ownership adjacent to the lake shoreline
- Concerns and impacts regarding specific pollutants
- Current lake water quality impairment and potential future impairment for nutrients
- Potential sources of pollutants in the lake and watershed
- Soil erosion and high velocity ravines
- Concerns regarding flood and drought response
- Stakeholder interest and concerns about use of the lake for recreation
- Land cover data and estimated pollutant loads
- City stormwater management plan and practices
- BMPs that could be employed in the watershed
- Public education and outreach opportunities
- Stakeholder concerns and questions about Plan implementation
- Sources of funding for Plan implementation

Key questions and concerns (paraphrased and summarized below) of stakeholders that were discussed in the meetings and influenced Plan goals and content, included, but are not limited to the following:

- **Water quality:**
  - Stakeholders asked if the City had examined the available water quality data for the lake and determined the relative severity of the pollutant concentrations. Data was summarized and presented in meetings to support this discussion. It was discussed that the lake is currently on the 303(d) list of impaired water bodies for mercury in fish tissue, and is not listed as impaired for nutrients, but may be trending toward nutrient impairment.
  - Stakeholders asked if the City could identify sources of pollutants in order that these pollutant sources could be mitigated. It was discussed that additional data may need to be collected and analyses conducted to identify pollutant sources and relative impacts of those sources.
- **Water quantity:**
  - Stakeholders asked if the City had determined whether the lake is a sustainable long-term source of water supply. In order to begin to address this question, MDNR and USGS partnered with this City to update the Lake Yield Study (Appendix A).
  - Stakeholders expressed concerns that the lake is the City's sole source of water supply and that City does not have a backup source of drinking water.
- **Outreach and public engagement:**
  - Stakeholders indicated that an increase of public awareness is needed regarding the use of the lake as the City's drinking water source, and the water quality concerns in the lake.
  - Stakeholders asked about how to most effectively engage with the public, and how to sustain this engagement. The City expressed intentions to seek out ongoing stakeholder and public input through established groups and in-person meetings. Members of the local media outlets were present at meetings and provided information via articles and radio broadcasts. Social media use was included and was encouraged to be used an ongoing means of outreach. Outreach through schools (primary, secondary, and higher education) was determined to be another important component of the City's future plans for outreach.
  - Stakeholders indicated that public meetings are welcome and should continue in an ongoing manner after the 2019 Plan is finalized. The City stated its intent to continue in-person meetings with stakeholders.
- **Funding and partnerships:** Stakeholders asked if sources of funding exist that could be used to address needs at the lake and in the watershed. Sources of funding were discussed, including the State Revolving Fund, MDNR's Multipurpose Water Resources Program Fund, and Soil and Water Conservation Program and U.S. Department of Agriculture (USDA) - Natural Resources

Conservation Service (NRCS) cost share programs. Discussions about partnerships with agencies, local governments, and managers of funding sources was central to this topic.

- **Agricultural landowner concerns:** Agricultural producers and land owners expressed both interest and concerns about the City's expectations for use of BMPs on their property, and perceived impacts of agriculture on the lake water quality. This was a key topic in each meeting, and the City engaged to address agricultural land owners' concerns. In summary, the City stated that agriculture is not the only contributor to pollutants in the lake; however, the City also expressed that it is important to understand that any BMPs that are implemented in the watershed would help reduce nutrient and sediment loads. MDNR Soil and Water Conservation Program and District staff provided several presentations on funding and cost-share opportunities for agricultural land owners.

2.3.2 Stakeholder Survey Results

The University of Missouri Extension conducted an online survey of stakeholders in March 2019. Potential survey respondents were notified of the survey opportunity at public meetings and by email. A total of 54 people submitted responses to the five questions in the survey. Survey results are provided in Appendix B. The survey results were used to inform the content of public meetings, particularly the Citizen's Cabinet, and the content of this Plan. In summary, respondents to the survey provided the following information and input:

- 50 of the 54 respondents were aware of the lake is a drinking water source (survey question 1). Two of the other respondents were unsure if the lake is a drinking water source. The other two respondents responded that they did not think the lake is a source of drinking water.
- 52 of the 54 respondents expressed a connection to either living, working, recreating, or drinking water from the watershed (survey question 2).
- When asked if the respondents had enough information to know about watershed concerns, half the respondents (27) answered "No, but I would like to learn more" (survey question 3). 18 of the respondents answered "Yes", 8 answered "Unsure", and one answered "No, I'm not interested".
- Respondents' three greatest concerns for the lake (survey question 4) included illegal dumping, septic systems, groundwater contamination, and public education about issues impacting the watershed. Respondents' four least concerns for the lake included public use, wildlife, boating and local residents (wildlife, boating, and local residents tied for the second least concern after public use).
- A majority of respondents answered that they were willing to take action at some level to improve water quality in the lake (survey question 5).

3.0 Goals, Objectives, and Strategies

This section describes the goals, objectives, and strategies developed to guide this Plan's use for the protection of the lake and its watershed. The City used stakeholder input, lake and watershed data, and additional resources to develop the goals, objectives, and strategies throughout the planning process (Section 2.0). The goals of this Plan include:

- Goal 1: Maintain and improve water quality for drinking water and aquatic life uses in Sugar Creek Lake
- Goal 2: Maintain a sustainable quantity of water supply for the City of Moberly and its water customers
- Goal 3: Provide ongoing opportunities for public and stakeholder engagement regarding water quality and quantity at Sugar Creek lake and for the City of Moberly

To achieve each goal, the City developed broad objectives with specific implementation strategies. Table 1 through Table 3 summarize the objectives and strategies of Goals 1 through 3, respectively. Each table includes an implementation schedule for each strategy. Some strategies are listed as having an "ongoing" implementation schedule, which means that efforts are either indefinitely ongoing or have been initiated.

Table 1 Objectives, Strategies, and Implementation Schedule for Goal 1

Goal 1: Maintain and improve water quality for drinking water and aquatic life uses in Sugar Creek Lake		
Objective	**Strategy**	**Implementation Schedule**
1. Collect additional data to improve understanding of pollutants in the lake.	1. Develop a Quality Assurance Project Plan (QAPP) for sampling that will support the City's need to better understand pollutant loads and sources. Submit the QAPP for Missouri Department of Natural Resources (MDNR) review and approval.	
	2. Measure soluble phosphorus concentration in the lake and septic tank effluent in the watershed near the lake.	
	3. Measure concentrations of total nitrogen and plant-available forms of nitrogen in the lake.	
	4. Coordinate and schedule volunteer Stream Team training to be held in or near the watershed.	
	5. Conduct total suspended solids (TSS) and turbidity sampling in concert with other parameters to track sediment runoff and determine whether there is a correlation to nutrient loading from stormwater runoff. Use this data to identify possible sources of nutrient and sediment loads.	
	6. Install and operate a continuous lake level and rainfall gauge to track rainfall and lake level, for use in concert with lake sampling data and analyses.	

Goal 1: Maintain and improve water quality for drinking water and aquatic life uses in Sugar Creek Lake		
Objective	**Strategy**	**Implementation Schedule**
2. Gather more information about water quality in the lake and sources of pollutants in the watershed.	1. Develop a QAPP for sampling that will support the City's need to better understand pollutant loads and sources. Submit the QAPP for MDNR review and approval.	
	2. Continue to obtain information about land-use in the watershed, such as review and mapping of the data from the National Land Cover Dataset (NLCD) and Soil and Water Conservation District (SWCD) information.	
	3. Conduct water quality modeling and conduct monitoring of specific known pollutant sources (e.g., old mines, old rail lines, high velocity ravines, etc.), to gain understanding about sources impacting lake water quality.	
3. Address challenges with septic tanks and lagoons.	1. Conduct an inventory of small, onsite wastewater treatment systems, including septic tanks, septic treatment systems, and lagoons.	
	2. Develop and update small onsite treatment system standards for new users, in coordination with Randolph County Health Department.	
	3. Improve City compliance assistance tools by identifying and addressing gaps in ordinances within the city and county.	
	4. Develop a program to assist in cost-sharing of individuals with septic system pumping.	
	5. Consider investing City funds into acquisition of inactive or unused properties in watershed that are identified as a source of pollutants to the lake.	
	6. Provide Educational opportunities and encourage public involvement to engage property owners, tenants, realtors, bankers, and septic tank pumpers.	
4. Address non-point sources of pollutants.	1. Establish partnerships with the local SWCD, Missouri Department of Conservation (MDC), MDNR, and US Department of Agriculture – Natural Resources Conservation Service (NRCS). Seek out financial assistance opportunities through these partnerships.	Ongoing
	2. Establish a partnership with the Randolph County Health Department and the County Commission.	Ongoing
	3. Encourage the use of design standards for projects exposed to stormwater, with a goal of no more than 3 ton/acre/year soil loss.	
	4. Inspect high-risk ravines that drain to the lake that are likely to be transporting the highest quantities of sediment to the lake. Consider BMPs that would address erosion and subsequent sediment transport to the lake.	
	5. Determine feasibility of the use of up-watershed reservoirs or forebays as BMPs.	
	6. Determine locations along the lake shore that would most benefit from erosion protection, and if feasible, implement BMPs.	

Table 2 Objectives, Strategies, and Implementation Schedule for Goal 2

Goal 2: Maintain a sustainable quantity of water supply for the City of Moberly and its water customers		
Objective	**Strategy**	**Implementation Schedule**
1. Understand current source capacity.	1. Include the MDNR Firm Yield Study results in the Source Water Protection Plan.	June 2019
	2. Review the results of MDNR's 2019 Firm Yield Assessment and USGS's 2019 Bathymetric Survey report with MDNR, and discuss need and strategies to supplement source capacity.	Ongoing
2. Understand current and future water demands that account for economic development.	1. Gather information and data regarding future water demands that considers population growth and economic growth of the City.	Ongoing
	2. Develop an economic development-oriented water supply plan that uses desired and predicted growth to quantify future water needs.	Ongoing
	3. Identify funding options to conduct more detailed water supply planning.	Ongoing
	4. Identify funding sources to purchase and/or construct additional source(s) of water supply.	Ongoing
3. Gather more information about water quality in the lake and sources of pollutants in the watershed.	1. Identify all potential nearby sources of water supply, and conduct planning at the feasibility level regarding availability and cost, and utilizing data from previous studies as well as additional data and/or studies.	Ongoing
	2. Continue communication with The U.S. Army Corps of Engineers regarding obtaining additional water supply storage at Long Branch Lake.	Ongoing
	3. Determine the feasibility of purchasing water storage at Long Branch Lake, and distribution of the water to the City's customers.	Ongoing
	4. Consider the feasibility of the City expanding water service to a regional system of customers (i.e., other cities, county, and rural water districts).	
	5. Identify funding sources to purchase and/or construct additional source(s) of water supply and distribution.	

Goal 2: Maintain a sustainable quantity of water supply for the City of Moberly and its water customers		
Objective	**Strategy**	**Implementation Schedule**
4. Develop and preserve water supply storage volume at Sugar Creek Lake.	1. Reduce sediment loads entering the lake by implementing strategies under Goal 1.	
	2. Consider the feasibility of the construction of up-watershed reservoirs to increase water supply storage.	
	3. Consider the feasibility and potential costs/benefits of raising the dam at Sugar Creek Lake to increase water storage volume.	
	4. Consider the feasibility and cost of dredging at Sugar Creek Lake to increase water storage volume.	
	5. Complete a project to reduce seepage through the abutments of the dam, which would increase the available water supply yield from the lake.	Ongoing
	6. Consider the feasibility of indirect water reuse to increase water availability.	
	7. Conduct a hydraulic and hydrologic analysis in the watershed to gain knowledge of water transport and availability under various climate conditions.	
	8. Identify funding options for implementation of strategies that are considered to be feasible.	
5. Encourage water users and customers to use water conservation practices.	1. Quantify all non-revenue use of water from the City's system.	
	2. Determine if reductions can be made to non-revenue uses of water, including distribution system water loss.	
	3. Provide educational information to the public about ways to conserve water.	
	4. Consider methods to incentivize water conservation practices, especially among the highest water users.	

Table 3 Objectives, Strategies, and Implementation Schedule for Goal 3

Goal 3: Provide ongoing opportunities for public and stakeholder engagement regarding water quality and quantity at Sugar Creek Lake and for the City of Moberly		
Objective	Strategy	Implementation Schedule
1. Target each group of stakeholders with different types of engagement.	1. Define the various types of stakeholders and groups that the City should engage.	Ongoing
	2. Build a contact list for stakeholders and groups that the City is actively engaging.	Ongoing
	3. Establish at least two stakeholder groups that meet regularly in-person; one with a focus on water quality at the lake, and another with a focus on water supply.	One group established in 2018
	4. Include educational information in water bills.	
	5. Establish a quarterly water newsletter to be distributed to City customers and stakeholders who work, live or recreate in the watershed.	
	6. Continue to engage with stakeholders with interest in recreation at the lake in all available forums or media.	
2. Engage the public to establish support for the Source Water Protection Plan.	1. Develop a water-themed mascot and related messaging to engage with and provide messaging to the public.	
	2. Use storytelling techniques in messaging and media to engage and inform the public.	
	3. Consider other creative ways to engage the public through in-person engagements and media.	
	4. Utilize partnerships to engage a broader base (SWCD, Randolph County Health Department, Randolph County Commission, Moberly Area Economic Develop Corporation, etc.).	
3. Continue to take steps to be an example to the public by implementing best practices first.	1. Continue to implement the measurable goals of the City's Stormwater Management Plan.	Ongoing
	2. Continue to implement consistent policies and improvements to permitting, management, and follow up on new development sites.	Ongoing
	3. Implement and update City housekeeping procedures and staff training to protect the City's stormwater infrastructure, and prevent runoff of pollutants.	

4.0 Watershed Characteristics

The watershed, approximately 7,000 acres (11 square miles) in size, is located in north central Missouri in Randolph County (Large Figure 1). The watershed stretches approximately 6 miles from its northern boundary, located south of the City of Cairo, Missouri, to its southern boundary, located in the northwestern portion of the City of Moberly. The following subsections describe characteristics of the watershed, including surface waters (Section 4.1), physiographic setting and climate (Section 4.2), surface waters (Section 4.1), soils and geology (Section 4.3), and land use and land cover (Section 4.4).

4.1 Surface Waters

Surface waters within the watershed, including waterbodies and wetlands, are included on Large Figure 1. As shown in Large Figure 1, multiple first and second order unnamed streams serve as tributaries to the lake. The outlet of the lake is Sugar Creek, which flows 4.6 miles until its confluence with the East Fork of the Little Chariton River.

4.2 Physiographic Setting and Climate

The watershed, approximately 7,000 acres in size, is a subwatershed of Missouri's Little Chariton River Watershed (Hydrologic Unit Code 10280203) located in the Missouri River Basin. The watershed lies within an ecological region known as the Central Dissected Till Plains, which is located north of the Missouri River and formed through soil deposition from glaciation (reference (1)). The Dissected Till Plains extend into Iowa, Illinois, Kansas and Nebraska and are relatively flat, other than river valleys and hills formed through erosion, much of which resulted from glacial runoff (reference (1)). Elevation in the watershed ranges from approximately 870 feet at the top of the eroded Sugar Creek River Valley to 746.8 feet at the dam spillway (Large Figure 4 and Appendix C).

North central Missouri has a humid continental climate characterized by long, hot summers and cool winters (reference (2)). The region (Moberly, MO climate station) receives an average annual precipitation of 43.22 inches (1981-2010, reference (3)). May is typically the wettest month, receiving an average precipitation of 5.16 inches (reference (4)). The historical high and low annual precipitations at the Moberly Climate Station between 1936 and 2018 were 65 inches in 2008 and 22 inches in 1988 (reference (5)). The average annual temperature for the area is 53.8 degrees Fahrenheit. January, the coldest month of the year, averages high and low temperatures of 37 and 19 degrees Fahrenheit, respectively, while July, the hottest month of the year, averages high and low temperatures of 87 and 67 degrees Fahrenheit (reference (4)).

4.3 Soils and Geology

The following sub-sections include soil and geology information for the watershed. Section 4.3.1 includes the predominant soil types found within the watershed, Section 4.3.2 includes an analysis of soil erosivity and stream power within the watershed to identify erosion prone areas, and Section 4.3.3 provides information on the uppermost geologic units in the watershed.

4.3.1 Soil Types

Based on the USDA NRCS Soil Survey, the predominant soil types within the watershed are depicted on Large Figure 5 and summarized in Large Table 1. Soil types within the watershed consist of silty loams that range from nearly level to gently sloping soils in the upper areas of the watershed (Mexico-Leonard-Putnam association) to moderate to steep slopes near the lakeshore (Gosport-Gorin association). In general, soil types on steeper slopes tend to have greater drainage than those on level to moderately sloped areas. Permeability of the soil, which is the ability of the soil to infiltrate water, is very low for the silt loams within the watershed, which increases their potential erosion and seasonal wetness.

4.3.2 Soil Erosivity and Stream Power

Erosion prone areas within the watershed were identified using the Universal Soil Loss Equation (USLE) and stream power indices. The USLE (Appendix D, Equation 1) predicts annual average soil loss or erosivity due to rainfall. The Stream Power Index (SPI) equation measures the erosive power of flowing water (Appendix D, Equation 2) and identifies areas within the watershed that are prone to channel formation. Barr identified areas of the watershed most prone to erosion by combining USLE and SPI results (Large Figure 6); areas with high soil loss and a high SPI are considered to have greatest risk of erosion and occur within ravines close to the shore of the lake (Large Figure 7). Barr recommends that the City inspect these ravines periodically for erosion issues.

4.3.3 Geology

According to the Missouri Geological Survey Geosciences Technical Resources Assessment Tool (GeoSTRAT), the geology underling the watershed area is comprised of Mississippian and Pennsylvania aged bedrock units overlain by approximately 50 to 65 feet of unconsolidated residuum. The Pennsylvanian bedrock units found near the surface around the watershed consist of the Marmaton Group and the Cabaniss Subgroup of the Cherokee Group. In a typical geologic sequence the Marmaton Group conformably overlies the Cabaniss Subgroup.

According to GeoSTRAT, the Cabaniss Subgroup is the shallowest bedrock on the western edge of and underlying the lake, while the Marmaton Group is the shallowest bedrock along the eastern edge of the lake. The Cabaniss Subgroup in Missouri is comprised of sandstone, siltstone, shale, limestone and coal beds and consists of 11 successions or cyclic units with coal beds near the top with some minor exceptions. The Marmaton Group is comprised of a succession of shake, limestone, clay, and coal beds. In comparison with the Cabaniss Subgroup, the Marmaton Group contains thicker and consistent limestone units.

In contrast to the geologic information provided by GeoSTRAT, the well log for a nearby water supply well No. 006285 (Large Figure 1), located approximately 0.8 miles southwest of the lake's spillway, indicates that the Mississippian Warsaw Formation is the shallowest bedrock unit. The Warsaw formation is comprised of a coarsely crystalline, fossiliferous limestone intermittent with finely crystalline dolomitic limestone (reference (6)).

4.4 Land Use and Land Cover

The watershed has a variety of land uses due to the combination of rural, urban, and recreational areas. The lake is a popular recreation destination for activities such as fishing and boating. Land adjacent to the lake primarily consists of forest, agriculture (pasture and hay), and private residences. As of the 2016 National Land Cover Database (NLCD) dataset, approximately half of the land use in the watershed is used for agricultural production (Large Figure 8).

4.4.1 Land Cover Change and Pollutant Loads

Large Figure 9 and Large Figure 8 display 2001 and 2016 land use in the watershed from NLCD, respectively. Based on the NLCD's 2016 dataset, pasture and hay land comprise the land use type with the greatest area in the watershed, followed by cultivated crops, forest, other land (developed areas and barren lands), open water, other vegetated areas, and wetlands. Table 4 and Figure 1 display land use changes between the 2001 and 2016 land cover datasets. As seen in Table 4 and Figure 1, forested areas experienced the greatest increase between the 2001 and 2016 data sets (16.1 percent increase), while other vegetated areas, which include grassland/herbaceous and shrub/scrub land uses, experienced the greatest decrease between the 2001 and 2016 data sets (80.7 percent decrease).

Table 4 2001 and 2016 Sugar Creek Lake Watershed Land Use Data by Category

Land Use Category	2001 Category Percent of Total Land Use	2016 Category Percent of Total Land Use	Category Percent Change from 2001 to 2016
Pasture/Hay	**Total: 30.63%**	**Total: 30.15%**	-1.6%
Cultivated Crops	**Total: 23.96%**	**Total: 23.47%**	-2.0%
Forest	Subcategories: • Deciduous: 23.53% • Evergreen: 0.02% • Mixed: 0.02% **Total: 23.57%**	Subcategories: • Deciduous: 26.04% • Evergreen: 0.02% • Mixed: 1.29% **Total: 27.36%**	+16.1%
Other	Subcategories: • Developed High Intensity: 0.17% • Developed Medium Intensity: 1.45% • Developed Low Intensity: 3.35% • Developed Open Space: 6.49% • Barren Land: 0.07% **Total: 11.53%**	Subcategories: • Developed High Intensity: 0.56% • Developed Medium Intensity: 2.29% • Developed Low Intensity: 3.94% • Developed Open Space: 5.74% • Barren Land: 0.10% • **Total: 12.63%**	+9.6%
Open Water	**Total: 5.92%**	**Total: 5.50%**	-7.1%
Other Vegetated Areas	Subcategories: • Grassland/herbaceous: 3.91% • Shrub/scrub: 0.05% **Total: 3.96%**	Subcategories: • Grassland/herbaceous: 0.71% • Shrub/scrub: 0.05% **Total: 0.76%**	-80.7%
Wetlands	Subcategories: • Emergent herbaceous wetlands: 0.16% • Woody wetlands: 0.26% **Total: 0.42%**	Subcategories: • Emergent herbaceous wetlands: 0.05% • Woody wetlands: 0.07% **Total: 0.12%**	-71.6%
TOTAL	**100%**	**100%**	--

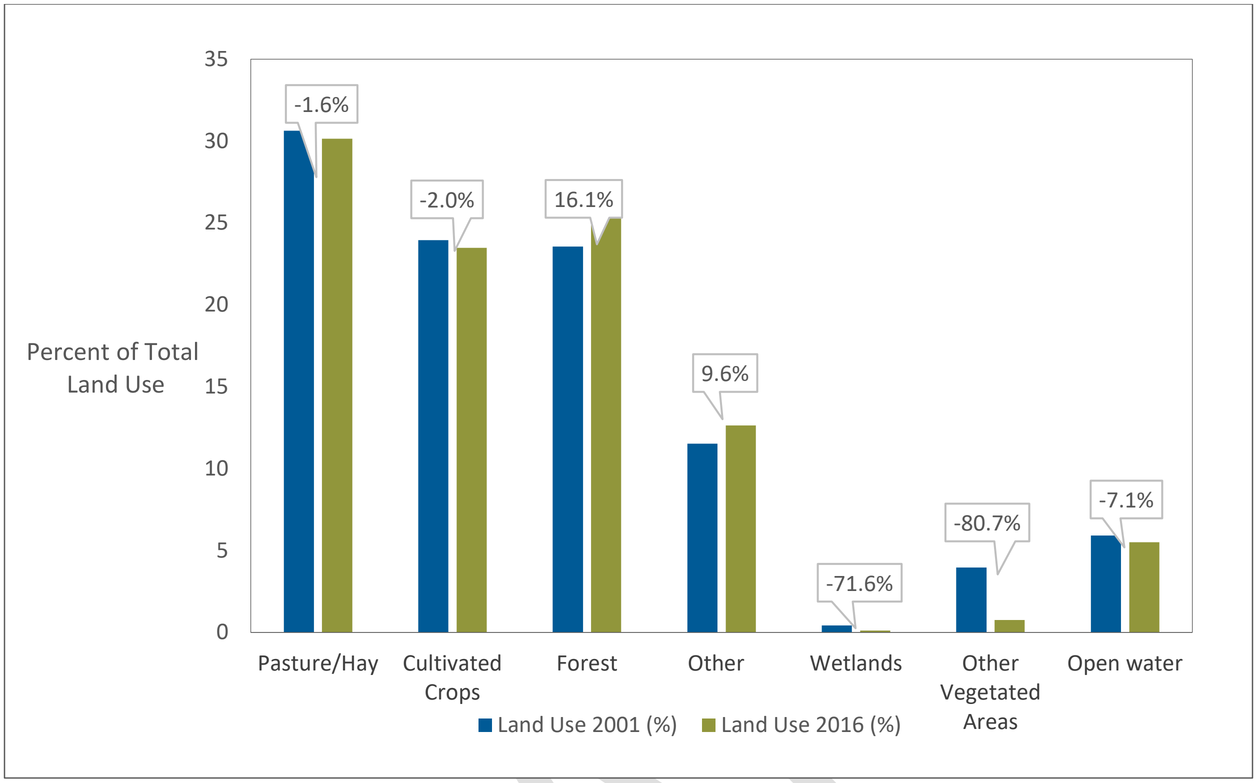

Figure 1 **Land Use Change in the Sugar Creek Lake Watershed between 2001 and 2016 by Land Use Category**

Land use may be used to estimate some pollutant loads in the watershed that may run off to the lake, such as nutrients and sediment. Three common pollutants of interest for the watershed from land use sources include total phosphorus, total nitrogen, and suspended solids. A review of land use loading factors in the watershed determined that natural landscapes, such as forests, grasslands, and barren land contribute the lowest pollutant loads of various land use types within the watershed, while cultivated crops and urban development contribute the highest pollutant loads of the watershed's land use types. Table 5 presents the loading factors for each pollutant by land use type.

An analysis of land use and loading factors in the watershed indicate that from 2001 to 2016, overall watershed loading from total phosphorus and total suspended solids have decreased by 0.029 lbs/acre/year and 363 lbs/acre/year, respectively, while loading from total nitrogen has increased by 0.93 lbs/acre/year. Large Figure 10 through Large Figure 15 display loading and the loading change from 2001 to 2016 by subwatershed.

Table 5 Land Use Loading Factors

Land Use Type	Loading Factor (lbs/acre/year)		
	Total Phosphorus(1)	Total Nitrogen(2)	Total Suspended Solids(3)
Barren Land	0.10	3.34	2
Cultivated Crop	0.89	5.68	2626
Deciduous Forest	0.09	2.19	5
Developed, High Intensity	0.30	10.28	350
Developed, Low Intensity	0.30	9.70	150
Developed, Medium Intensity	0.30	5.16	250
Developed, Open Space	0.31	3.56	64.5
Emergent Herbaceous Wetlands	0.22	2.07	43
Evergreen Forest	0.09	2.19	5
Grassland/Herbaceous	0.09	0.96	5
Mixed Forest	0.09	2.19	5
Open Water	0.00	0.00	0.00
Pasture/Hay	0.54	4.45	50
Shrub/Scrub	0.13	1.10	27
Woody Wetlands	0.22	2.07	43

(1) Sources reference (7), reference (8), Appendix A to reference (9), and reference (10)
(2) Sources reference (7), reference (11), and Appendix A to reference (9)
(3) Sources (reference (7) and reference (12)

4.5 Other Features of Interest

Other watershed features of interest relevant to this Plan include Cooksies Quarry and private septic systems. The influence of Cooksies Quarry and private septic systems on the lake's water quality was frequently mentioned as pollutant sources in stakeholder meetings during the planning process of this Plan (Section 2.0). Cooksies Quarry is an inactive stone quarry located on City property east of lake's eastern arm (Large Figure 1). The City currently owns and has complete control over the quarry property (Large Figure 3). Due to a lack of data, the Quarry's influence on lake sedimentation has not been quantified. Private septic systems may contribute nutrients and pathogens to surface waters, particularly in areas where groundwater and soil conditions are unsuitable or the density of septic systems is high (reference (13)). The influence of private septic systems on the lake's water quality is undetermined; however, Strategy 1, Objective 2 of Goal 1 of this Plan is to quantify and address the contributions from these pollutant sources to prioritize actions to reduce pollutant loads to the lake (Table 1).

5.0 Sugar Creek Lake Characteristics

The following sub-sections describe the lake's impairment status, water quality, sediment quality. Section 5.1 describes the lake's water quality and MDNR impairment status. Section 5.2 discusses the influence of sedimentation on the lake's sediment quality and water quality.

5.1 Water Quality

Maintaining and improving water quality in the lake, particularly with respect to drinking water supply and recreation, is a high priority for stakeholders. Primary stressors for the lake include sediment, organic material, and nutrients. Nutrients encompass all forms of phosphorus and nitrogen, including free ammonia. The sources of the lake's stressors may include land use (Section 4.4) and soil erosivity (Section 4.3.2). Although the lake's only impairment as of the writing of this Plan is for mercury in fish tissue (refer to Section 5.1.1), the City does not consider mercury to be a primary stressor in the lake with respect to the lake's use as a drinking water source. The impairment for mercury in fish tissue is by air deposition, and as such, is not specifically addressed in this Plan.

5.1.1 Impairment Criteria

The lake is classified by the State of Missouri as an "L1" lake, which are lakes or reservoirs used primarily for public drinking water supply. State designated uses for the lake, which dictate water quality standards, include livestock and wildlife protection, protection of warm water habitat, human health protection, whole body contact recreation, secondary contact recreation, and drinking water supply.

The lake's only water quality impairment is for mercury in fish tissue, as listed on the state's Clean Water Commission Approved 2018 Section 303(d) listed waters (reference (14)). MDNR added the lake to the 303(d) list for the mercury in fish tissue impairment in 2014. Each state is required to submit their 303(d) list, or list of impaired and threatened waters, for EPA approval. At the time this Plan was written, MDNR was in the process of developing their Draft 2020 303(d) List.

MDNR revised the state's water quality standards on March 31, 2018 (10 CSR 20-7.031). A significant change to the new standards included numeric nutrient criteria for lakes. The purpose of the nutrient criteria standards is to address adverse impacts to a lake's beneficial uses from eutrophication, or the "process by which a body of water becomes enriched in nutrients, such as nitrogen and phosphorus, which stimulate the excessive growth of algae and other plants" and ultimately deplete dissolved oxygen (DO), resulting in a decreased quality of aquatic life (reference (15)).

MDNR published the Nutrient Criteria Implementation Plan (reference (15)) on July 26, 2018 to describe the implementation strategy for the newly established nutrient criteria, which are dependent upon a lake's ecoregion. The lake is located in the Plains ecoregion for the Nutrient Criteria Implementation Plan (Appendix E). Table 6 presents the nutrient criteria for the Plains ecoregion.

MDNR based the decision framework for the nutrient criteria on the EPA's bioconfirmation guiding principles (reference (15)). As described in the Nutrient Criteria Implementation Plan and illustrated in

Figure 2, a lake in Missouri is considered to be impaired for nutrient criteria if it meets the following criteria:

- The geometric mean of Chl-a samples taken between May and September in a calendar year exceeds the respective ecoregion Chla-response impairment threshold value more than once in the most recent three years of data; or
- The geometric mean of either total nitrogen, total phosphorus, or Chl-a samples taken between May and September in a calendar year exceed the respective ecoregion Chl-a response impairment threshold value in the most recent three years of data and one of the five response assessment endpoints are also identified in the same calendar year. The response endpoints include:
    - Occurrence of eutrophication-related mortality or morbidity events for fish and other aquatic organism (Response Endpoint 1)
    - Epilimnetic excursions from DO or pH criteria (Response Endpoint 2)
    - Cyanobacteria counts in excess or 100,000 cells/mL (Response Endpoint 3)
    - Observed shifts in aquatic diversity attributed to eutrophication (Response Endpoint 4)
    - Excessive levels of mineral turbidity that consistently limit algal productivity during the period of May 1 – September 30 (Response Endpoint 5)

Table 6 Numeric Criteria Threshold Values for the Plains Ecoregion

Chl-a Response Impairment Threshold (µg/L)	Nutrient Screening Thresholds (µg/L)		
	TP	TN	Chl-a
30	49	843	18

MDNR's Nutrient Criteria Implementation Plan (Appendix E) requires the following data requirements to assess a lake against the numeric criteria in 10 CSR 20-7.031(5)(N):

1. "At least four samples collected between May 1 and September 30 under representative conditions;
2. Each sample must have been analyzed for at least Chl-a, TN, TP, and Secchi depth;
3. At least three years of samples (years do not have to be consecutive). Data older than seven years will not be considered, consistent with the Department's Listing Methodogy.
4. Data collected under a Quality Assurance Project Plan (QAPP)."

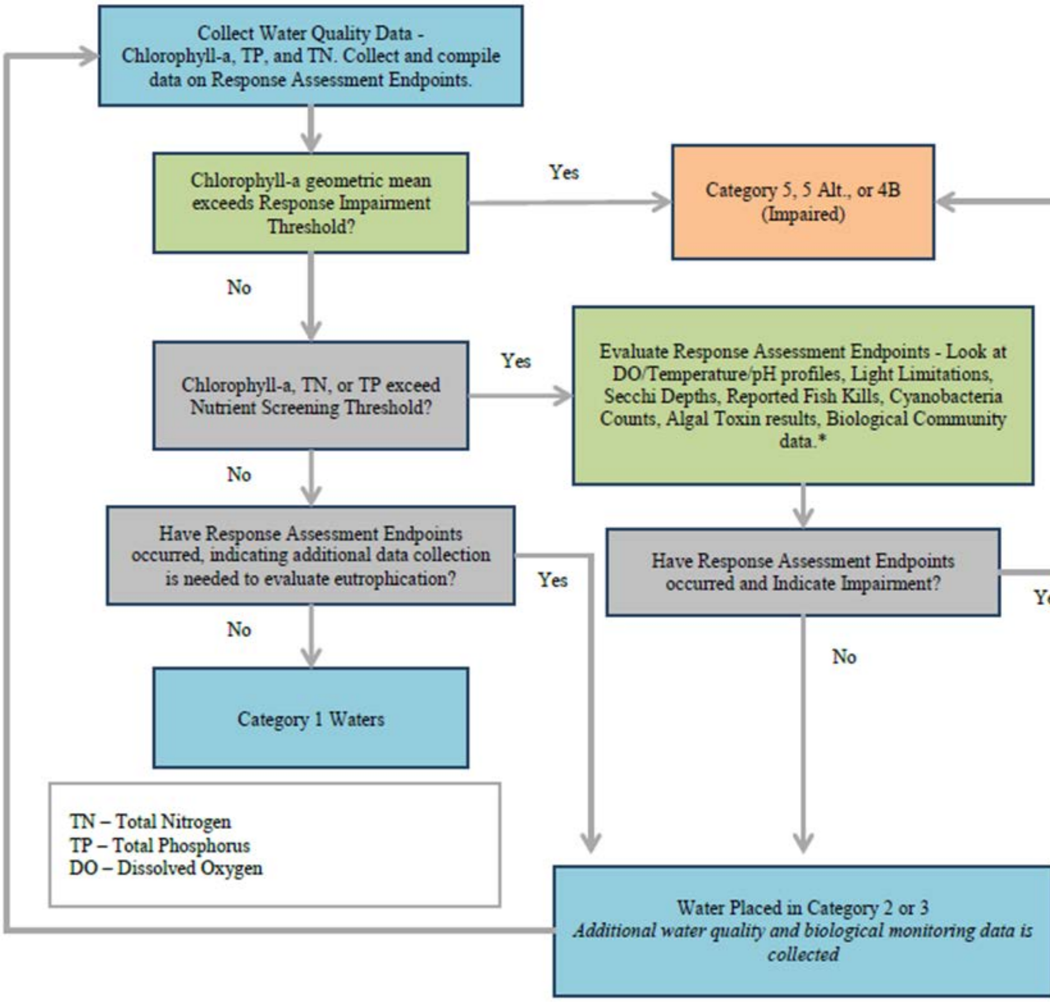

Figure 2 Missouri Ecoregional Numeric Nutrient Criteria Decision Framework based on the Bioconfirmation Approach

5.1.2 Water Quality Data

Water quality data in the lake has been collected over the past two decades by the City and Lakes of Missouri Volunteer Program (LMVP). Table 7 presents a summary of water quality data collected by the City and LMVP.

Table 7 Summary of Sugar Creek Lake Water Quality Data Collection

	City of Moberly	Lakes of Missouri Volunteer Program
Sample Parameters	• 5-Day Biochemical Oxygen Demand (BOD_5) • Alkalinity • Ammonia (NH_3) • Ammonia, Free • Chemical Oxygen Demand (COD) • Coliforms • Conductivity • Copper • Dissolved Oxygen (DO) • e. Coli • Hardness • Manganese • Nitrate (NO_3) • Nitrate, as Nitrogen (NO_3 - N) • Nitrite (NO_2) • Organics • pH • Phosphate (PO_4) • Temperature • Total Dissolved Solids (TDS) • Total Suspended Solids (TSS) • Turbidity • UV 254	• Algal data • Inorganic Suspended Solids (ISS) • Secchi Depth • Temperature • Total Nitrogen • Total Phosphorus • Total Chlorophyll-a
Sample Locations	Sites 1 through 8	Sites 1 and 2
Sample Years	2010 through present	2000 through present
QAPP Available for Data Collection?	No	Yes

5.1.2.1 City Water Quality Data

The City collects water quality data seasonally (spring through summer) from eight locations on the lake (Large Figure 16). As of 2019, a QAPP has not been developed for the City's water quality data collection program. Large Table 2 summarizes the water quality data from the eight sample locations. Because a QAPP or another sampling plan was not developed prior to collecting this data, the monitoring parameter data were not collected in a consistent manner and the data does not have clear goals assigned for its use or a formal QA/QC process, implemented through a QAPP or sampling and analysis plan, to protect data quality. Because of this, the data has been and can continue to be somewhat limited in its usefulness for long-term decision-making. However, the data can be used as an indicator of certain issues and has been used by the City and stakeholders to identify pollutant and water treatment concerns. It is recommended that the City develop a QAPP and conduct further analysis to allow the data collected under a QAPP to inform and support City actions and decisions. Developing a QAPP would support consistency in data collection, clarify the goals around data collection, and help to position the City to apply for funding to implement water quality improvement projects, such as through Clean Water Act Section 319(h) Nonpoint Source Management Program grant funding.

5.1.2.2 LVMP Water Quality Data

The LMVP has collected water quality data in accordance with a MDNR-approved QAPP at two locations on the lake since 2000 (Large Figure 16). LMVP monitoring data is summarized in the following sub-sections and Large Table 3 and Large Table 4. LVMP's water quality data may be used by MDNR to evaluate whether the lake is impaired for nutrient criteria according to 10 CSR 20-7.031(5)(N). Available lake data indicate the lake is not impaired for nutrient criteria; however, data indicate the lake may be trending toward impairment and could become listed as impaired if measures are not implemented to reduce nutrient loading. The following sub-sections describe lake water quality data with respect to MDNR's nutrient criteria.

Chl-a Response Impairment Threshold

As seen in Figure 3 and Large Table 3, the lake is not considered impaired due to the Chl-a response impairment threshold. Summer geometric means at LVMP Sites 1 and 2 do not exceed the impairment threshold more than once in the most recent three years of data collection.

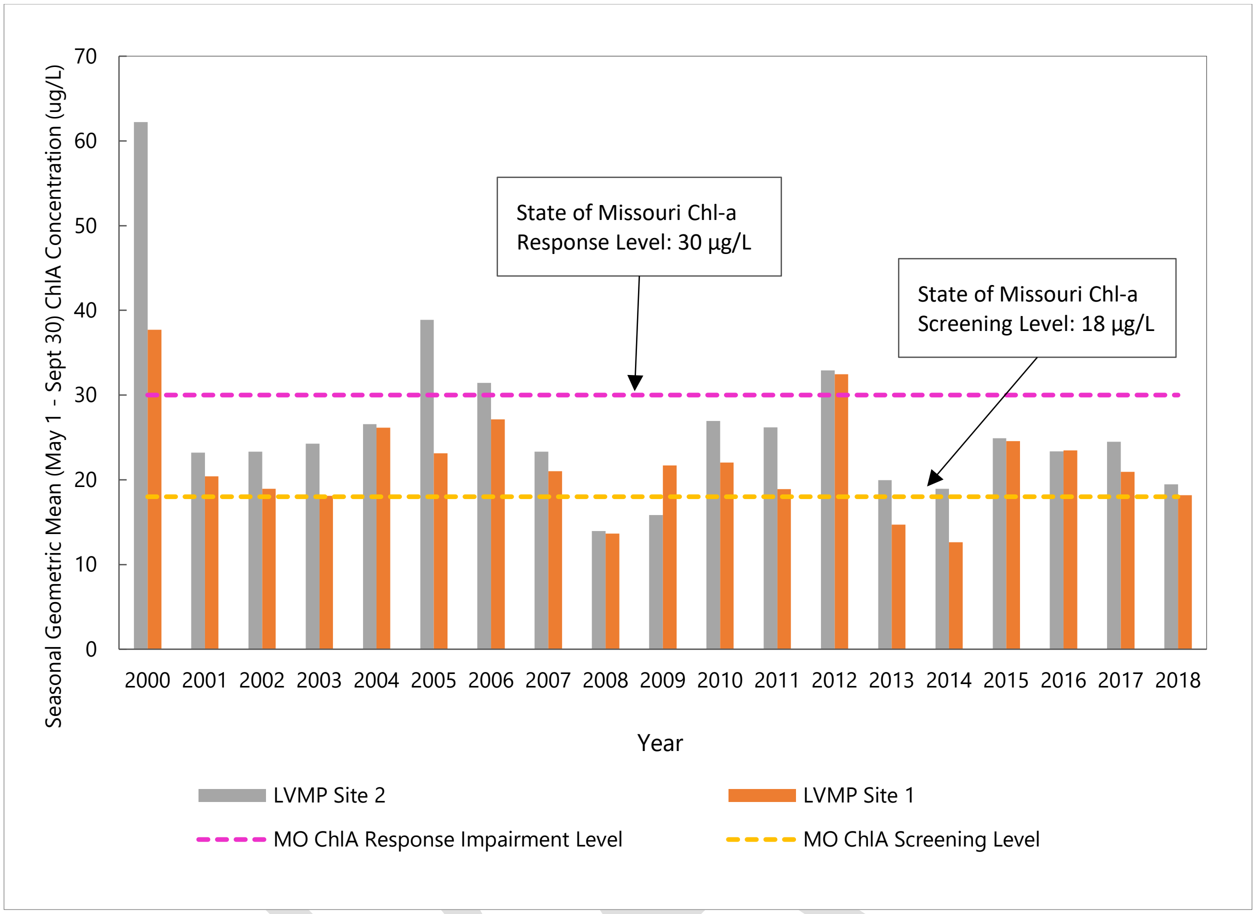

Figure 3 Chlorophyll-a Seasonal Geometric Mean at LVMP Sites 1 and 2

Nutrient Screening Thresholds

Exceedances of chlorophyll-a, total nitrogen, and total phosphorus nutrient thresholds at LMVP sites 1 and 2 during the most recent three years of data collection include:

- **Chlorophyll-a:** LVMP Site 1 and Site 2 annual geometric means exceed the nutrient screening threshold from 2016 through 2018 (Figure 3 and Large Table 3).
- **Total nitrogen:** LVMP Site 1 annual geometric means exceed the impairment threshold in 2017 and 2018. LVMP Site 2 annual geometric means exceed the nutrient screening threshold in 2017 (Figure 4 and Large Table 3).
- **Total phosphorus:** LVMP Site 1 and Site 2 annual geometric means do not exceed the impairment threshold during the most recent three years of data collection (Figure 5 and Large Table 3).

According to MDNR's Nutrient Criteria Implementation Plan (Section 5.1.1), the lake would be considered impaired for nutrient criteria if one of the five response assessment endpoints are identified in the same calendar year that a nutrient screening threshold is exceeded. As discussed in the following sections, available data for Response Endpoints 1-5 do not indicate impairment.

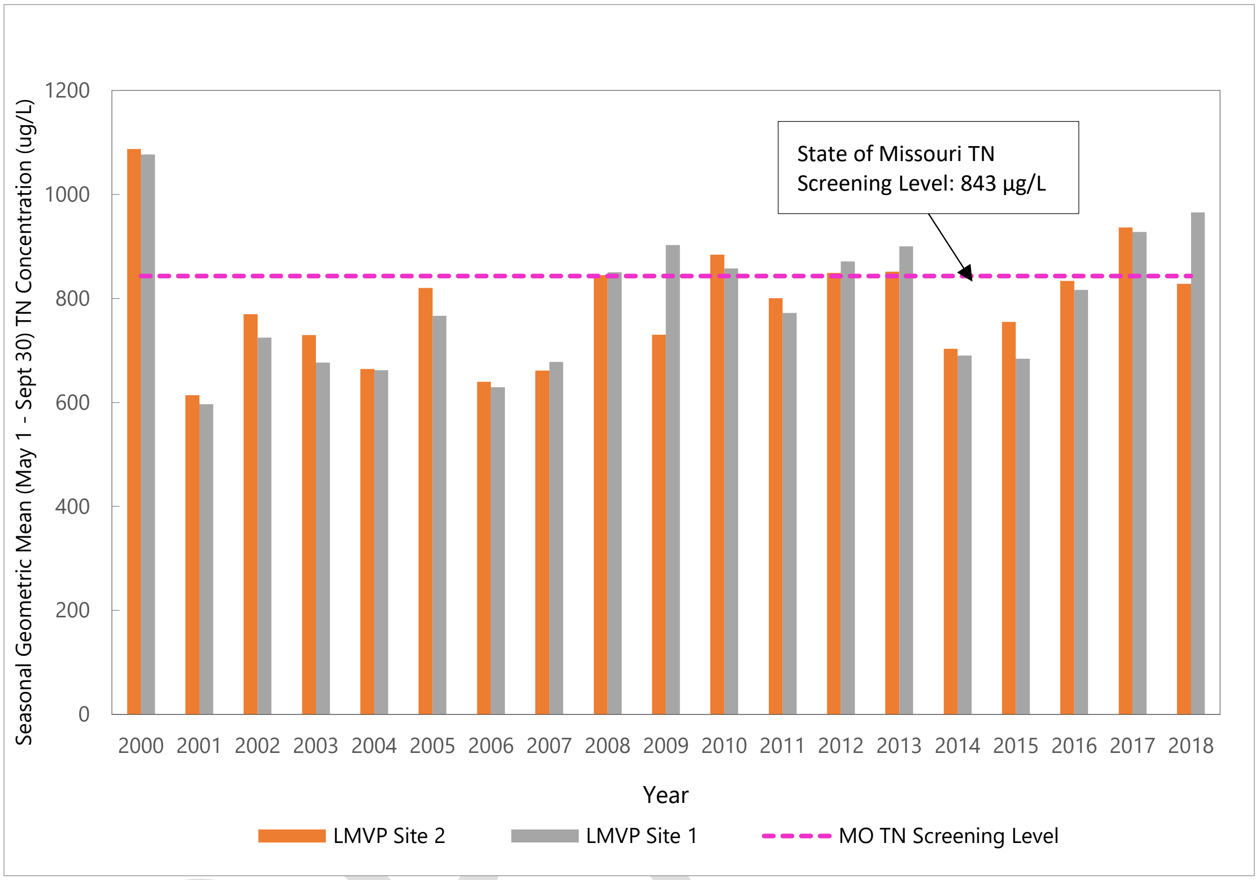

Figure 4 **Total Nitrogen Seasonal Geometric Mean at LVMP Sites 1 and 2**

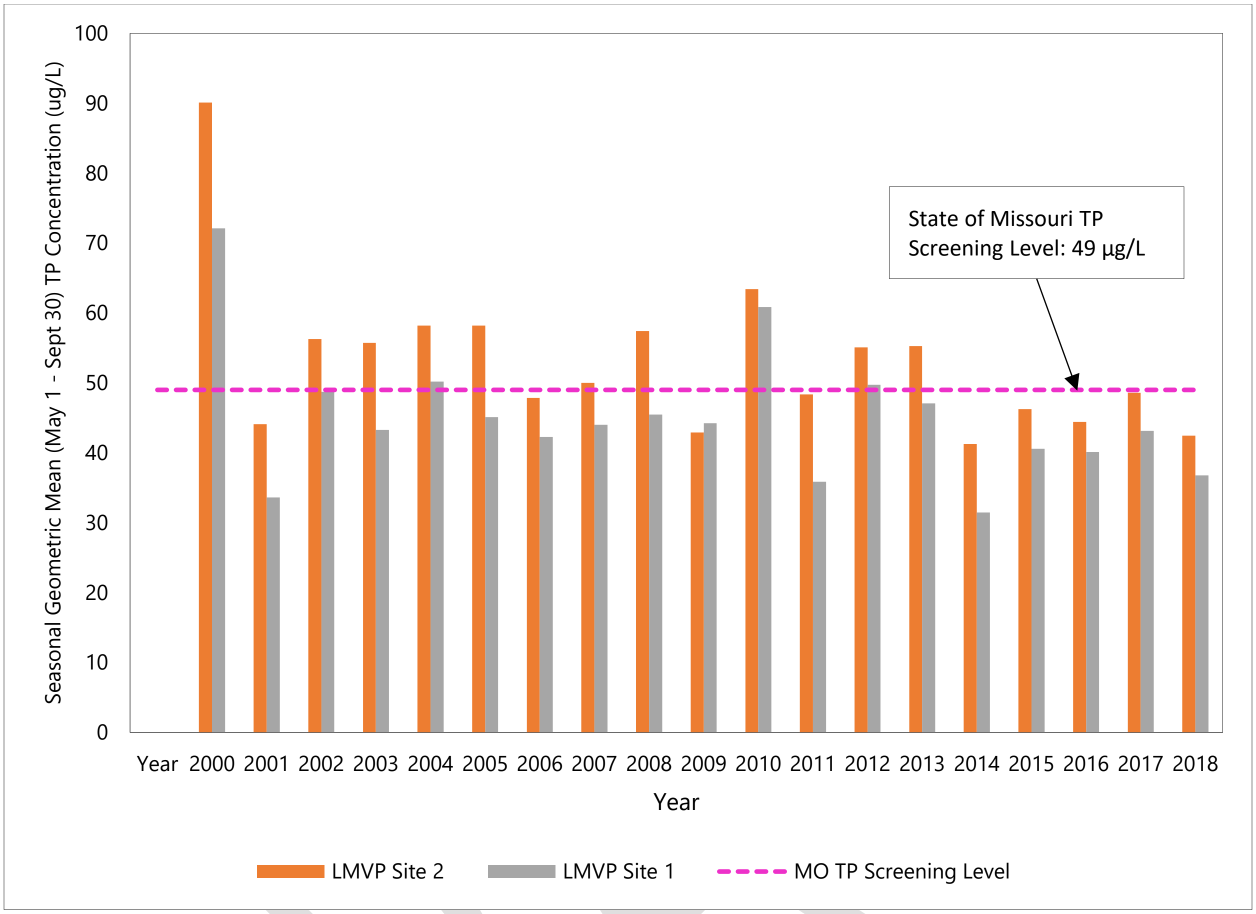

Figure 5 Total Phosphorus Seasonal Geometric Mean at LVMP Sites 1 and 2

Response Endpoints

Available lake data from MDNR and the LVMP do not indicate that exceedances of nutrient criteria response endpoints have been identified in the previous three years of water quality data collection. A summary of the MDNR's Listing Methodology is provided in the Nutrient Criteria Implementation Plan (Appendix E), available data for each response endpoint (Section 5.1.1, also provided in Large Table 3), includes the following:

- Response Endpoint 1: This endpoint criteria is exceeded if two or more fish kills have occurred within the last three years of available data or there is one large (>100 fish and covering more than ten percent of the lake area) fish kill documented to be caused by DO excursions, pH, algal blooms, or the toxins associated with algal blooms (10 CSR 20-7.031(5)(N)6.A). Available fish mortality reports from the MDC indicate no fish kills have occurred in the lake since the MDC began fish mortality data collection (references (16), (17), (18), (19), (20), (21), (22), (23), (23), (24), (25))

- Response Endpoint 2: This endpoint criteria will be evaluated further if the following occur: if more than 10% of the epilimnetic DO measurements during the May and September are below 5.0 mg/L minimum to protect aquatic life or more than 10% of the pH measurements are outside the 6.5 to 9.0 range to protect aquatic life, the binomial probabilities will be used to determine if the criterion have been exceeded [10 CSR 20-7.031(5)(N)6.B]. Data collected by the City, which has not been collected under a QAPP, indicate DO and pH data do not exceed Response Endpoint 2 (Table 8 and Large Table 2). Because this data was not collected under a QAPP, this data is only useful as an indicator and would not be used for endpoint assessment by MDNR.

- Response Endpoint 3: This endpoint criteria is exceeded if the following algal toxin value thresholds are exceeded: microcystin - 4.0 ug/L, cylindospermopsin - 8.0 ug/L, anaytoxin-a - 8.0 ug/L, and saxitoxin - 4.0 ug/L. These toxin levels are associated with a total toxigenic algal species cell count greater than or equal to 100,000 cell/mL [10 CSR 20-7.031(5)(N)6.C]. Data collected by the LMVP, summarized in Table 9, indicate algal toxin thresholds are not exceeded. Additional algal data, collected by the City is summarized in Large Table 5.

- Response Endpoint 4: This endpoint criteria is exceeded if MDNR finds evidence in biological shifts in fish or invertebrate communities related to eutrophication [10 CSR 20-7.031(5)(N)6.D]. MDNR will request aquatic community data from multiple sources to perform an evaluation of this endpoint. MDC provided the City with fish sampling population statistics from 2001, 2005, 2009, 2014 (reference (26)); the information provided in these statistics does not indicate this endpoint criteria is exceeded.

- Response Endpoint 5: This endpoint criteria is exceeded if the yearly average Secchi depth is below the applicable ecoregional value (0.6 meters for the Plains ecoregion). Additional analysis of average Chl-a/TP ratios will also be conducted before determining impairment status. Unless attributed to other physical factors, Chl-a/TP ratios at or below 0.15 and an ISS value greater than or equal to 10 mg/L as determined by yearly means will serve as an indicator of excessive mineral turbidity and constitute evidence of impairment [10 CSR 20-7.031(5)(N)6.E]. As seen in Large Table 4, available LVMP data does not indicate this endpoint criteria is exceeded.

Table 8 City DO and pH Data Summary for Sugar Creek Lake

DO Response Endpoint	pH Response Endpoint	Percent of Samples in Exceedance of Response Endpoint	
		DO, *in situ*	pH
10% of samples < 5.0 mg/L	10% of samples <6.5 or >9.0	1.3%	0%

Table 9 Lakes of Missouri Volunteer Program 2018 Algal Data

LMVP Site Number	Date	Microcystin Threshold (4.0 µg/L)		Cylindrospermopsin Threshold (8.0 µg/L)	
		Sample Result (µg/L)	> Endpoint Threshold? (Y/N)	Sample Result (µg/L)	> Endpoint Threshold? (Y/N)
1	5/18/2018	<0.15	N	<0.05	N
2	6/6/2018	<0.15	N	<0.05	N
2	6/26/2018	<0.15	N	<0.05	N
2	7/18/2018	<0.15	N	<0.05	N
2	9/2/2018	<0.15	N	<0.05	N
2	9/18/2018	<0.15	N	<0.05	N
2	10/1/2018	0.36	N	<0.05	N

5.2 Sediment Quality

Lake sedimentation from external (i.e., lake inputs) and internal (i.e., lake bottom sediment) sources is anticipated to be a significant source of pollutants in the lake, particularly nutrients and organics. The purpose of Strategy 5, Objective 1 of Goal 1 of this Plan is to determine potential sources of nutrient and sediment loads to the lake through data collection and analysis (Table 1). Section 6.3 of this Plan presents additional information regarding the effects of sedimentation on lake volume and yield.

Sediment deposition from erosion prone areas and high velocity streams, such as ravines near the lakeshore, transports pollutants into the lake, which ultimately end up in the water column and lake bottom sediment. Large Figure 7, discussed in Section 4.3.2, displays the City's priority areas for erosion inspections. Large Figure 17 presents an analysis of average growing season turbidity in the lake, which indicates areas of significant sedimentation loading from external sources, such as ravines.

Lake bottom sediment serves as a source and sink for pollutants in the lake's water column. The sediment serves as a pollutant source when lake turnover, which occurs each spring and fall, has the potential to significantly re-suspend pollutants from the upper lake bottom sediment layers into the water column. Suspension of sediment likely has an adverse impact on surface water concentrations of nutrients, turbidity, and total suspended solids during these times. During lake stratification in summer and winter, lake bottom sediment serves as a pollutant sink once sediment suspended in the water column begins to settle. Large Table 6 presents a summary of sediment samples from the LVMP sample locations 1 and 2 in May 2017. Sediment samples were not collected under a QAPP.

6.0 Water Supply

According to the 2019 Census of Missouri Public Water Systems (reference (27)), the lake supplies drinking water for 13,974 people at an average daily demand in of 1.15 MGD to the City. From 2001 to 2017, the City used an average of 473 million gallons per year (1.30 MGD). Usage during this timeframe peaked in 2004 at 579 MGY (1.59 MGD) and was at its lowest in 2009 (393 MGY, 1.08 MGD). The lake does not supply water to areas outside City limits, but does serve as an emergency supply for both the Thomas-Hill Public Water Supply District (THPWD), which serves a population of 10,315 (reference (28)), and the Moberly Area Correctional Center. The Clarence Cannon Wholesale Water Commission, which retrieves raw water from the North Fork of the Salt River (Mark Twain Lake), supplies water for both the THPWD and Moberly Area Correctional Center.

6.1 Water Treatment

The City's WTP intake is located near the southeast corner of the lake (Large Figure 1 and Large Figure 16). The WTP has a capacity of 5 MGD. The City's WTP processes include chemical addition (rapid mix), coagulation, flocculation, sedimentation, filtration, and disinfection. Treated water is either immediately routed to the City's distribution system via a wet well, or is stored in clearwells prior to distribution. WTP improvements were constructed in 2006; the significant components included the raw water intake, raw water pump station upgrades, backup generator, carbon silo, caustic soda feed equipment, supervisory control and data acquisition upgrades, covered secondary basins, mixed media filter controls, new high service main leaving the City's boundary, and meters on the raw water and high service mains. The water treatment system improvements and ultrasonic algae treatment units (discussed in Section 6.2) have significantly reduced DBP formation in treated drinking water, an achievement of the DBP reduction goal of the 2004 Plan.

Figure 6 Moberly Water Treatment Plant Intake

6.2 Algae Treatment

Nutrients in the lake, particularly nitrogen and phosphorus, have contributed to algal blooms in that present treatment challenges for the City's WTP. The City has not had a blue-green algae bloom at the lake, and has gathered algae speciation data from the lake (Large Table 5). However, the lake does seasonally have algae blooms of nuisance algae that has caused water treatment challenges, such as the formation of DBPs, and safety concerns at boat ramps and docks because of slippery conditions. The City installed two solar-powered ultrasonic algae controller units in 2017, and a third unit in 2019, to reduce the propagation of algae (Figure 7). The City removes the algae controller units during the winter months and redeploys them each spring. These units have proved effective in significant reduction of algae and associated impacts, including the reduction of DBPs

Figure 7 Ultrasonic Algae Controller Unit in Sugar Creek Lake

6.3 Bathymetric and Lake Yield Analyses

The following sub-sections present USGS and MDNR studies of changes in lake's volume. Section 6.3.1 summarizes USGS's 2018 Bathymetric Survey findings and Section 6.3.2 summarizes MDNR's 2019 Firm Yield Study.

6.3.1 USGS Bathymetric Survey and Change Analysis

The USGS completed a study of the lake in 2018 to analyze the bathymetric change due to erosion and deposition since the previous survey in 2003. The 2018 survey concluded that at the spillway elevation of 746.8 feet, the surface area is 332 acres and the capacity is 5,020 acre-feet. The study found the lake to have a similar surface area to the 2003 survey, but to have a decreased capacity of 230 acre-feet from the 2003 survey due to sediment deposition of approximately 1 – 1.5 feet across the lake bottom. Appendix C provides the USGS 2018 survey report, which includes a change analysis figure that depicts bathymetric change between the 2003 survey and 2018 survey due to erosion and sediment deposition.

6.3.2 MDNR Lake Yield Study

MDNR completed a water supply yield study of the lake for the City in June 2019 to provide an updated understanding of the lake's capacity to meet the City's water demands during drought of record (1951-1960) conditions. The most recent yield study of the lake occurred in 2005. The 2019 study used USGS bathymetry survey data and Reservoir System Simulation (HEC-ResSim), a simulation program developed by the U.S. Army Corps of Engineers, to predict the lake's yield during drought of record conditions for an estimated City water demand of 1.33 MGD, the City's average demand between 1992 and 2017. MDNR's 2019 Lake Yield Study report is included in Appendix A.

The study included two scenarios to account for the effects of seepage from the lake's dam abutment on estimated yield during drought conditions. MDNR estimated that 1 MGD of lake volume is lost to seepage at full pool, or a spillway elevation of 756.8 feet. Figure 8 displays the seepage bypass from the abutment of the dam into the spillway.

The first scenario, Scenario 1,assumed no seepage throughout the model run while the second scenario accounted for an estimated seepage range of 750 gpm at full pool to 0 gpm when the lake is empty. The first scenario concluded the lake will yield 1.44 MGD during the 10 year drought of record timescale, thus meeting the estimated 1.33 MGD demand. Although Scenario 1 determined that Sugar Creek Lake could meet the 1.33 MGD demand over ten years during an extended drought, the study noted that a total of 314 out of 3,560 days of the model run resulted in near insufficient water supply conditions. The second scenario, Scenario 2, concluded the lake's estimated yield, considering seepage, at 1.17 MGD is not sufficient to meet the 1.33 MGD demand.

The yield study also evaluated the lake's storage due to sedimentation from 2003 to 2033. The study included an analysis of the effects of sedimentation, assuming seepage, using storage-elevation curves developed from the 2003 and 2018 bathymetric surveys. For this analysis, the modelers assumed the 2003-2018 storage curve, a loss of 4.6%, would also occur from 2018 to 2033. The analysis determined that an additional 12 days of insufficient yield resulted from sedimentation between 2003 and 2033.

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Figure 8 Seepage Bypass from the Sugar Creek Lake Dam to the Lake Spillway

MDNR's study highlights the significant effects of sedimentation and seepage on available water supply volume in the lake, including the fact that a portion of the intake is estimated to be buried under approximately 12 feet of sediment. The study recommends the City take steps to reduce volume lost to seepage and create a management plan to ensure water supply in the event the intake must be moved to a higher elevation. A third recommendation of the study is to install USGS level gages upstream of the lake and at the intake location to more accurately estimate inflow to the lake and lake levels. The City is currently taking steps to evaluate and construct an engineered solution to significantly reduce the seepage in the dam abutment.

6.4 Summary of Water Supply Impacts

As discussed in Section 6.2 through Section 6.3.2, significant water supply impacts for the lake include nutrient loading and sedimentation. In summary, actions taken by the City to address adverse water supply impacts include, but are not limited to, WTP upgrades, installation of the ultrasonic algae controller units, design of a project to reduce seepage in the dam abutment, and implementation of the goals, objectives, and strategies identified in this Plan.

7.0 Proposed Implementation

As discussed in Section 1.2, the purpose of this Plan is to identify the goals, objectives, and strategies for the lake and provide stakeholders with a guidance document for the lake's long-term protection as the drinking water source for the City. Table 1 through Table 3 in Section 2.3.1 outline the specific strategies developed for each objective and goal and the proposed implementation schedule for each strategy.

As seen in Table 1 through Table 3, the implementation timeline for the each strategy varies; the City began to implement several strategies before the finalization of this Plan, while the implementation of many other strategies is in early stages. Two fundamental strategies to accomplish the goals of this Plan include establishing two stakeholder groups that meet regularly (Objective 1, Strategy 3 of Goal 3) and further developing partnerships for implementation opportunities (Objectives 1 and 2, Strategy 4 of Goal 1). The City intends to proceed with these engagement strategies as a foundation for the implementation of the technical and data related strategies. The City intends to review and update this Plan once every five years in order to revise and implement new strategies to achieve the City's goals for the lake, watershed, and long-term water supply.

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Large Tables

Large Table 1 Predominant NRCS Soil Types within Sugar Creek Lake Watershed

Soil Unit	Soil Type	Drainage Class	Farmland Classification	Hydrologic Soil Group (1)	Soil Notes (2)
60058	Bethesda channery silt loam, 20-70% slopes	Well drained	Not prime farmland	B	• Occurs in areas of mine spoil at sites of past surface mines • High soil acidity (generally supports poor-quality timbers and shrubs)
50021	Calwoods silt loam, 2-5% slopes, eroded	Somewhat poorly drained	Not prime farmland	D	• Natural fertility is low (mostly used for hay, pasture, or timber) • High shrink-swell potential • Seasonal perched water table is common • Unsuited for septic system absorption fields due to wetness and low permeability
30068	Gorin silt loam, 5-9% slopes, eroded	Somewhat poorly drained	Farmland of statewide importance	C	• Natural fertility is low (mostly used for hay, pasture, or timber) • High shrink-swell potential • Seasonal perched water table is common • Unsuited for septic system absorption fields due to wetness and low permeability
50024	Gosport silt loam, 14-30% slopes, eroded	Moderately well drained	Farmland of statewide importance	D	• Most common soil type adjacent to lake • Weathered bedrock 20-40 inches below ground surface limits rooting • Natural fertility is low (mostly used for woodland or pasture) • High shrink-swell potential • Unsuited for septic system absorption fields due to slope and limited depth to bedrock
50008	Keswick silt loam, 5-9% slopes, eroded	Moderately well drained	Not prime farmland	D	• Keswick silt loam (all slopes): • Natural fertility is medium (mostly used for hay, pasture, cultivated crops, or timber) • High shrink-swell potential • Seasonal perched water table is common • Unsuited for septic system absorption fields due to wetness and slope
50030	Keswick silt loam, 9-20% slopes, eroded	Somewhat poorly drained	Not prime farmland	D	

Soil Unit	Soil Type	Drainage Class	Farmland Classification	Hydrologic Soil Group (1)	Soil Notes (2)
60022	Leonard silt loam, 1-6% slopes, eroded	Poorly drained	Prime farmland if drained	C/D	• Natural fertility is medium (mostly used for hay, cultivated crops, or pasture) • High shrink-swell potential • Seasonal perched water table is common • Unsuited for septic system absorption fields due to wetness and low permeability
50058	Mexico silt loam, 0-2 % slopes	Poorly drained	Not prime farmland	D	• Mexico silt loam (all slopes): • Natural fertility is medium (mostly used for hay, cultivated crops, or pasture) • High shrink-swell potential • Seasonal perched water table is common • Unsuited for septic system absorption fields due to wetness and low permeability
50059	Mexico silt loam, 1-4% slopes, eroded	Poorly drained	Not prime farmland	D	
66099	Piopolis silty clay loam, 0-2% slopes, frequently flooded	Poorly drained	Not prime farmland	C/D	• Natural fertility is medium (mostly used for hay, cultivated crops, or pasture) • Moderate shrink-swell potential • Seasonal perched water table is common • Unsuited for septic system absorption fields due to wetness and low permeability
50012	Putnam silt loam, 0-1% slopes	Poorly drained	Not prime farmland	D	• Natural fertility is medium (mostly used for hay, cultivated crops, or pasture) • High shrink-swell potential • Seasonal perched water table is common • Unsuited for septic system absorption fields due to wetness and low permeability

(1) A = low runoff potential; B = moderately low runoff potential; C = moderately high runoff potential; D = high runoff potential
(2) Source: reference (29)

Large Table 2 Water Quality and Standards Comparison

Sample Parameter	Units	Year	Sample Locations											
			Location 1				Location 2				Location 3			
			Number of Samples	Avg	Min	Max	Number of Samples	Avg	Min	Max	Number of Samples	Avg	Min	Max
Alkalinity	mg/L	2010	11	105	94	124	11	98.5	84	116	11	97	82	116
		2011	12	105	90	120	12	102	88	116	12	100	84	110
		2012	13	110	92	132	13	106	84	120	13	104	80	120
		2017	17	110	66	136	24	158	82	280	15	111	88	128
		2018	6	92	60	112	6	97.0	90	110	6	96	90	104
Ammonia (NH_3) [1]	mg/L	2010	8	0.59	0.29	0.93	8	0.35	0.21	0.60	8	0.37	0.17	0.7
		2011	6	0.43	0.36	0.54	6	0.26	0.19	0.35	6	0.22	0.17	0.3
		2012	5	0.48	0.19	0.83	5	0.27	0.14	0.40	5	0.21	0.06	0.3
		2013	6	0.44	0.40	0.55	6	0.33	0.23	0.49	6	0.32	0.17	0.5
		2017	23	0.151	0.0	0.94	32	0.19	0.0	1.13	20	0.07	0.00	0.4
		2018	6	0.143	0.02	0.50	6	0.09	0.01	0.14	6	0.08	0.00	0.2
Biochemical oxygen demand (BOD_5)	mg/L	2010	7	3.7	2.6	5.2	6	2.70	1.4	3.2	6	2.1	1.4	2.5
		2011	3	7.3	4.0	13.0	1	14.0	14.0	14.0	2	9.5	4.0	15.0
		2012	4	3.5	2.0	4.0	2	3.70	3.3	4.0	3	4.2	3.0	5.0
		2013	6	5.7	3.4	13.0	3	4.20	2.5	7.0	2	7.5	3.0	12.0
		2017	7	15.2	0.2	80.0	7	21.30	0.4	74.0	4	16.7	0.7	61.0
Chemical oxygen demand (COD)	mg/L	2010	8	21.7	15.3	28.2	8	22.8	8.8	35.4	8	18.5	13.2	22.6
		2011	6	18.7	14.0	24.0	6	15.5	7.4	22.1	6	16.8	11.4	24.0
		2012	5	37.8	18.5	73.0	5	25.1	11.6	55.0	5	24.5	12.2	52.0
		2013	6	35.1	25.6	69.3	6	27.9	11.0	60.4	6	29.3	16.8	69.4
		2017	7	21.3	10.0	34.0	9	17.1	1.0	35.0	9	14.4	4.0	23.0
Coliforms	MPN	2010	4	1918	412	>2419.6	4	2311	1986	>2419.6	4	1566	655	>2419.6
		2011	6	1163	10	>2419.6	6	963	4	>2419.6	6	645	12	>2419.6
		2012	4	1968	1300	>2419.6	4	1960	579	>2419.6	4	902	205	>2419.6
		2013	6	1941	425	>2419.6	6	1146	166	>2419.6	6	1263	15	>2419.6
		2017	6	1737	706	3873	7	2516	159	>5794	5	1143	134	4611
Copper [1]	µg/L	2017	17	4.1	0.0	14.0	23	3.48	0.0	18.0	15	1.0	0.0	9.0
		2018	6	1.7	0.0	8.0	6	0.50	0.0	2.0	6	1.2	0.0	2.0
Dissolved oxygen, initial (*in situ*)	mg/L	2010	8	8.3	7.7	8.8	8	8.30	7.8	8.8	8	8.2	7.2	8.7
		2011	4	8.6	7.8	9.7	4	8.60	7.8	9.6	4	8.7	8.0	9.6
		2012	4	8.6	7.9	9.4	4	8.70	8.4	9.2	4	8.9	8.5	9.2
		2013	5	8.5	7.2	9.8	5	8.80	7.5	9.8	5	8.9	7.5	9.8
		2017	3	9.5	9.2	9.6	6	9.20	8.8	9.6	2	9.4	9.2	9.6
Dissolved oxygen, final (*in situ*)	mg/L	2010	8	6.6	4.9	8.0	8	6.90	5.5	7.8	8	7.2	6.4	7.7
		2011	4	7.8	6.5	9.1	4	8.00	7.0	8.8	4	8.0	7.2	8.9
		2012	4	6.8	6.7	7.1	4	7.00	6.4	7.6	4	7.7	6.6	8.4
		2013	5	5.5	1.7	8.2	5	7.10	5.2	8.8	5	6.9	3.3	8.9
		2017	3	8.1	6.0	9.4	6	7.60	4.9	9.0	2	7.7	5.9	9.5
Dissolved oxygen, laboratory	mg/L	2010	8	8.2	6.7	9.3	8	8.20	6.6	9.3	8	8.4	6.8	9.5
		2011	6	8.6	6.8	9.8	6	8.80	7.5	10.2	6	9.2	8.5	10.1
		2012	5	8.9	8.2	10.4	5	9.40	8.3	10.3	5	9.8	8.3	11.2
		2013	6	8.5	6.6	9.6	6	9.00	7.4	10.8	6	9.6	7.5	12.0
		2017	7	10.3	8.5	12.2	8	10.3	9.1	11.7	5	11.0	9.9	11.9
Hardness	mg/L	2010	11	109	92	122	11	104	84	124	11	102	80	114
		2011	12	121	106	152	12	119	106	138	12	116	102	130
		2012	13	126	108	142	13	124	98	136	13	123	102	136
		2017	17	126	96	158	23	175	96	328	15	125	96	160
		2018	6	107	72	138	6	113	100	136	6	110	100	130
Manganese	mg/L	2010	11	0.29	0.14	0.45	11	0.15	0.08	0.27	11	0.13	0.05	0.27
		2011	12	0.24	0.08	0.41	12	0.14	0.07	0.36	12	0.11	0.06	0.20
		2012	13	0.27	0.14	0.45	13	0.15	0.11	0.22	13	0.11	0.06	0.17
Manganese, filtered	mg/L	2017	17	0.082	0.009	0.214	24	0.096	0.010	0.405	15	0.028	0.006	0.057
		2018	6	0.033	0.004	0.068	6	0.010	0.004	0.016	6	0.012	0.005	0.018
Manganese, unfiltered	mg/L	2017	17	0.329	0.139	0.883	24	0.235	0.059	0.758	15	0.131	0.077	0.198
		2018	6	0.295	0.133	0.839	6	0.103	0.058	0.175	6	0.096	0.058	0.178
Nitrate, as nitrogen (NO_3 - N)	mg/L	2017	7	2.50	2.20	3.00	9	5.00	0.10	16.00	5	1.800	1.40	2.00
Nitrite (NO_2) [1]	mg/L	2017	10	0.024	0.000	0.128	13	0.030	0.000	0.210	9	0.007	0.000	0.023
		2018	6	0.032	0.000	0.177	6	0.030	0.000	0.145	6	0.026	0.000	0.141
Organics	mg/L	2010	12	0.227	0.162	0.461	12	0.201	0.159	0.243	12	0.194	0.166	0.240
		2011	12	0.145	0.110	0.206	12	0.141	0.121	0.206	12	0.137	0.118	0.206
		2012	12	0.152	0.105	0.260	12	0.134	0.118	0.174	12	0.127	0.098	0.160

Large Table 2 Water Quality and Standards Comparison

Sample Parameter	Units	Year	Sample Locations											
			Location 1				Location 2				Location 3			
			Number of Samples	Avg	Min	Max	Number of Samples	Avg	Min	Max	Number of Samples	Avg	Min	Max
pH	S.U	2010	20	7.7	7.1	8.2	20	7.95	7.0	8.8	20	8.1	7.4	8.9
		2011	18	7.9	7.3	8.6	18	8.07	7.5	8.6	18	8.2	7.5	8.7
		2012	18	7.9	7.5	8.4	18	8.15	7.7	8.6	18	8.3	7.6	8.8
		2013	6	7.8	7.5	8.1	6	8.17	7.8	8.9	6	8.2	7.8	8.7
		2017	24	8.2	7.3	8.6	32	7.94	7.4	9.0	20	8.3	7.7	9.0
		2018	6	7.9	7.8	8.1	6	8.14	7.9	8.6	6	8.2	7.8	8.6
Phosphate (PO_4)	mg/L	2017	23	0.316	0.00	2.79	29	0.83	0.02	4.30	19	0.10	0.01	0.50
		2018	6	0.402	0.06	1.10	6	0.05	0.01	0.10	6	0.05	0.03	0.06
Specific conductivity (microohms)	µmhos	2017	14	268.9	146	360	17	391	192	860	12	233	151	296
		2018	6	220.2	141	279	6	224	204	254	6	225	201	263
Temperature	Deg. C	2010	8	20	9	30	8	20.1	10	29	8	20	10	29
		2011	6	20	15	27	6	19.8	14	28	6	20	14	28
		2012	5	19	12	29	5	19.4	11	30	5	20	11	30
		2013	6	20	8	25	6	19.7	8	25	6	20	8	25
		2017	6	9	7	13	8	8.80	5	18	4	8	6	9
Total dissolved solids (TSS)	mg/L	2017	14	177	91	243	17	258	127	500	12	158	101	199
		2018	6	114.1	0.36	178	6	151	138	171	6	125	0	166
Total suspended solids (TSS)	mg/L	2010	1	38	38	38	1	12.0	12	12	1	8.0	8.0	8.0
		2017	7	29	15	52	9	121	1	665	5	14.4	7.0	22.0
Turbidity	NTU	2010	12	28.7	14.1	38.9	12	15.0	8.9	25.5	12	11.7	5.7	27.1
		2011	12	28.9	6.2	58.8	12	14.0	7.9	20.6	12	10.8	7.1	16.7
		2012	13	38.9	10.5	73.6	13	17.9	10.1	27.7	13	11.0	4.7	21.7
		2017	17	56.6	13.7	400	24	92.0	2.7	1310	15	12.4	8.6	26.3
		2018	6	99.8	17.4	340	6	9.91	5.31	13.2	6	6.9	4.8	9.6
UV254	cm^{-1}	2017	17	0.22	0.09	0.66	24	0.24	0.07	0.70	15	0.12	0.09	0.18
		2018	6	0.24	0.11	0.56	6	0.11	0.10	0.13	6	0.10	0.10	0.11

Large Table 2 Water Quality and Standards Comparison

Sample Parameter	Units	Sample Locations: Location 4 Number of Samples	Location 4 Avg	Location 4 Min	Location 4 Max	Location 5 Number of Samples	Location 5 Avg	Location 5 Min	Location 5 Max	Location 6 Number of Samples	Location 6 Avg	Location 6 Min	Location 6 Max
Alkalinity	mg/L	11	98	82	122	11	94	80	108	11	97	82	114
		12	102	86	118	12	101	82	116	12	102	84	114
		13	108	90	120	13	106	90	120	13	106	90	120
		15	109	88	120	15	109	88	122	19	110	88	124
		6	96	90	110	6	97	90	106	6	95	88	112
Ammonia (NH_3) [(1)]	mg/L	8	0.37	0.16	0.71	8	0.36	0.12	0.73	8	0.37	0.15	0.71
		6	0.23	0.15	0.38	6	0.26	0.15	0.45	6	0.26	0.16	0.37
		5	0.22	0.08	0.35	5	0.21	0.06	0.37	5	0.23	0.06	0.32
		6	0.32	0.19	0.48	6	0.30	0.17	0.50	6	0.35	0.24	0.52
		20	0.05	0.01	0.12	20	0.05	0.00	0.11	27	0.06	0.00	0.22
		6	0.06	0.00	0.15	6	0.06	0.00	0.15	6	0.16	0.00	0.80
Biochemical oxygen demand (BOD_5)	mg/L	5	2.4	1.2	3.0	5	6.5	1.5	24.0	4	3.1	2.5	3.8
		2	8.0	3.0	13.0	2	8.0	3.0	13.0	2	7.0	3.0	11.0
		2	3.8	3.6	4.0	2	4.1	4.0	4.2	1	2.4	2.4	2.4
		3	5.3	2.8	10.0	3	2.5	2.0	3.0	3	3.7	3.0	5.0
		5	3.2	1.0	7.0	5	2.8	0.9	4.0	4	3.1	2.0	6.0
Chemical oxygen demand (COD)	mg/L	8	19.7	9.3	38.0	8	19.0	12.1	24.3	8	19.3	9.0	30.0
		6	19.2	15.4	22.3	6	17.8	11.6	20.7	6	17.1	12.5	27.0
		5	28.2	9.9	58.0	5	28.0	10.1	55.0	5	27.4	10.1	54.0
		6	28.9	19.2	54.7	6	26.0	16.4	52.7	6	22.8	0.0	58.9
		5	15.8	10.0	29.0	5	17.2	9.0	23.0	8	21.3	3.0	56.0
Coliforms	MPN	4	1772	1046	>2419.6	4	1585	298	>2419.6	4	2045	921	>2419.6
		6	733	2	>2419.6	6	620	14	>2419.6	5	887	64	>2419.6
		3	1785	517	>2419.6	4	1026	248	>2419.6	4	1117	135	>2419.6
		6	1516	22	>2419.6	6	1124	54	>2419.6	6	1262	46	>2419.6
		5	531	122	1421	5	456	64	1430	6	479	5	1333.0
Copper [(1)]	µg/L	15	1.5	0.0	5.0	15	1.2	0.0	5.0	18	2.9	0.0	12.0
		6	0.5	0.0	1.0	6	0.7	0.0	3.0	6	3.5	0.0	7.0
Dissolved oxygen, initial (*in situ*)	mg/L	8	8.3	7.7	8.8	8	8.4	7.7	8.8	8	8.5	7.7	9.2
		4	8.7	8.0	9.7	4	8.2	7.0	9.6	4	8.2	7.0	9.6
		4	8.8	8.4	9.2	4	8.8	8.4	9.1	4	8.6	8.3	9.0
		6	8.8	7.5	9.8	4	8.8	7.6	9.9	5	8.8	7.5	9.8
		4	10.1	9.7	10.5	5	10.3	9.9	10.7	6	9.7	8.7	10.4
Dissolved oxygen, final (*in situ*)	mg/L	8	7.4	6.3	8.2	8	7.3	6.4	7.8	8	7.2	6.5	7.9
		4	8.0	7.2	8.6	4	7.6	7.0	8.4	4	7.6	6.9	8.6
		4	7.3	6.5	8.0	4	7.4	6.7	8.2	4	7.2	5.8	8.0
		6	7.1	4.0	8.7	4	7.8	6.3	8.8	5	7.4	6.2	9.0
		4	7.2	4.4	8.7	5	7.8	6.2	8.7	6	7.2	5.3	9.0
Dissolved oxygen, laboratory	mg/L	8	8.4	5.8	9.7	8	8.5	6.2	9.8	8	8.8	7.0	10.3
		6	9.2	8.5	10.0	6	9.3	8.7	10.0	6	9.3	8.7	10.0
		5	9.9	8.6	10.9	5	9.8	8.4	11.0	5	9.1	7.8	10.0
		6	9.7	7.6	11.9	6	9.4	7.7	11.7	6	9.6	7.6	11.6
		5	10.9	10.0	11.9	5	11.2	10.1	11.9	8	10.8	9.9	11.8
Hardness	mg/L	11	100	82	114	11	101	80	116	11	100	80	114
		12	116	96	134	12	114	92	136	12	115	94	130
		13	121	96	134	13	121	94	138	13	119	94	134
		15	119	96	132	15	119	94	134	19	121	96	140
		6	112	102	134	6	114	104	128	6	114	100	132
Manganese	mg/L	11	0.14	0.06	0.26	11	0.16	0.05	0.41	11	0.16	0.07	0.30
		12	0.11	0.06	0.20	12	0.09	0.02	0.26	12	0.12	0.06	0.20
		13	0.12	0.06	0.19	13	0.11	0.06	0.16	13	0.13	0.07	0.25
Manganese, filtered	mg/L	15	0.025	0.000	0.045	15	0.032	0.002	0.059	19	0.041	0.006	0.177
		6	0.009	0.005	0.013	6	0.012	0.002	0.015	6	0.013	0.008	0.022
Manganese, unfiltered	mg/L	15	0.127	0.088	0.164	15	0.130	0.074	0.178	19	0.178	0.110	0.478
		6	0.097	0.069	0.122	6	0.110	0.056	0.177	6	0.124	0.071	0.172
Nitrate, as nitrogen (NO_3 - N)	mg/L	5	1.90	1.00	2.80	5	1.80	1.60	2.00	8	3.40	0.70	13.00
Nitrite (NO_2) [(1)]	mg/L	9	0.007	0.000	0.023	9	0.229	0.000	2.000	10	0.011	0.000	0.029
		6	0.025	0.000	0.137	6	0.025	0.001	0.136	6	0.031	0.000	0.169
Organics	mg/L	12	0.198	0.162	0.236	12	0.197	0.164	0.239	12	0.199	0.166	0.254
		12	0.139	0.112	0.208	12	0.138	0.111	0.205	12	0.143	0.120	0.216
		12	0.129	0.100	0.169	12	0.131	0.106	0.170	12	0.133	0.112	0.194

Large Table 2 Water Quality and Standards Comparison

Sample Parameter	Units	Sample Locations											
		Location 4				Location 5				Location 6			
		Number of Samples	Avg	Min	Max	Number of Samples	Avg	Min	Max	Number of Samples	Avg	Min	Max
pH	S.U	19	8.1	7.4	8.9	20	8.1	7.4	8.9	20	8.2	7.5	8.9
		18	8.2	7.6	8.8	18	8.3	7.6	8.8	18	8.3	7.6	8.8
		18	8.3	7.8	8.7	18	8.3	7.8	8.8	18	8.3	7.8	8.8
		6	8.2	7.7	8.8	6	8.2	7.7	8.6	6	8.2	7.7	8.7
		20	8.3	7.8	9.0	20	8.4	7.8	9.0	27	8.3	7.7	8.9
		6	8.2	7.9	8.5	6	8.2	7.8	8.6	6	8.2	8.0	8.6
Phosphate (PO_4)	mg/L	19	0.07	0.01	0.20	19	0.06	0.00	0.20	25	0.26	0.00	3.70
		6	0.07	0.00	0.13	6	0.06	0.03	0.17	6	0.04	0.00	0.08
Specific conductivity (microohms)	µmhos	12	222	171	259	12	249	208	287	14	246	148	311
		6	227	203	261	6	237	204	270	6	235	201	281
Temperature	Deg. C	8	19	8	29	8	21	10	29	8	21	10	29
		6	20	14	28	6	20	14	28	6	20	14	28
		5	20	12	30	5	20	12	30	5	20	12	30
		6	20	8	25	6	20	9	25	6	20	9	25
		4	8	6	9	4	8	7	9	7	10	8	17
Total dissolved solids (TSS)	mg/L	12	152	115	180	12	168	136	203	14	176	102	355
		6	150	132	178	6	156	145	187	6	153	136	177
Total suspended solids (TSS)	mg/L	1	7	7	7	1	7	7	7	1	14.0	14.0	14.0
		5	11.8	8	16	5	9.4	7	13	8	18.2	11.2	24.0
Turbidity	NTU	12	11.8	6.0	24.1	12	11.1	5.0	25.2	12	13.7	6.6	29.4
		12	10.2	6.2	18.2	12	9.6	4.6	18.6	12	12.1	6.8	17.6
		13	12.1	4.6	21.1	13	10.7	6.4	23.3	13	13.1	7.6	21.9
		15	12.6	7.0	21.8	15	10.9	7.5	18.9	19	21.8	7.3	77.8
		6	11.6	5.9	20.3	6	6.0	3.7	8.0	6	16.6	6.4	23.8
UV254	cm^{-1}	15	0.12	0.08	0.19	15	0.12	0.09	0.18	19	0.15	0.08	0.33
		6	0.12	0.10	0.17	6	0.11	0.10	0.12	6	0.12	0.10	0.19

Large Table 2 Water Quality and Standards Comparison

Sample Parameter	Units	Sample Locations							
		Location 7				Location 8			
		Number of Samples	Avg	Min	Max	Number of Samples	Avg	Min	Max
Alkalinity	mg/L	11	95	80	108	11	95	80	110
		12	101	80	114	12	102	84	112
		13	106	90	120	13	105	92	120
		15	110	88	122	18	111	88	136
		6	95	90	108	6	96	90	108
Ammonia (NH_3) [(1)]	mg/L	8	0.34	0.11	0.69	8	0.33	0.11	0.71
		6	0.29	0.14	0.62	6	0.29	0.14	0.65
		5	0.19	0.01	0.29	5	0.20	0.00	0.30
		6	0.31	0.17	0.49	6	0.31	0.18	0.48
		20	0.07	0.00	0.45	24	0.05	0.00	0.22
		6	0.05	0.00	0.11	6	0.06	0.01	0.15
Biochemical oxygen demand (BOD_5)	mg/L	5	2.5	1.0	3.8	3	2.2	0.8	3.0
		1	14.0	14.0	14.0	1	12.0	12.0	12.0
		2	4.8	4.6	5.0	2	5.7	5.0	6.4
		1	2.0	2.0	2.0	--	--	--	--
		4	2.1	0.9	3.4	4	2.1	0.9	4.0
Chemical oxygen demand (COD)	mg/L	8	18.5	11.3	25.7	8	18.2	13.8	23.3
		6	16.4	13.3	22.7	6	18.5	9.2	35.0
		5	28.6	13.3	53.0	5	25.0	5.4	51.0
		6	27.1	15.1	60.7	6	30.8	16.6	60.0
		5	15.8	12.0	20.0	6	11.0	1.0	21.0
Coliforms	MPN	4	1959	578	>2419.6	4	1767	816	>2419.6
		6	758	1	>2419.6	6	611	1	>2419.6
		4	1888	727	>2419.6	4	1350	345	>2419.6
		6	1056	29	>2419.6	6	1288	19	>2419.6
		5	180	14	638.0	5	111	20	148
Copper [(1)]	µg/L	15	1.8	0.0	16.0	18	0.8	0.0	5.0
		6	0.2	0.0	1.0	6	0.3	0.0	2.0
Dissolved oxygen, initial (*in situ*)	mg/L	8	8.3	7.6	8.7	8	8.3	7.7	8.7
		4	8.1	7.0	9.5	4	8.2	7.0	9.5
		4	8.7	8.4	9.1	4	8.6	7.9	9.1
		4	8.8	7.5	9.9	4	8.6	7.3	9.9
		4	10.2	9.9	10.4	5	10.0	9.3	10.4
Dissolved oxygen, final (*in situ*)	mg/L	8	7.1	6.1	7.8	8	6.4	0.3	7.7
		4	7.7	6.9	8.8	4	7.6	6.8	8.5
		4	7.1	5.8	8.4	4	6.7	5.1	8.2
		4	7.9	6.3	8.8	4	7.8	6.2	8.9
		4	7.8	7.0	8.4	5	8.0	6.6	9.1
Dissolved oxygen, laboratory	mg/L	8	8.7	7.2	9.7	8	8.4	7.5	9.6
		6	9.1	8.3	10.1	6	9.1	7.9	10.1
		5	9.3	8.2	10.8	5	9.0	6.3	10.4
		6	9.1	7.4	11.6	6	8.7	7.1	11.6
		5	11.3	10.8	11.6	6	11.2	10.3	11.7
Hardness	mg/L	11	100	80	110	11	102	82	114
		12	115	98	126	12	116	98	130
		13	120	98	136	13	120	96	136
		15	122	98	140	6	114	100	142
		6	113	96	132	6	114	100	142
Manganese	mg/L	11	0.15	0.05	0.31	11	0.15	0.05	0.30
		12	0.11	0.05	0.25	12	0.11	0.05	0.24
		13	0.12	0.07	0.23	13	0.13	0.07	0.37
Manganese, filtered	mg/L	15	0.042	0.008	0.163	18	0.047	0.009	0.187
		6	0.010	0.008	0.014	6	0.011	0.007	0.014
Manganese, unfiltered	mg/L	15	0.143	0.076	0.446	18	0.142	0.066	0.488
		6	0.091	0.056	0.131	6	0.100	0.053	0.174
Nitrate, as nitrogen (NO_3 - N)	mg/L	5	1.72	1.30	2.30	6	1.80	1.40	2.30
Nitrite (NO_2) [(1)]	mg/L	9	0.006	0.000	0.018	10	0.006	0.000	0.015
		6	0.025	0.000	0.133	6	0.025	0.000	0.138
Organics	mg/L	12	0.195	0.164	0.226	12	0.192	0.159	0.222
		12	0.139	0.115	0.210	12	0.141	0.113	0.216
		12	0.127	0.104	0.173	12	0.127	0.105	0.165

Large Table 2 Water Quality and Standards Comparison

Sample Parameter	Units	Sample Locations							
		Location 7				Location 8			
		Number of Samples	Avg	Min	Max	Number of Samples	Avg	Min	Max
pH	S.U	20	8.2	7.5	8.9	20	8.1	7.5	8.8
		18	8.2	7.6	8.7	18	8.2	7.7	8.7
		18	8.3	7.8	8.9	18	8.3	7.6	8.9
		6	8.1	7.8	8.5	6	8.0	7.5	8.3
		20	8.3	7.7	9.0	24	8.3	7.6	9.0
		6	8.3	8.0	8.5	6	8.2	7.8	8.5
Phosphate (PO_4)	mg/L	19	0.05	0.01	0.20	22	0.08	0.01	0.38
		6	0.04	0.01	0.08	6	0.0	0.01	0.04
Specific conductivity (microohms)	µmhos	12	249	166	292	14	267	158	548
		6	232	216	270	6	229	209	267
Temperature	Deg. C	8	21	11	29	8	21	11	28
		6	20	14	28	6	20	14	27
		5	20	12	29	5	20	12	29
		6	20	10	24	6	19	10	24
		4	9	8	9	5	8	8	9
Total dissolved solids (TSS)	mg/L	12	159	102	186	14	162	108	200
		6	156	142	187	6	149	142	162
Total suspended solids (TSS)	mg/L	1	8.0	8.0	8.0	1	3	3	3
		5	9.0	6.0	12.0	6	10	5	15
Turbidity	NTU	12	11.2	5.3	21.5	12	9.8	5.4	21.2
		12	10.6	4.9	21.2	12	9.3	4.9	18.3
		13	10.6	6.7	17.4	13	9.9	6.0	18.2
		15	9.5	5.3	20.2	18	9.2	5.2	33.2
		6	7.0	4.4	12.8	6	6.6	3.6	13.0
UV254	cm^{-1}	15	0.12	0.09	0.19	18	0.12	0.09	0.25
		6	0.11	0.09	0.12	6	0.11	0.09	0.12

(1) Negative sample results occurred for these parameters and were assumed to be zer

Large Table 3a Sugar Creek Lake Volunteer Monitoring Site 1 Nutrient Criteria Comparison

Year	Number of Samples	Chlorophyll-a Response Impairment Threshold			Total Phosphorus Screening Threshold (49 µg/L)				Total Nitrogen Screening Threshold (843 µg/L)				Chlorophyll-a Screening Threshold (18 µg/L)				Endpoint Criteria				
		Summer Geometric Mean	Exceeds Threshold ? (Y/N)	Impaired?(1)	Summer Geometric Mean	Exceeds Threshold ? (Y/N)	Consider Endpoints ? (Y/N)	Impaired?(2)	Summer Geometric Mean	Exceeds Threshold ? (Y/N)	Consider Endpoints ? (Y/N)	Impaired?(2)	Summer Geometric Mean	Exceeds Threshold ? (Y/N)	Consider Endpoints ? (Y/N)	Impaired?(2)	Eutrophication-Related Mortality Events(3)	pH or DO Epilimnetic Excursions(4)(5)	Cyanobacteria(6)	Eutrophication-Related Aquatic Diversity Shifts(7)	Excessive Mineral Turbidity(8)
2000	2	37.7	Y	N	72.1	Y	N	N	1077	Y	N	N	37.7	Y	N	N	No data	No data	N	N	N
2001	7	20.4	N	N	33.6	N	N	N	597	N	N	N	20.4	Y	Y	N	No data	No data	N	N	N
2002	9	18.9	N	N	48.7	N	N	N	725	N	N	N	18.9	Y	Y	N	No data	No data	N	N	N
2003	8	18.1	N	N	43.3	N	N	N	676	N	N	N	18.1	Y	N	N	No data	No data	N	N	N
2004	8	26.2	N	N	50.2	Y	N	N	662	N	N	N	26.2	Y	N	N	N	No data	N	N	N
2005	10	23.1	N	N	45.1	N	N	N	767	N	N	N	23.1	Y	Y	N	N	No data	N	N	N
2006	9	27.1	N	N	42.3	N	N	N	629	N	N	N	27.1	Y	Y	N	N	No data	N	N	N
2007	6	21.0	N	N	44.0	N	N	N	678	N	N	N	21.0	Y	Y	N	N	No data	N	N	N
2008	8	13.6	N	N	45.5	Y	N	N	850	Y	N	N	13.6	N	Y	N	N	No data	N	N	N
2009	6	21.7	N	N	44.2	Y	Y	N	903	Y	N	N	21.7	Y	Y	N	N	No data	N	N	N
2010	8	22.0	N	N	60.9	Y	Y	N	858	Y	Y	N	22.0	Y	Y	N	N	N	N	N	N
2011	7	18.9	N	N	35.9	N	Y	N	772	N	Y	N	18.9	Y	Y	N	N	N	N	N	N
2012	7	32.5	Y	N	49.8	Y	Y	N	871	Y	N	N	32.5	Y	Y	N	N	N	N	N	N
2013	8	14.7	N	N	47.1	Y	Y	N	900	Y	Y	N	14.7	N	N	N	N	N	N	N	N
2014	8	12.6	N	N	31.5	N	Y	N	690	N	Y	N	12.6	N	N	N	N	No data	N	N	N
2015	7	24.6	N	N	40.6	N	N	N	684	N	N	N	24.6	Y	N	N	N	No data	N	N	N
2016	8	23.5	N	N	40.1	N	N	N	816	N	N	N	23.5	Y	Y	N	N	No data	N	N	N
2017	8	20.9	N	N	43.2	N	N	N	928	Y	N	N	20.9	Y	Y	N	N	No data	N	N	N
2018	7	18.2	N	N	36.8	N	N	N	966	Y	Y	N	18.2	Y	Y	N	Report forthcoming	No data	N	N	N

(1) Per Missouri's Nutrient Criteria Implementation Plan (rule reference), a lake is considered impaired for nutrient criteria if the geometric mean of Chl-a samples taken between May and September in a calendar year exceeds the respective ecoregion Chla-response impairment threshold value more than once in three years' time.

(2) For lakes where the geometric mean of Chl-a, TN, or TP exceeds the ecoregional nutrient screening evaluation thresholds, the additional response assessment endpoints will be evaluated. When one of these endpoints indicate a eutrophication impact in the same year as a nutrient screening threshold exceedance, the lake will be placed into category 5 and on the 303(d) list.

(3) Following the Department's Listing Methodology Document (Appendix B of the Nutrient Implementation Plan), this endpoint criteria is exceeded if two or more fish kills have occurred within the last three years of available data or there is one large (>100 fish and covering more than ten percent of the lake area) fish kill documented to be caused by dissolved oxygen excursions, pH, algal blooms, or the toxins associated with algal blooms (10 CSR 20-7.031(5)(N)6.A).

(4) Following the Department's Listing Methodology Document (Appendix B of the Nutrient Implementation Plan), this endpoint criteria will be evaluated further if the following occur: if more than 10% of the measurements are below 5.0 mg/L minimum to protect aquatic life or more than 10% of the measurements are outside the 6.5 to 9.0 range to protect aquatic life, the binomial probabilities will be used to determine if the if the criterion have been exceeded [10 CSR 20-7.031(5)(N)6.B].

(5) Dissolved oxygen data is collected by the City of Moberly and is not part of the approved Quality Assurance Project Plan.

(6) This endpoint criteria is exceeded if the following algal toxin value thresholds are exceeded: microcystin - 4.0 ug/L, cylindospermopsin - 8.0 ug/L, anaytoxin-a - 8.0 ug/L, and saxitoxin - 4.0 ug/L. These toxin levels are associated with a total toxigenic algal species cell count greater than or equal to 100,000 cell/mL [10 CSR 20-7.031(5)(N)6.C].

(7) This endpoint criteria is exceeded if the Department finds evidence in biological shifts in fish or invertebrate communities related to eutrophication [10 CSR 20-7.031(5)(N)6.D]. The Department will request aquatic community data from multiple sources to perform an evaluation of this endpoint. The Department provided the City of Moberly with fish sampling population statistics from 2001, 2005, 2009, 2014 (reference (26)); the information provided in these statistics does not indicate this endpoint criteria is met

(8) This endpoint criteria is exceeded if there are measured lake Secchi depths less than 0.6 meters in the Plains ecoregion. Yearly average Secchi depths below the applicable ecoregional value may constitute evidence of impairment. Additional analysis of average Chl-a/TP ratios will also be conducted before determining impairment status. Unless attributed to other physical factors, Chl-a/TP ratios at or below 0.15 and an ISS value greater than or equal to 10 mg/L as determined by yearly means will serve as an indicator of excessive mineral turbidity and constitute evidence of impairment. Assessment threshold values for Secchi depth, Chla-/TP ratio, and ISS shall all be exceeded before determining a water is impaired [10 CSR 20-7.031(5)(N)6.E].

Large Table 3b Sugar Creek Lake Volunteer Monitoring Site 2 Nutrient Criteria Comparison

Year	Number of Samples	Chlorophyll-a Response Impairment Threshold (30 µg/L)			Total Phosphorus Screening Threshold (49 µg/L)				Total Nitrogen Screening Threshold (843 µg/L)				Chlorophyll-a Screening Threshold (18 µg/L)				Endpoint Criteria				
		Summer Geometric Mean	Exceeds Threshold? (Y/N)	Impaired?[1]	Summer Geometric Mean	Exceeds Threshold? (Y/N)	Consider Endpoints? (Y/N)	Impaired?[2]	Summer Geometric Mean	Exceeds Threshold? (Y/N)	Consider Endpoints? (Y/N)	Impaired?[2]	Summer Geometric Mean	Exceeds Threshold? (Y/N)	Consider Endpoints? (Y/N)	Impaired?[2]	Eutrophication-Related Mortality Events[3]	pH or DO Epilimnetic Excursions[4][5]	Cyanobacteria[6]	Eutrophication-Related Aquatic Diversity Shifts[7]	Excessive Mineral Turbidity[8]
2000	2	62.2	Y	N	90.1	Y	N	N	1087	Y	N	N	62.2	Y	N	N	No data	No data	N	N	N
2001	7	23.2	N	N	44.1	N	N	N	614	N	N	N	23.2	Y	Y	N	No data	No data	N	N	N
2002	9	23.3	N	N	56.3	N	N	N	770	N	N	N	23.3	Y	Y	N	No data	No data	N	N	N
2003	8	24.3	N	N	55.7	N	N	N	730	N	N	N	24.3	Y	Y	N	No data	No data	N	N	N
2004	8	26.6	N	N	58.2	Y	N	N	664	N	N	N	26.6	Y	Y	N	N	No data	N	N	N
2005	9	38.9	Y	N[9]	58.2	N	N	N	820	N	N	N	38.9	Y	Y	N	N	No data	N	N	N
2006	9	31.4	Y	N[9]	47.9	N	N	N	640	N	N	N	31.4	Y	Y	N	N	No data	N	N	N
2007	6	23.3	N	N	50.0	N	N	N	661	N	N	N	23.3	Y	Y	N	N	No data	N	N	N
2008	8	13.9	N	N	57.4	Y	N	N	845	Y	N	N	13.9	N	Y	N	N	No data	N	N	N
2009	6	15.9	N	N	42.9	Y	Y	N	730	N	N	N	15.9	N	N	N	N	No data	N	N	N
2010	8	26.9	N	N	63.4	Y	Y	N	884	Y	Y	N	26.9	Y	N	N	N	N	N	N	N
2011	7	26.2	N	N	48.3	N	Y	N	800	N	Y	N	26.2	Y	Y	N	N	N	N	N	N
2012	7	32.9	Y	N	55.1	Y	Y	N	849	Y	Y	N	32.9	Y	Y	N	N	N	N	N	N
2013	8	20.0	N	N	55.3	Y	Y	N	852	Y	Y	N	20.0	Y	Y	N	N	N	N	N	N
2014	8	18.9	N	N	41.3	N	Y	N	703	N	Y	N	18.9	Y	Y	N	N	No data	N	N	N
2015	7	24.9	N	N	46.2	N	N	N	755	N	N	N	24.9	Y	N	N	N	No data	N	N	N
2016	8	23.4	N	N	44.4	N	N	N	834	N	N	N	23.4	Y	Y	N	N	No data	N	N	N
2017	8	24.5	N	N	48.6	N	N	N	937	Y	N	N	24.5	Y	Y	N	N	N	N	N	N
2018	7	19.5	N	N	42.4	N	N	N	828	N	Y	N	19.5	Y	Y	N	Report forthcoming	No data	N	N	N

(1) Per Missouri's Nutrient Criteria Implementation Plan (rule reference), a lake is considered impaired for nutrient criteria if the geometric mean of Chl-a samples taken between May and September in a calendar year exceeds the respective ecoregion Chla-response impairment threshold value more than once in three years' time.
(2) For lakes where the geometric mean of Chl-a, TN, or TP exceeds the ecoregional nutrient screening evaluation thresholds, the additional response assessment endpoints will be evaluated. When one of these endpoints indicate a eutrophication impact in the same year as a nutrient screening threshold exceedance, the lake will be placed into category 5 and on the 303(d) list.
(3) Following the Department's Listing Methodology Document (Appendix B of the Nutrient Implementation Plan), this endpoint criteria is exceeded if two or more fish kills have occurred within the last three years of available data or there is one large (>100 fish and covering more than ten percent of the lake area) fish kill documented to be caused by dissolved oxygen excursions, pH, algal blooms, or the toxins associated with algal blooms (10 CSR 20-7.031(5)(N)6.A).
(4) Following the Department's Listing Methodology Document (Appendix B of the Nutrient Implementation Plan), this endpoint criteria will be evaluated further if the following occur: if more than 10% of the measurements are below 5.0 mg/L minimum to protect aquatic life or more than 10% of the measurements are outside the 6.5 to 9.0 range to protect aquatic life, the binomial probabilities will be used to determine if the if the criterion have been exceeded [10 CSR 20-7.031(5)(N)6.B].
(5) Dissolved oxygen data is collected by the City of Moberly and is not part of the approved Quality Assurance Project Plan.
(6) This endpoint criteria is exceeded if the following algal toxin value thresholds are exceeded: microcystin - 4.0 ug/L, cylindospermopsin - 8.0 ug/L, anaytoxin-a - 8.0 ug/L, and saxitoxin - 4.0 ug/L. These toxin levels are associated with a total toxigenic algal species cell count greater than or equal to 100,000 cell/mL [10 CSR 20-7.031(5)(N)6.C].
(7) This endpoint criteria is exceeded if the Department finds evidence in biological shifts in fish or invertebrate communities related to eutrophication [10 CSR 20-7.031(5)(N)6.D]. The Department will request aquatic community data from multiple sources to perform an evaluation of this endpoint. The Department provided the City of Moberly with fish sampling population statistics from 2001, 2005, 2009, 2014 (reference (26)); the information provided in these statistics does not indicate this endpoint criteria is met
(8) This endpoint criteria is exceeded if there are measured lake Secchi depths less than 0.6 meters in the Plains ecoregion. Yearly average Secchi depths below the applicable ecoregional value may constitute evidence of impairment. Additional analysis of average Chl-a/TP ratios will also be conducted before determining impairment status. Unless attributed to other physical factors, Chl-a/TP ratios at or below 0.15 and an ISS value greater than or equal to 10 mg/L as determined by yearly means will serve as an indicator of excessive mineral turbidity and constitute evidence of impairment [10 CSR 20-7.031(5)(N)6.E].
(9) According to the Nutrient Implementation Plan, data older than seven years will not be considered for impairment.

Large Table 4 Sugar Creek Lake Volunteer Monitoring Sites 1 and 2 Secchi, Chl-a/TP, and Inorganic Suspended Solids Data

Year	Site 1							Site 2						
	Number of Samples	Secchi Depth (meters)		Chlorophyll-a / Total Phosphorus Ratio		Inorganic Suspended Solids (mg/L)		Number of Samples	Secchi Depth (meters)		Chlorophyll-a / Total Phosphorus Ratio		Inorganic Suspended Solids (mg/L)	
		Annual Average	< Ecoregional Value of 0.6? (Y/N)	Annual Average	≤ Nutrient Implementation Plan Suggestion of 0.15? (Y/N)	Annual Average	≥ Nutrient Implementation Plan Suggestion of 10? (Y/N)		Annual Average	< Ecoregional Value of 0.6? (Y/N)	Annual Average	≤ Nutrient Implementation Plan Suggestion of 0.15? (Y/N)	Annual Average	≥ Nutrient Implementation Plan Suggestion of 10? (Y/N)
2000	2	0.66	N	0.52	N	4.6	N	2	0.61	N	0.72	N	5.0	N
2001	5	0.99	N	0.59	N	3.5	N	7	0.80	N	0.50	N	5.3	N
2002	8	0.82	N	0.41	N	5.7	N	8	0.75	N	0.43	N	7.0	N
2003	7	0.83	N	0.41	N	5.9	N	8	0.75	N	0.43	N	9.1	N
2004	8	0.80	N	0.51	N	5.9	N	8	0.69	N	0.48	N	7.9	N
2005	10	0.76	N	0.52	N	5.4	N	9	0.69	N	0.66	N	7.4	N
2006	9	0.84	N	0.67	N	4.6	N	9	0.76	N	0.66	N	6.2	N
2007	6	0.86	N	0.52	N	4.5	N	6	0.70	N	0.52	N	5.5	N
2008	8	1.02	N	0.38	N	5.0	N	8	0.83	N	0.32	N	8.7	N
2009	6	0.80	N	0.48	N	5.8	N	6	0.75	N	0.36	N	7.6	N
2010	8	0.67	N	0.43	N	7.1	N	8	0.65	N	0.46	N	7.7	N
2011	7	0.83	N	0.53	N	4.6	N	7	0.70	N	0.52	N	7.4	N
2012	7	0.84	N	0.64	N	5.0	N	7	0.68	N	0.58	N	7.3	N
2013	8	0.63	N	0.41	N	11.5	**Y**	8	0.57	**Y**	0.41	N	14.0	**Y**
2014	8	1.07	N	0.44	N	2.8	N	8	0.88	N	0.45	N	4.7	N
2015	7	0.87	N	0.61	N	4.3	N	7	0.66	N	0.56	N	5.5	N
2016	8	0.80	N	0.65	N	3.9	N	8	0.72	N	0.56	N	5.4	N
2017	8	0.75	N	0.47	N	4.7	N	8	0.66	N	0.46	N	6.1	N
2018	7	0.94	N	0.54	N	3.6	N	7	0.78	N	0.57	N	4.4	N

Large Table 5 City of Moberly Sugar Creek Lake Algal Data

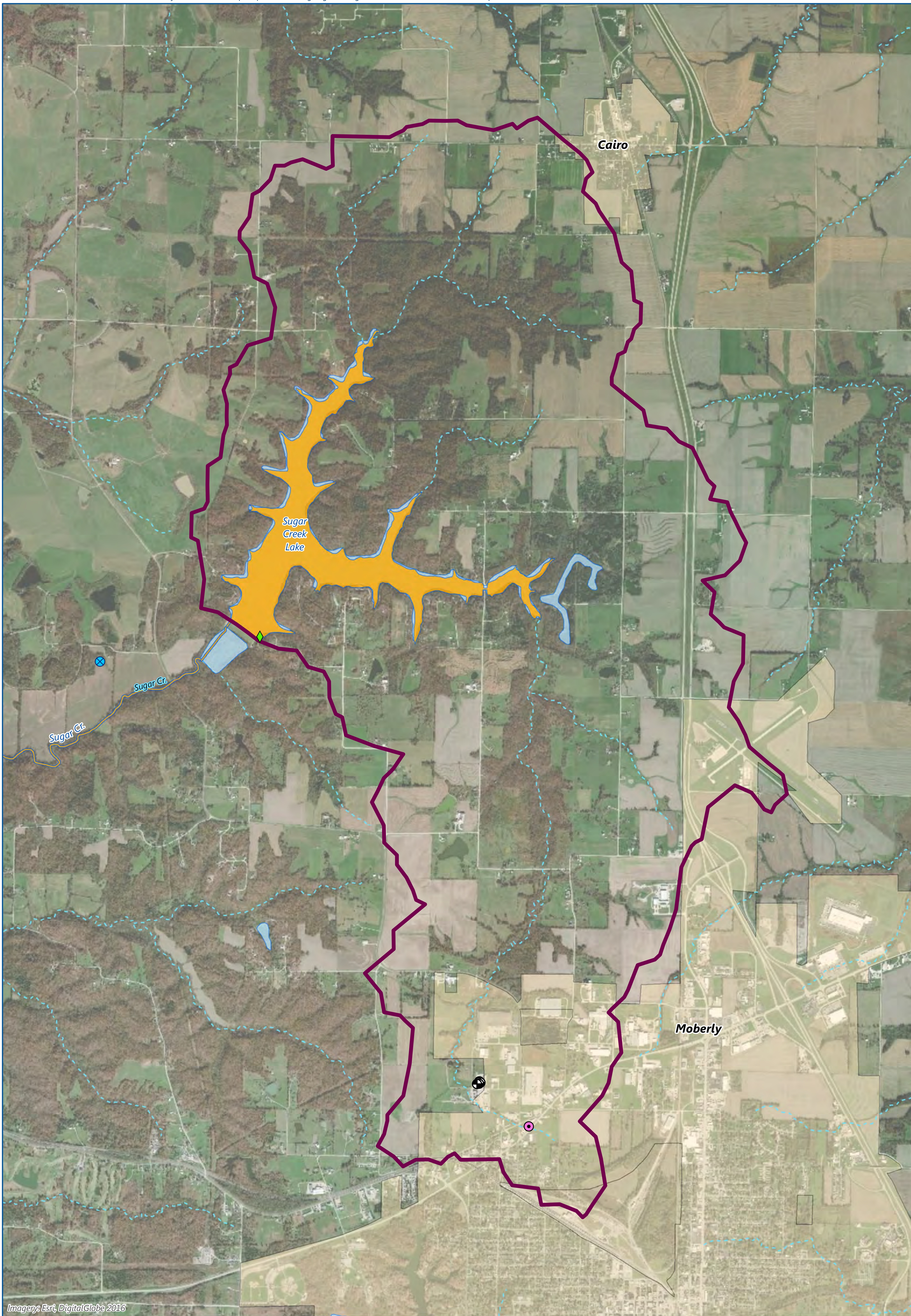
City Survey Location (Site #)	Date	Total Algae Count (count/mL)	Percent Count by Species Algae Genus							Other Algae Present
			Oscillatoria	Unidentified	Gloeocapsa	Cyclotella	Asterionella	Stephanodiscus	Nitzchia	
2	3/27/2017	1600	-	-	-	57.0	33.0	-	5.0	Stauroneis, Trachelomonas, Navicula, Stephanodiscus, Euglena
8	3/27/2017	1300	-	-	-	39.0	42.0	14.0	-	Nitzchia, Trachelomonas
2	3/30/2017	860	-	-	-	33.0	59.0	17.0	3.0	Navicula, Trachelomonas
2	7/26/2017	4900	76.5	9.0	5.0	1.0	-	-	<1.0	Phacotus, Trachelomonas, Closteriopsis, Actinastrum, Haematococcus, Synedra, Spirulina, Merismopedia, Euglena, Anabaena, Cylindrospermum, Aphanocapsa
6	7/26/2017	4600	75.5	8.0	4.5	-	-	-	<1.0	Phacotus, Trachelomonas, Closteriopsis, Actinastrum, Haematococcus, Synedra, Spirulina, Merismopedia, Anabaena, Aphanocapsa, Coelastrum
8	7/26/2017	4600	81.5	9.5	3.5	-	-	-	<1.0	Closteriopsis, Synedra, Cylindrospermum, Scenedesmus, Merismopedia, Trachelomonas, Cylindrospermopsis

Large Table 6 City of Moberly Sugar Creek Lake Bottom Sediment Data

Sample ID	Sample Date	Sub-Sample ID	Drainage ID	Map ID	Total Depth	Sediment Depth	BOD mg/L	TSS mg/L	%M	%TS	Total Kjeldahl Nitrogen	Nitrate, NO_3	Ammonia, NH_3	Organic Nitrogen	PAN	P_2O_5	SO_4-S	Manganese (Mn)	Comments
#1	5/9/2017	1A	Area #1	1A	2' 2"	1"													Area very shallow, little sediment, good bottom
		1B	Area #1	1B	3' 1"	1"	2.77	2,300	43.66	56.34	1,949	4	59	1,887	422	1,769	639	429	
		1C	Area #1	1C	3'0"	1"													
#2	5/9/2017	2A	Area #2	2A	3'8"	1"													Residential area with 15-20 docks
		2B	Area #2	2B	7'0"	2"	4.39	3,250	45.48	54.52	1,724	0	46	1,678	368	2,406	593	543	
		2C	Area #2	2C	11'0"	3"													
		2D	Area #2	2D	16'0"	12"													
#3	5/9/2017	3A	Area #3	3A	3'8"	10"													Fair amount of sediment, 3 to 4 ft. total depth
		3B	Area #3	3B	4'0"	6"	3.25	3,050	48.91	51.09	1,949	3	108	1,838	446	1,613	760	443	
		3C	Area #3	3C	3'8"	6"													
#4A	5/9/2017	4A1	Area #4E	4A1	3'10"	6"													Solid bottom, good cores
		4A2	Area #4E	4A2	9'0"	6"	3.21	2,610	47.64	52.36	2,301	4	50	2,248	488	126,342	2,261	803	
		4A3	Area #4E	4A3	13'0"	12"													
		4A4	Area #4E	4A4	13'4"	12"													
#4B	5/9/2017	4B1	Area #4N	4B1	2'10"	1"													4 coves, little sediment, good cores
		4B2	Area #4N	4B2	3'11"	1"	3.98	2,510	49.65	50.35	1,913	4	46	1,863	408	1,671	693	418	
		4B3	Area #4N	4B3	6'6"	1"													
		4B4	Area #4N	4B4	5'10"	1"													
#5	5/9/2017	5A	Area #5W	5A	5'8"	1"													4 coves, little sediment, good cores
		5B	Area #5W	5B	7'0"	1"	4.51	3,090	46.21	53.79	1,301	5	57	1,239	293	1,926	781	440	
		5C	Area #5W	5C	6'8"	1"													
		5D	Area #5W	5D	5'6"	1"													

Sample ID	Sample Date	Sub-Sample ID	Drainage ID	Map ID	Total Depth	Sediment Depth	BOD mg/L	TSS mg/L	%M	%TS	Total Kjeldahl Nitrogen	Nitrate, NO_3	Ammonia, NH_3	Organic Nitrogen	PAN	P_2O_5	SO_4-S	Manganese (Mn)	Comments
#6A	5/9/2017	6A1	Mixing Zone #1&#3	6A1	5'0"	1"													No core next to bridge, cores with sludge judge
		6A2	Mixing Zone #1&#3	6A2	5'10"	6"													
		6A3	Mixing Zone #1&#3	6A3	16'0"	12"	3.59	3,620	58.24	41.76	2,467	0	88	2,378	538	2,042	736	677	
		6A4	Mixing Zone #1&#3	6A4	16'0"	12"													
		6A5	Mixing Zone #1&#3	6A5	16'0"	12"													
#6B	5/9/2017	6B1	Mixing Zone #2&#4A	6B1	16'6"	1"													Channel +22 ft., solid bottom, rock and sand present
		6B2	Mixing Zone #2&#4A	6B2	15'0"	1"	4.35	2,510	43.99	56.01	2,146	0	1	2,145	430	3,598	1,405	927	
		6B3	Mixing Zone #2&#4A	6B3	17'0"	1"													
		6B4	Mixing Zone #2&#4A	6B4	18'0"	1"													
#7	5/9/2017	7A	Mixing Zone #1-#5	7A	21'0"	1"													Channel +22 ft., had to sample closer to banks
		7B	Mixing Zone #1-#5	7B	18'6"	1"	3.87	2,440	49.22	50.78	1,835	0	1	1,834	368	3,292	949	952	
		7C	Mixing Zone #1-#5	7C	19'0"	1"													
		7D	Mixing Zone #1-#5	7D	20'0"	1"													
#8	5/9/2017	8A	Intake Area	8A	21'0"	1"													Inlet location +22 ft, little sediment
		8B	Intake Area	8B	8'0"	2"	4.32	3,270	46.93	53.07	2,425	0	47	2,378	509	3,902	1,401	763	
		8C	Intake Area	8C	18'0"	1"													
		8D	Intake Area	8D	15'6"	1"													
						Average	*3.82*	*2,865*	*47.99*	*52.01*	*2,001*	*2*	*50*	*1,949*	*427*	*14,856*	*1,022*	*640*	

Large Figures



- Residential Water Supply Well No. 006285 [1]
- Monitoring Well
- Non-community Water Well
- City of Moberly Water Treatment Plant Intake
- Sugar Creek Lake Watershed
- Municipal Boundaries
- Section 303(d) Listed Waters - Lakes (2012)
- Section 303(d) Listed Waters - Rivers and Streams (2016)
- Surface Water
- Streams That May Cease Flow in Dry Periods
- Streams That Maintain Permanent Flow

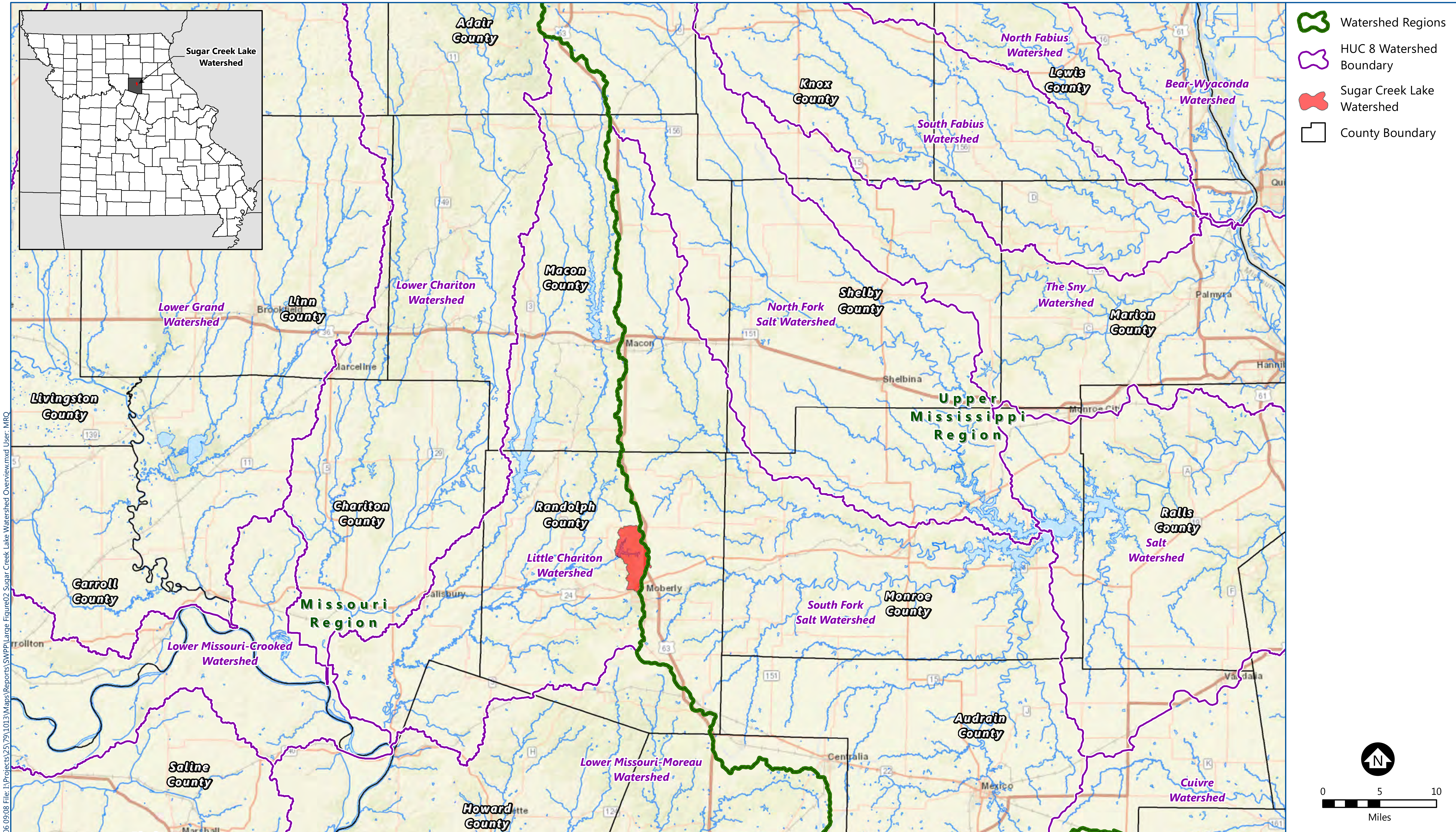
Source:
[1] Missouri Geological Survey

N
0 1,250 2,500
Feet

BARR

SUGAR CREEK
LAKE WATERSHED
Sugar Creek Lake SWPP
City of Moberly, Missouri

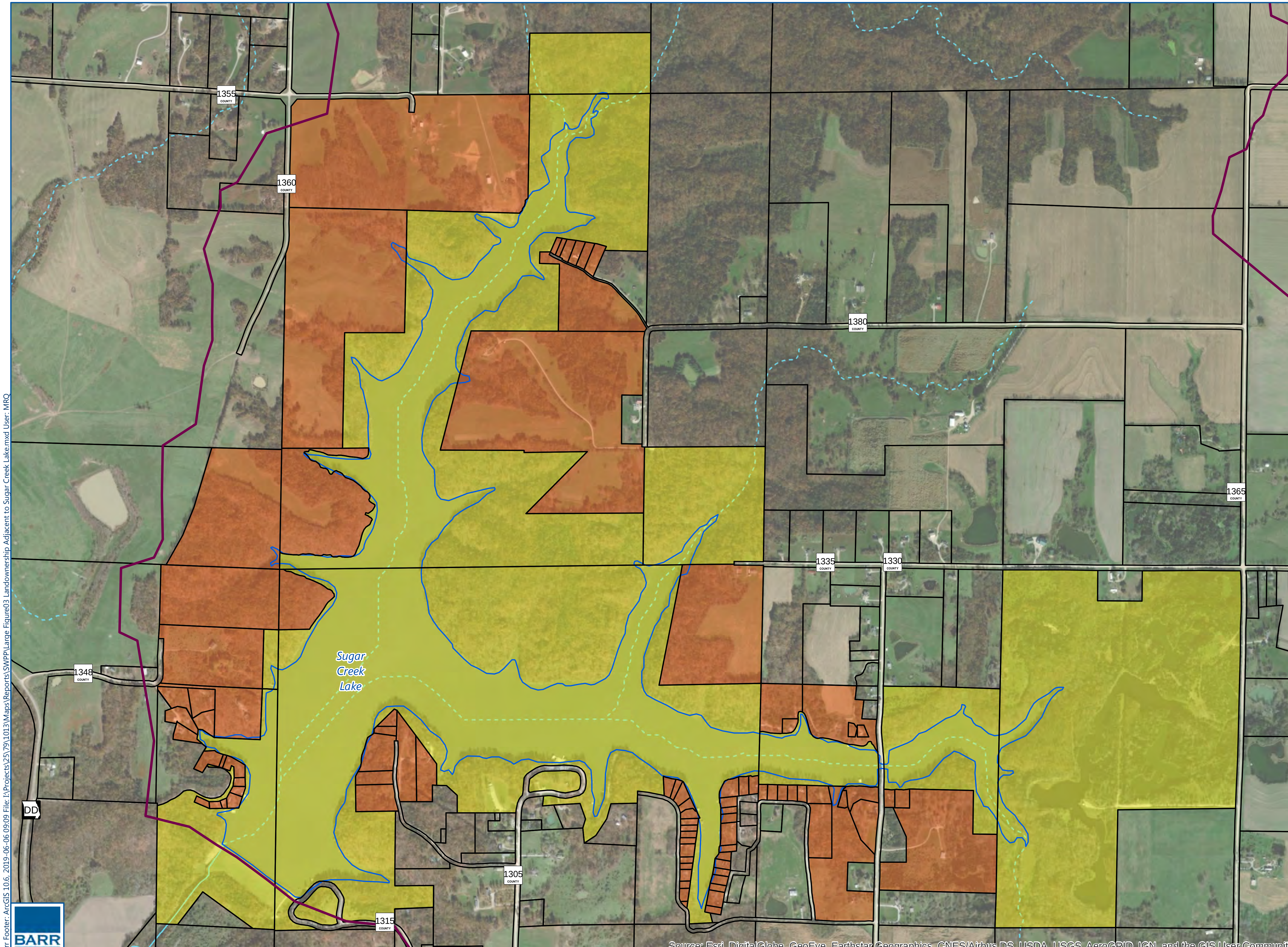
LARGE FIGURE 1



SUGAR CREEK LAKE WATERSHED OVERVIEW
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 2

Barr Footer: ArcGIS 10.6, 2019-06-06 09:08 File: I:\Projects\25\79\1013\Maps\Reports\SWPP\Large Figure\02 Sugar Creek Lake Watershed Overview.mxd User: MRQ



Sugar Creek Lake Watershed

Parcel

Landownership

City of Moberly

Private

Missouri's Use Designations Dataset (MUDD)

Streams That May Cease Flow in Dry Periods

Streams That Maintain Permanent Flow

Randolph County parcel datset received by ClearBasin Software, September 2018

N

0 500 1,000 1,500

Feet

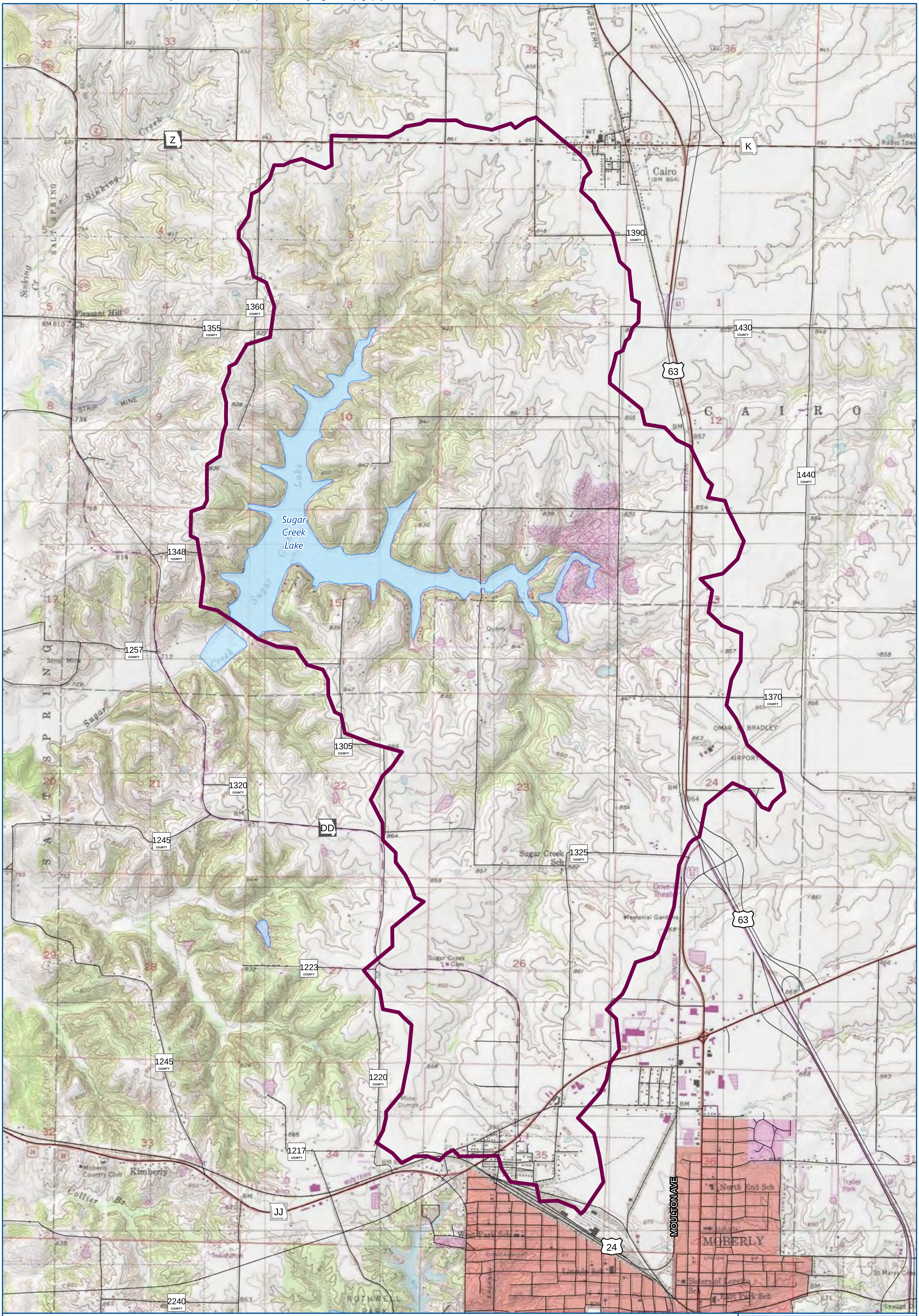
Imagery: Esri, DigitalGlobe 2016

LAND OWNERSHIP ADJACENT TO SUGAR CREEK LAKE
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 3

BARR

Barr Footer: ArcGIS 10.6, 2019-06-06 09:10 File: I:\Projects\25\79\1013\Maps\Reports\SWPP\Large Figure04 Topography.mxd User: MRQ



Sugar Creek Lake Watershed

Surface Water

0 1,500 3,000

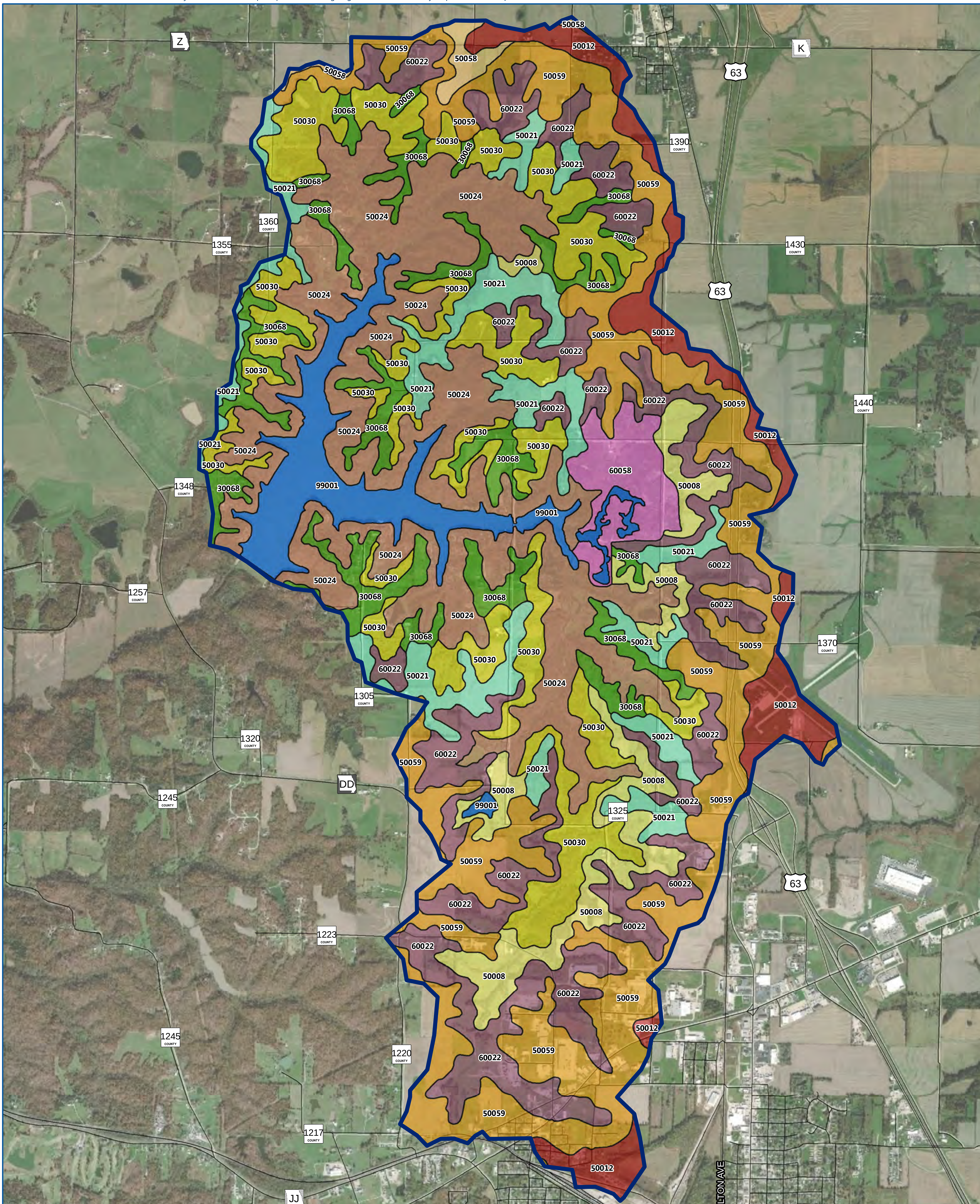
Feet

Imagery: Esri, DigitalGlobe 2016

TOPOGRAPHY
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 4

Barr Footer: ArcGIS 10.6, 2019-06-06 09:11 File: I:\Projects\25\79\1013\Maps\Reports\SWPP\Large Figure05 NRCS Soil Survey Map.mxd User: MRQ



Drainage Area	
Soil Unit Name	
60058 Bethesda channery silt loam, 20 to 70 percent slopes	50030 Keswick silt loam, 9 to 20 percent slopes, eroded
50021 Calwoods silt loam, 2 to 5 percent slopes, eroded	60022 Leonard silt loam, 1 to 6 percent slopes, eroded
30068 Gorin silt loam, 5 to 9 percent slopes, eroded	50058 Mexico silt loam, 0 to 2 percent slopes
50024 Gosport silt loam, 14 to 30 percent slopes, eroded	50059 Mexico silt loam, 1 to 4 percent slopes, eroded
50008 Keswick silt loam, 5 to 9 percent slopes, eroded	66099 Piopolis silty clay loam, 0 to 2 percent slopes, frequently flooded
	50012 Putnam silt loam, 0 to 1 percent slopes
	99001 Water

BARR

N

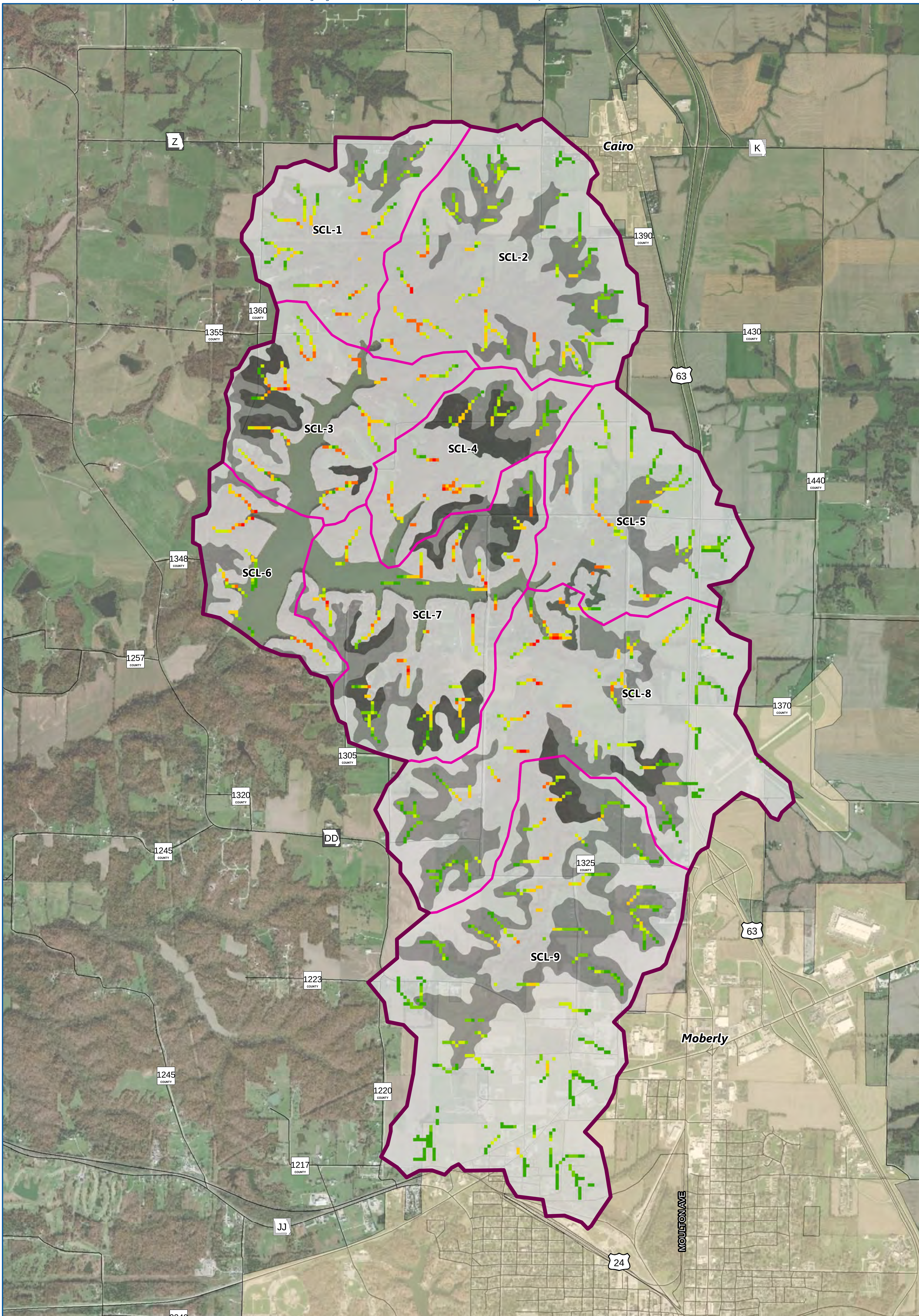
0 1,250 2,500 3,750

Feet

Imagery: Esri, DigitalGlobe 2016

NRCS SOIL SURVEY MAP
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 5



Sugar Creek Lake Watershed
Sugar Creek Lake Subwatersheds
Stream Power Index Percentile
75% (SPI=1.9, Low Erosion Vulnerability)
50% (SPI=2.5)
25% (SPI=3.0)
10% (SPI=3.4)
1% (SPI=3.9)
0.1% (SPI=4.3, High Erosion Vulnerability)

Estimated Soil Loss (USLE)
Low
Medium
High
Municipal Boundaries

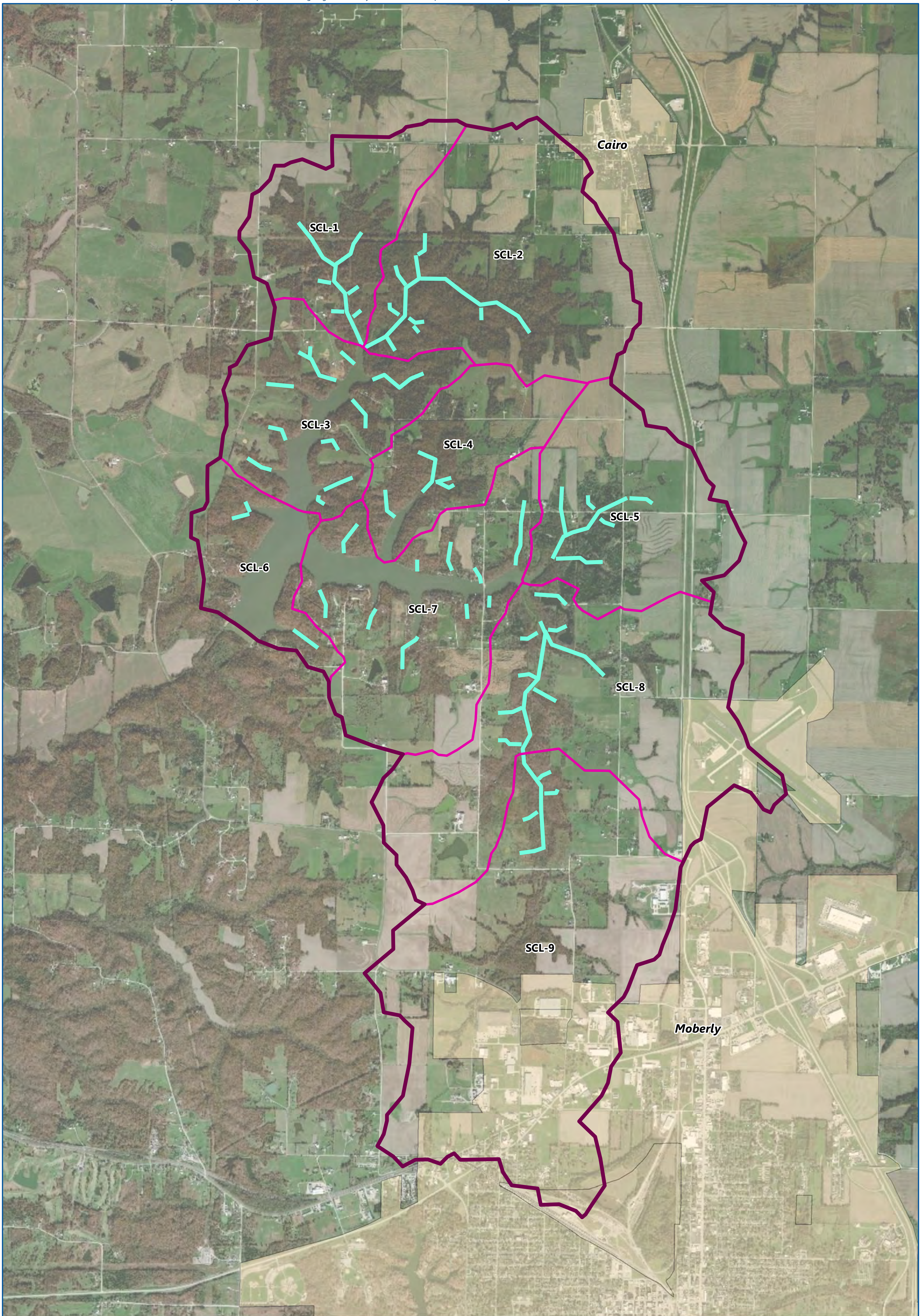
N
0 1,500 3,000
Feet

Imagery: Esri, DigitalGlobe 2016

BARR

STREAM POWER INDEX AND SOIL LOSS POTENTIAL
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 6



Sugar Creek Lake Watershed
Sugar Creek Lake Subwatersheds
High Risk Ravines for Erosion
Municipal Boundaries

0 1,500 3,000
Feet

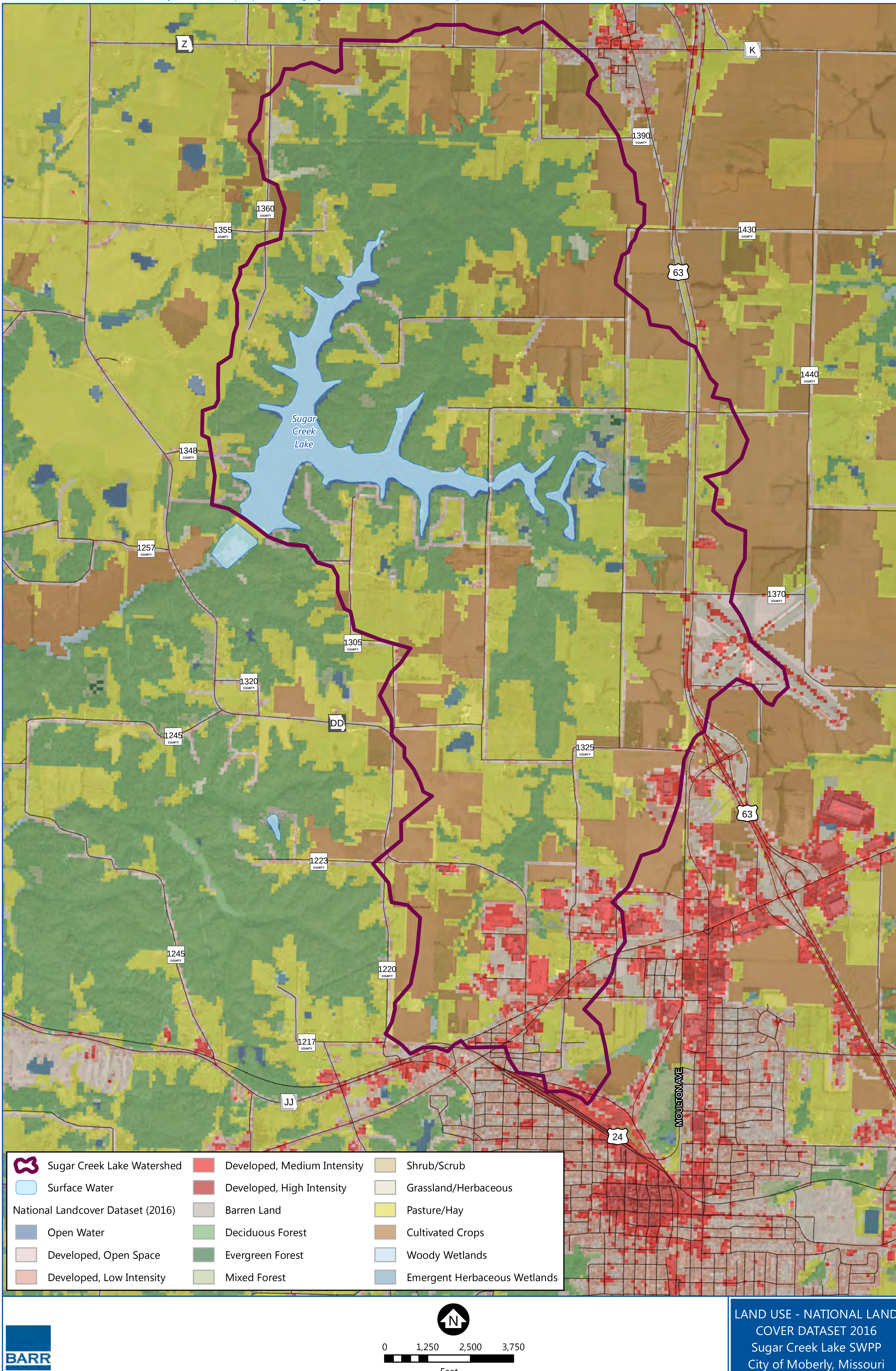
Imagery: Esri, DigitalGlobe 2016

BARR

PRIORITY AREAS OF EROSION INSPECTION
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 7

Barr Footer: ArcGIS 10.6, 2019-06-06 09:14 File: I:\Projects\25\79\1013\Maps\Reports\SWPP\Large Figure08 Land Use NLCD 2016.mxd User: MRQ

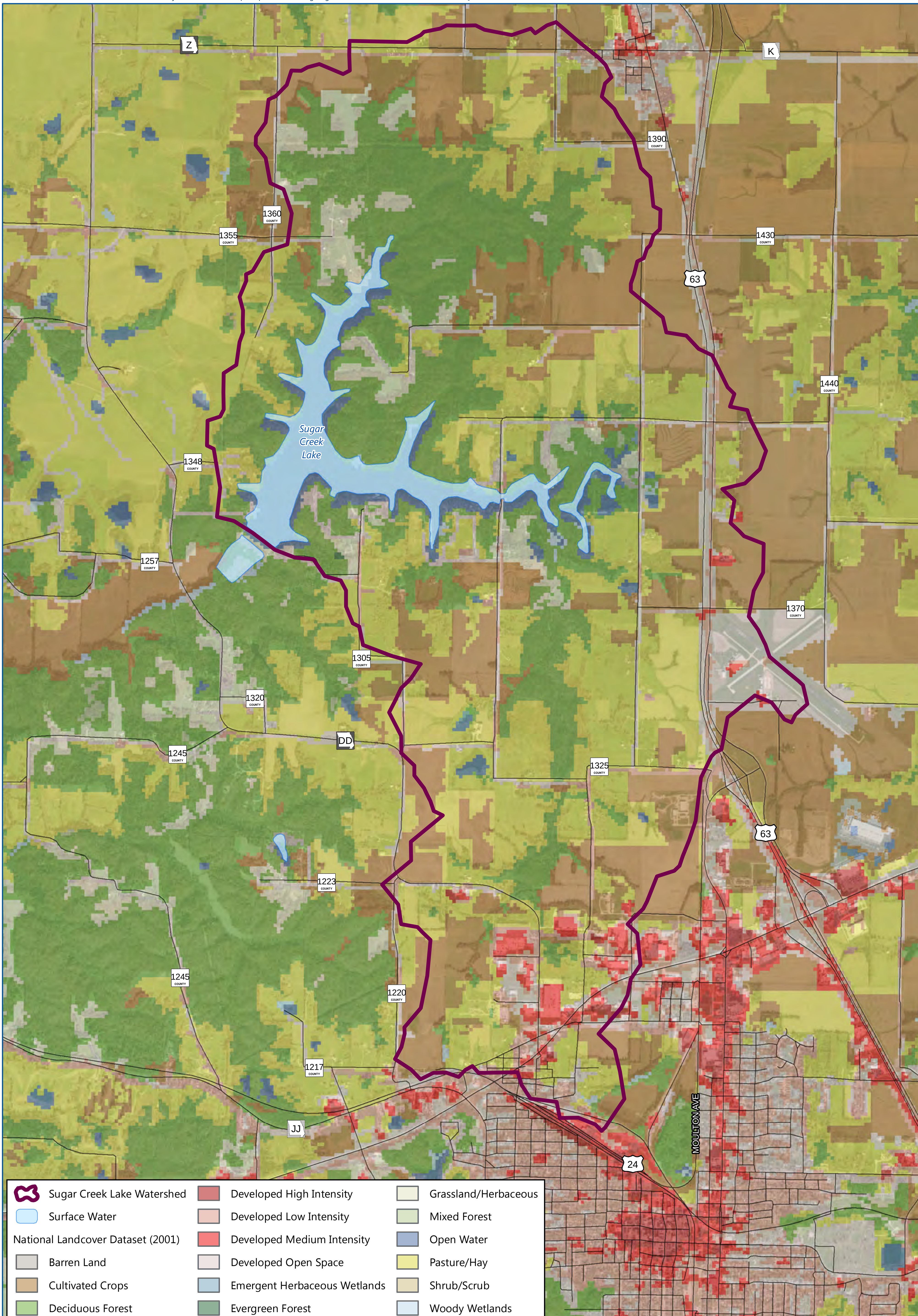


Imagery: Esri, DigitalGlobe 2016

LAND USE - NATIONAL LAND COVER DATASET 2016
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 8

Barr Footer: ArcGIS 10.6, 2019-06-06 09:15 File: I:\Projects\25\79\1013\Maps\Reports\SWPP\Large Figure09 Land Use NLCD 2001.mxd User: MRQ



N

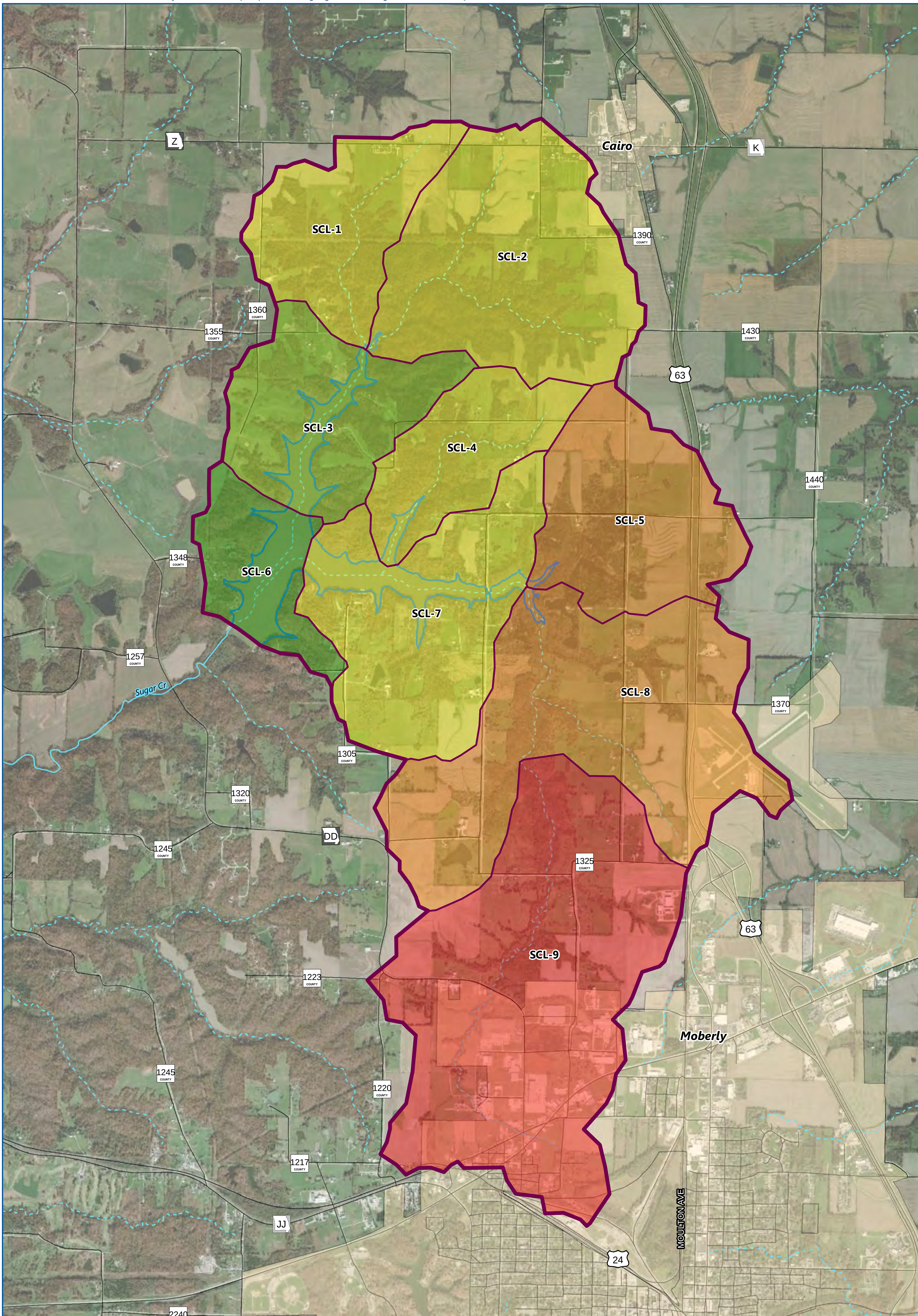
0 1,250 2,500 3,750

Feet

Imagery: Esri, DigitalGlobe 2016

LAND USE - NATIONAL LAND COVER DATASET 2001
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 9



Sugar Creek Lake Watershed
Sugar Creek Lake Subwatersheds
Municipal Boundaries
Missouri's Use Designations Dataset (MUDD)
Streams That May Cease Flow in Dry Periods
Streams That Maintain Permanent Flow

TN Yield (lbs/ac/yr)[1]
- 0.00 to 2.00
- 2.00 to 3.00
- 3.00 to 4.00
- 4.00 to 5.00
- 5.00 to 5.16

[1]Per 2016 NLCD Land Cover Data

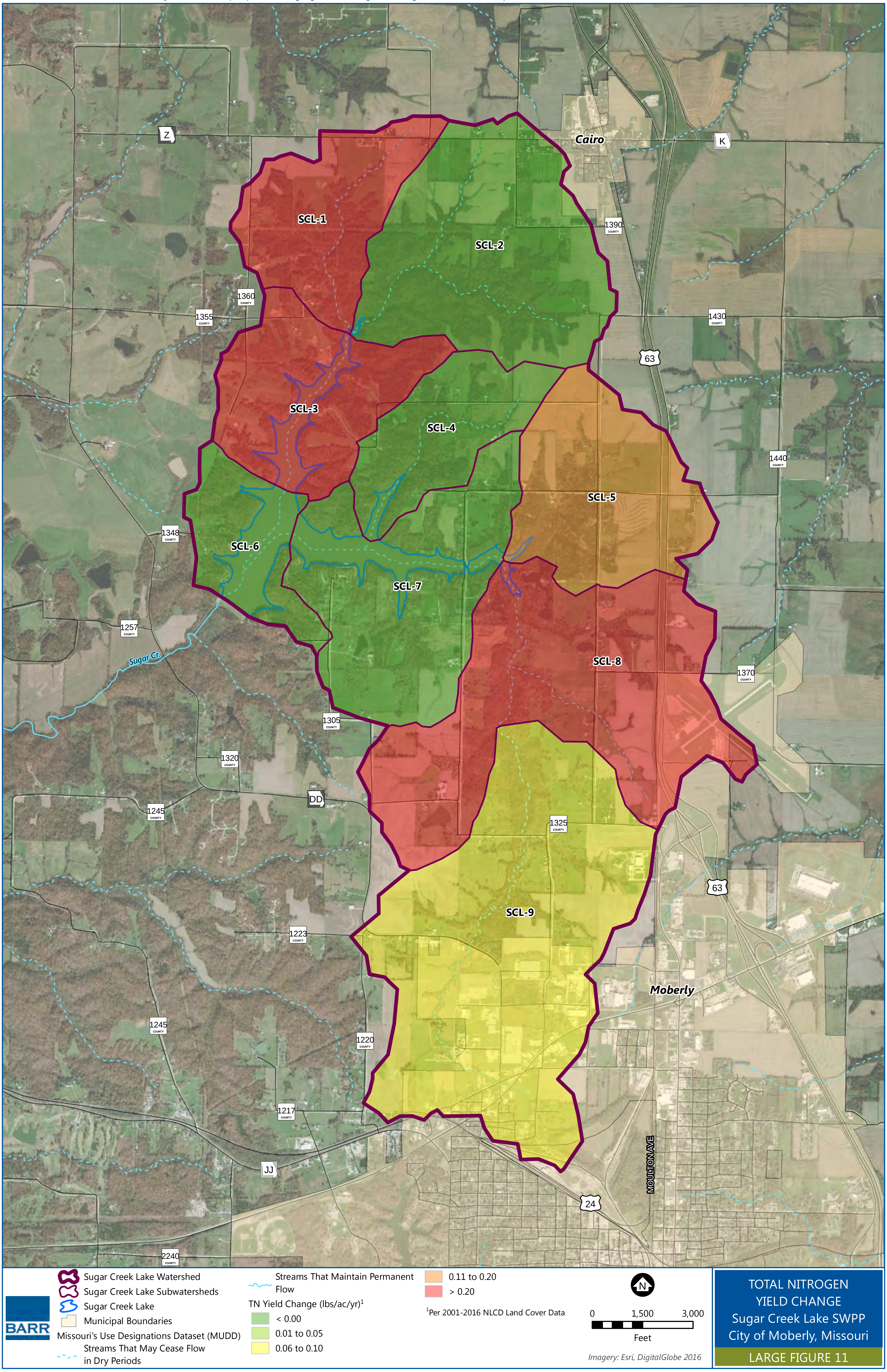
0 1,500 3,000
Feet

Imagery: Esri, DigitalGlobe 2016

BARR

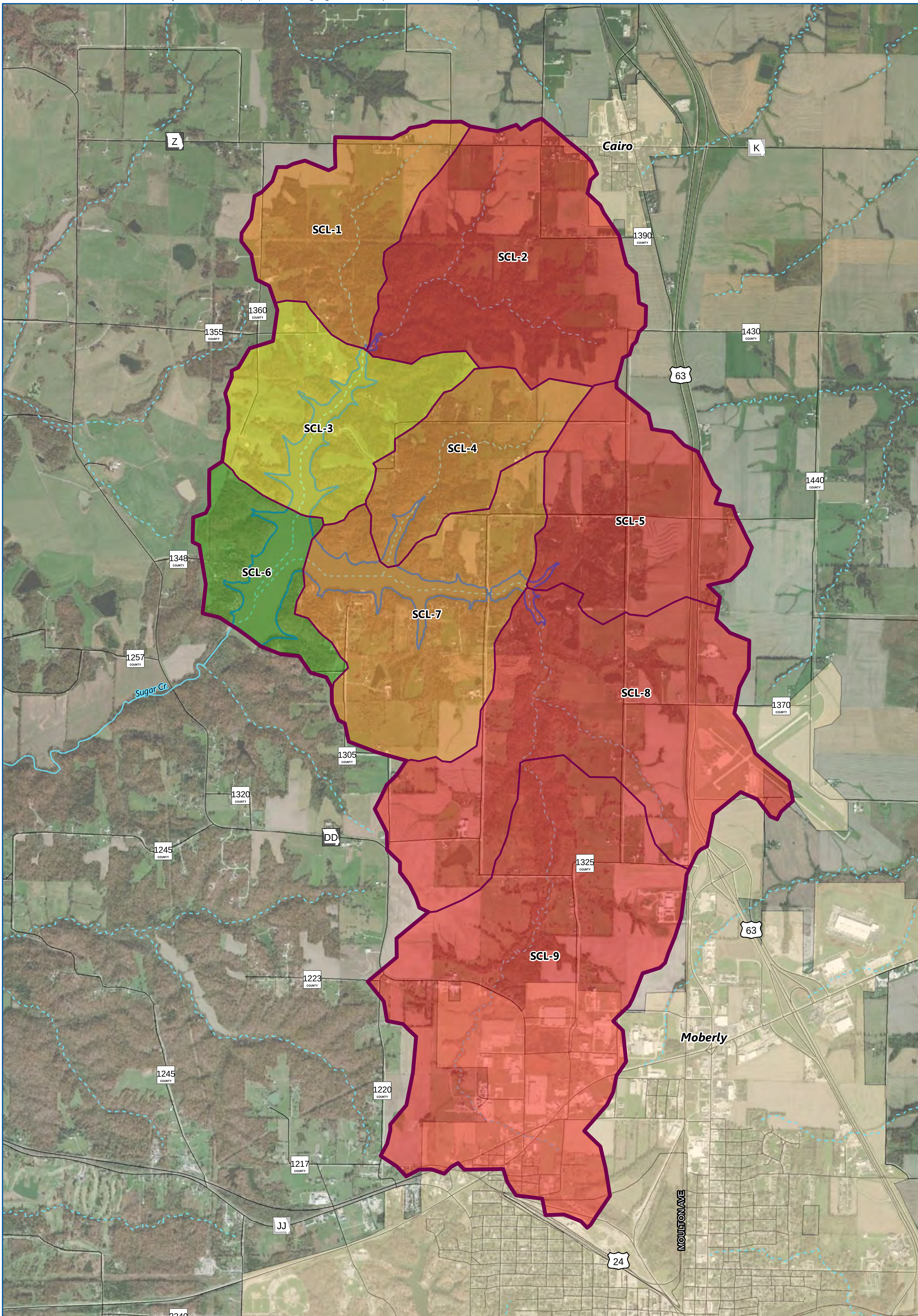
TOTAL NITROGEN YIELD
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 10



TOTAL NITROGEN YIELD CHANGE
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 11



Sugar Creek Lake Watershed
Sugar Creek Lake Subwatersheds
Sugar Creek Lake
Municipal Boundaries
Missouri's Use Designations Dataset (MUDD)
Streams That May Cease Flow in Dry Periods
Streams That Maintain Permanent Flow

TP Yield (lbs/ac/yr)[1]

- 0.00 to 0.15
- 0.15 to 0.20
- 0.20 to 0.30
- 0.30 to 0.40
- 0.40 to 0.55

[1]Per 2016 NLCD Land Cover Data

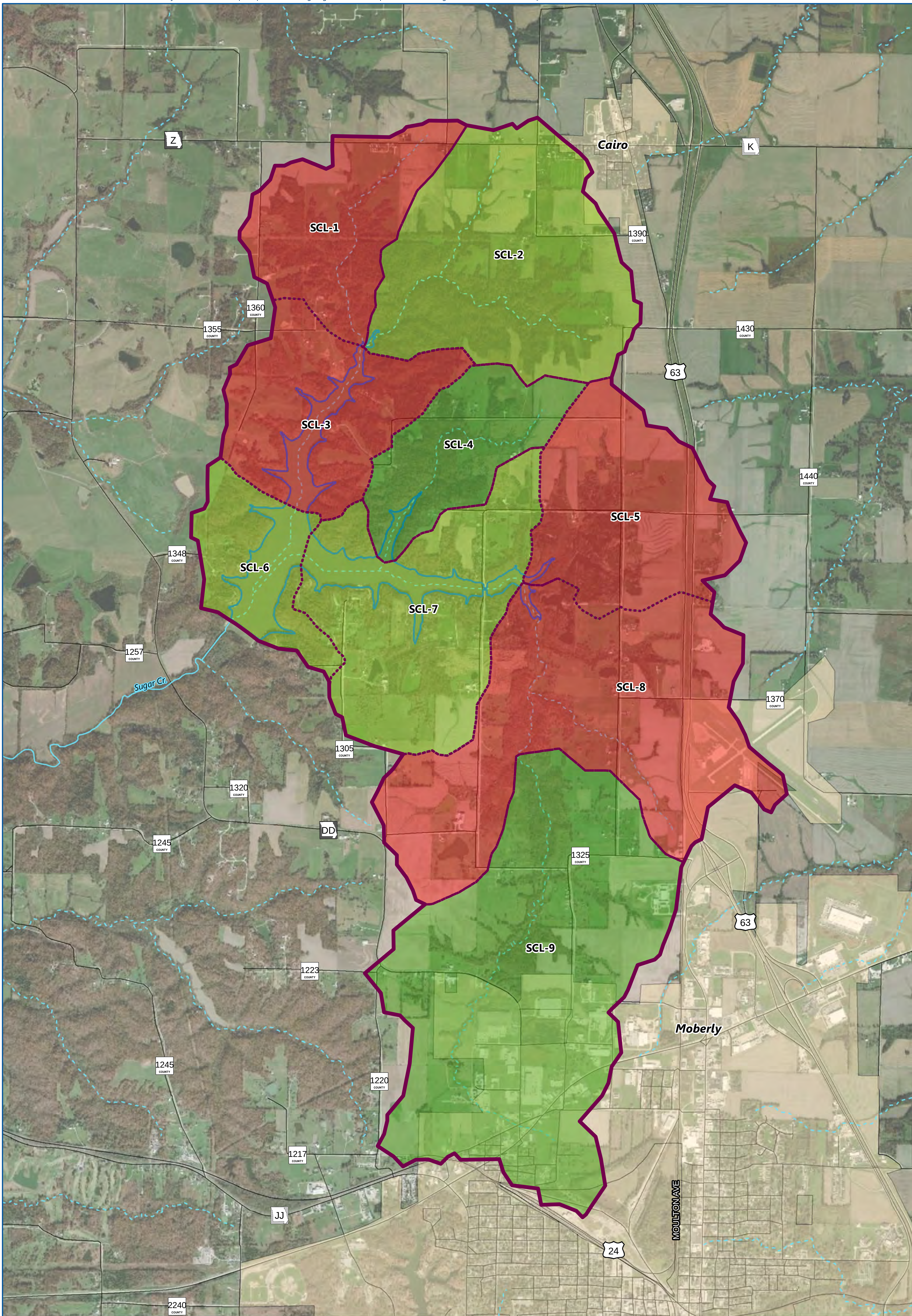
0 1,500 3,000
Feet

Imagery: Esri, DigitalGlobe 2016

BARR

TOTAL PHOSPHORUS YIELD
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 12



Sugar Creek Lake Watershed
Sugar Creek Lake Subwatersheds
Sugar Creek Lake
Municipal Boundaries
Missouri's Use Designations Dataset (MUDD)
Streams That May Cease Flow in Dry Periods
Streams That Maintain Permanent Flow

TP Yield Change (lbs/ac/yr)[1]
- < -0.03
- -0.03 to -0.01
- -0.01 to 0.00
- 0.00 to 0.01
- 0.01 to 0.03

[1] Per 2001-2016 NLCD Land Cover Data

0 1,500 3,000
Feet

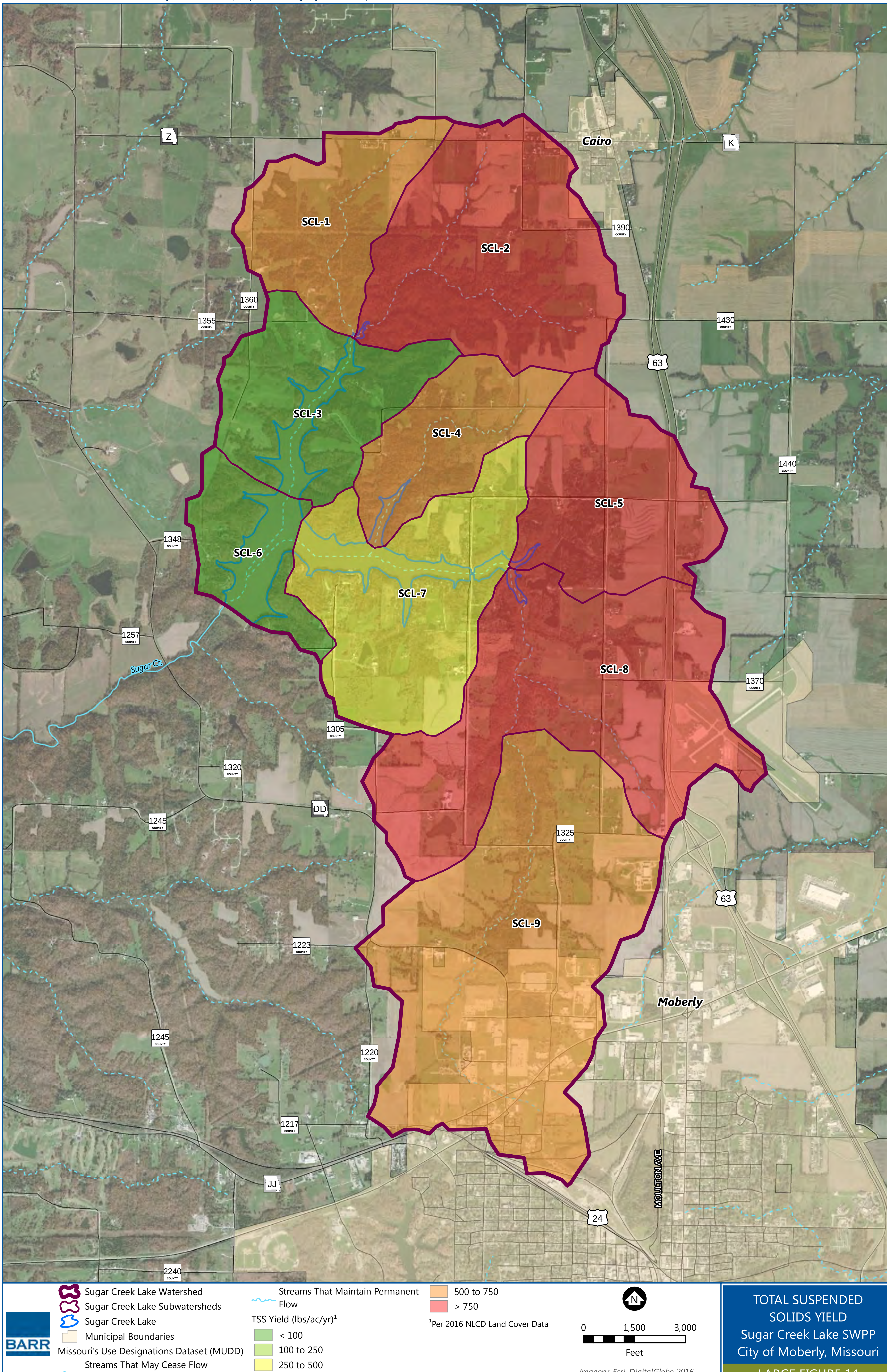
Imagery: Esri, DigitalGlobe 2016

BARR

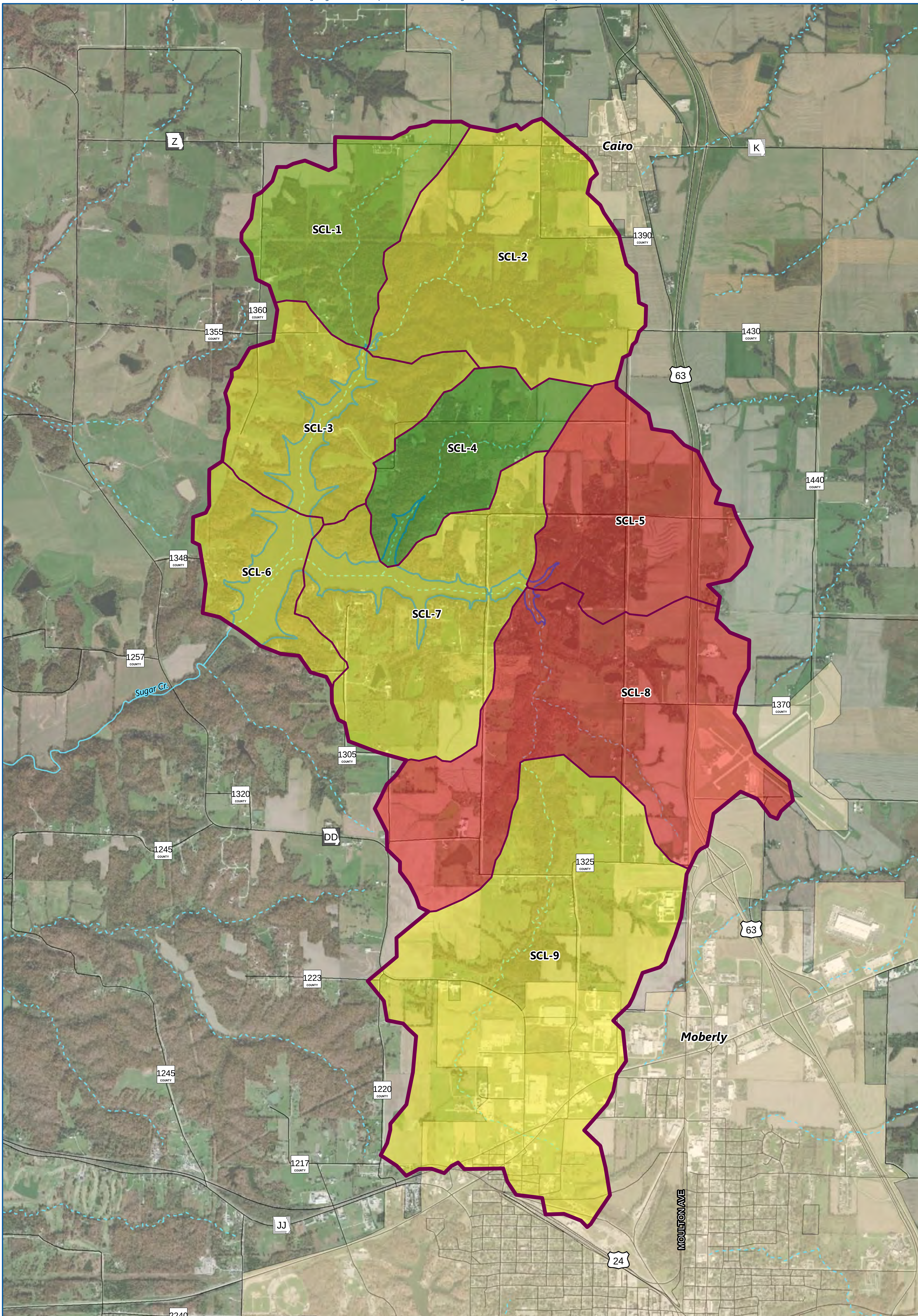
TOTAL PHOSPHORUS YIELD CHANGE
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 13

Barr Footer: ArcGIS 10.6, 2019-06-06 09:33 File: I:\Projects\25\79\1013\Maps\Reports\SWPP\Large Figure14 Total Suspended Solids Yield.mxd User: MRQ



TOTAL SUSPENDED SOLIDS YIELD
Sugar Creek Lake SWPP
City of Moberly, Missouri
LARGE FIGURE 14



Sugar Creek Lake Watershed
Sugar Creek Lake Subwatersheds
Sugar Creek Lake
Missouri's Use Designations Dataset (MUDD)
Streams That May Cease Flow in Dry Periods
Streams That Maintain Permanent Flow
Municipal Boundaries

TSS Yield Change (lbs/ac/yr)[1]
- <-250
- -250 to -100
- -100 to 0
- 0 to 100
- >100

[1]Per 2001-2016 NLCD Land Cover Data

N

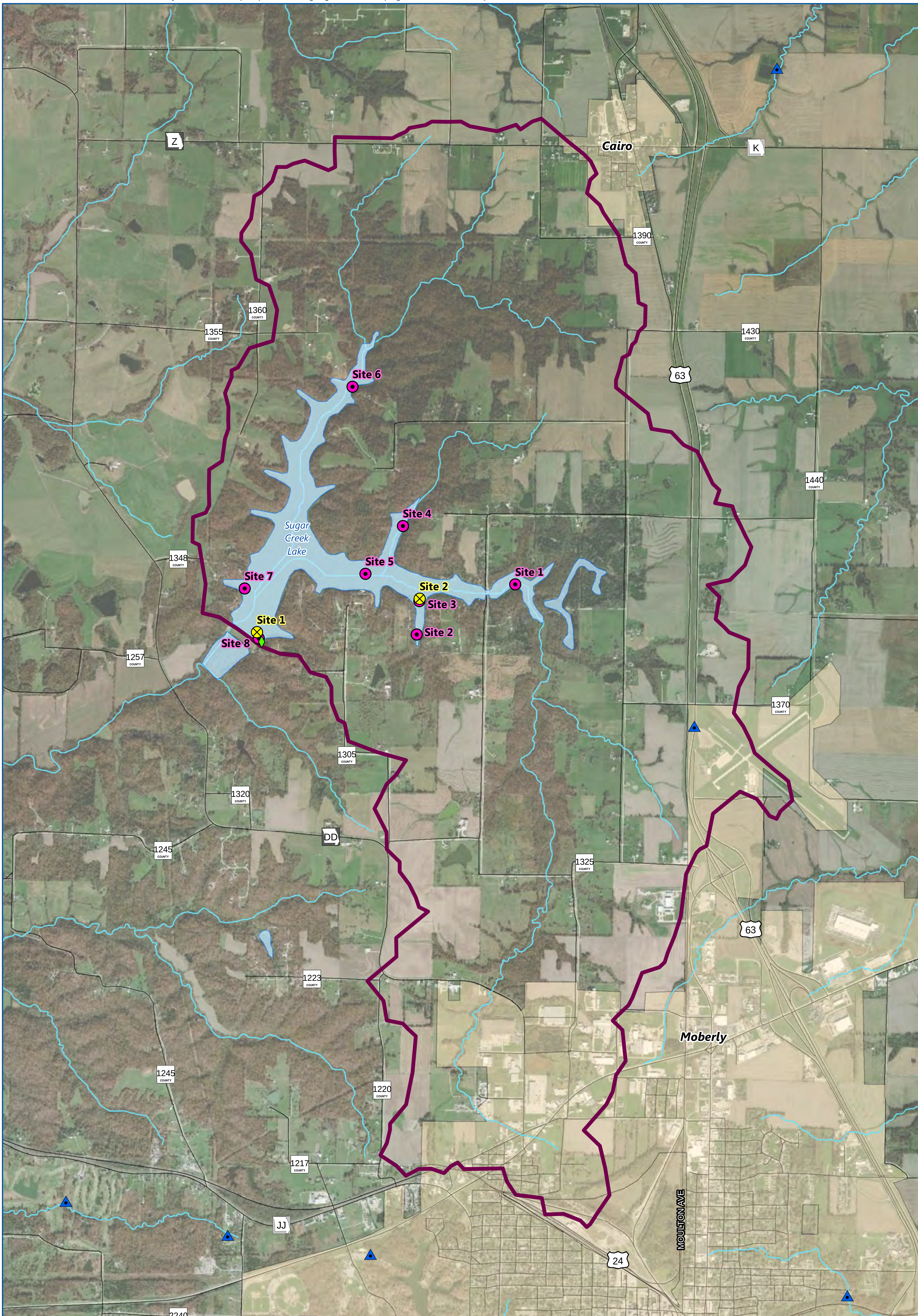
0 1,500 3,000
Feet

Imagery: Esri, DigitalGlobe 2016

BARR

TOTAL SUSPENDED SOILDS YIELD CHANGE
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 15



City of Moberly Water Treatment Plant Intake

Stormwater Outfall (Missouri DNR, 2015)

Volunteer Water Sampling Location

City Water Sampling Location

Sugar Creek Lake Watershed

Streams That May Cease Flow in Dry Periods

Streams That Maintain Permanent Flow

Surface Water

Municipal Boundaries

N

0 1,250 2,500

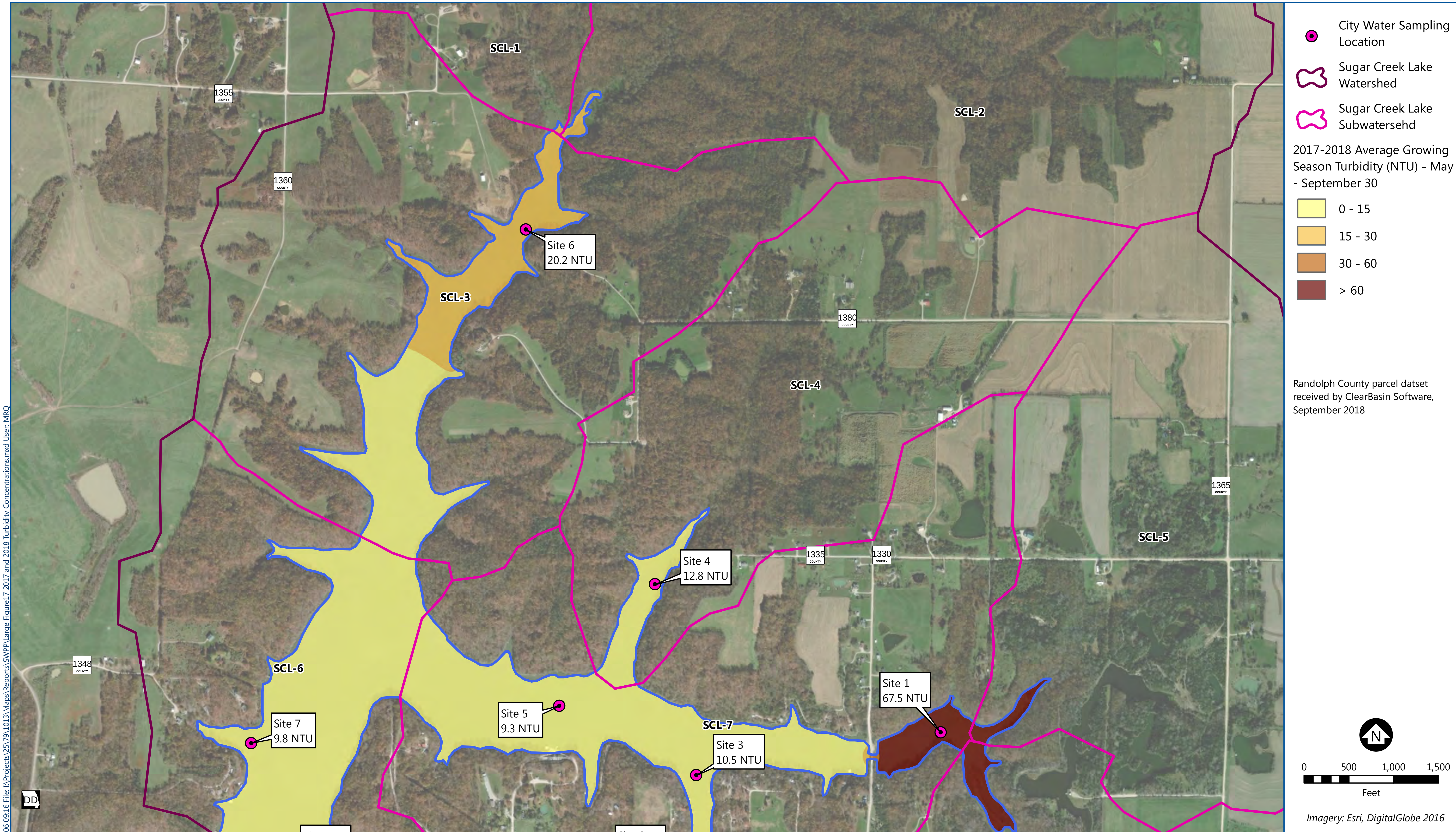
Feet

Imagery: Esri, DigitalGlobe 2016

BARR

WATER SAMPLING LOCATIONS
Sugar Creek Lake SWPP
City of Moberly, Missouri

LARGE FIGURE 16



2017 and 2018 TURBIDITY CONCENTRATIONS
Sugar Creek Lake SWPP
City of Moberly, Missouri
LARGE FIGURE 17

Appendices

Appendix A

2019 Sugar Creek Lake Yield Study

FIRM YIELD ASSESSMENT: SUGAR CREEK LAKE, RANDOLPH COUNTY, MISSOURI

By Karen Rouse, Emma Schneider

Executive Summary

Sugar Creek Lake in Randolph County Missouri is the sole water supply source for the City of Moberly. The City serves 12,174 people with an average daily use of 1.15 million gallons per day (MGD). In 2005, the Missouri Department of Natural Resources conducted a yield study of Sugar Creek Lake for the City of Moberly. The results indicated that if the community were to experience conditions similar to the drought of record (1951-1960), there would not be enough water in the reservoir to meet the City's water needs. In light of the results of the previous study, City managers have requested an updated yield study so that water planning efforts can be based on current data. The purpose of this study is to provide the City with an updated understanding of Sugar Creek Lake's capacity to meet the City's water demand during drought of record conditions. It is important to note for the purpose of this study it was assumed that no drought conservation actions were taken by the City of Moberly.

A new bathymetric study was conducted by the U.S. Geological Survey (USGS) in September 2018 to assess the volumetric capacity of the reservoir. The USGS study provided information on the magnitude of sedimentation that has occurred since the 2003 USGS bathymetry survey used in the 2005 yield study, and where within the reservoir that sedimentation occurred. The 2018 bathymetric study indicates that water storage has decreased by 240 acre-feet, or 4.6%, over the last 15 years. This equates to 78 million gallons of reservoir storage lost.

The data provided by the USGS was used as input data for HEC-ResSim, reservoir simulation software created by the U.S. Army Corps of Engineers. Two separate scenarios were simulated over an approximate 10 year period in HEC-ResSim. One scenario examined only water demand and reservoir yield. The second scenario included seepage from the reservoir as well as water demand and reservoir yield. For the purpose of this study 1.33 MGD was used to represent the daily demand, as that is the average demand over the past 25 years. From these analyses, the model indicates that if the current rate of seepage continues, Sugar Creek Lake can only yield 1.17 MGD if a similar drought to the 1950s drought were to recur. During the roughly 10 year drought period, the reservoir would not be able to provide water for a total of 146 days spread across three separate periods. Thus, were seepage not addressed, the reservoir would not be able to meet the City's water demand during drought of record conditions. When the current seepage rate is not included in models, the reservoir can yield 1.44 MGD over the 10 years; however, there are several periods where the reservoir nears insufficient water supply conditions. For a total of 300 days the surface of the reservoir is less than 3 feet above minimum operational elevation; on 14 of those days the surface of the reservoir is less than 0.5 feet above minimum operational elevation.

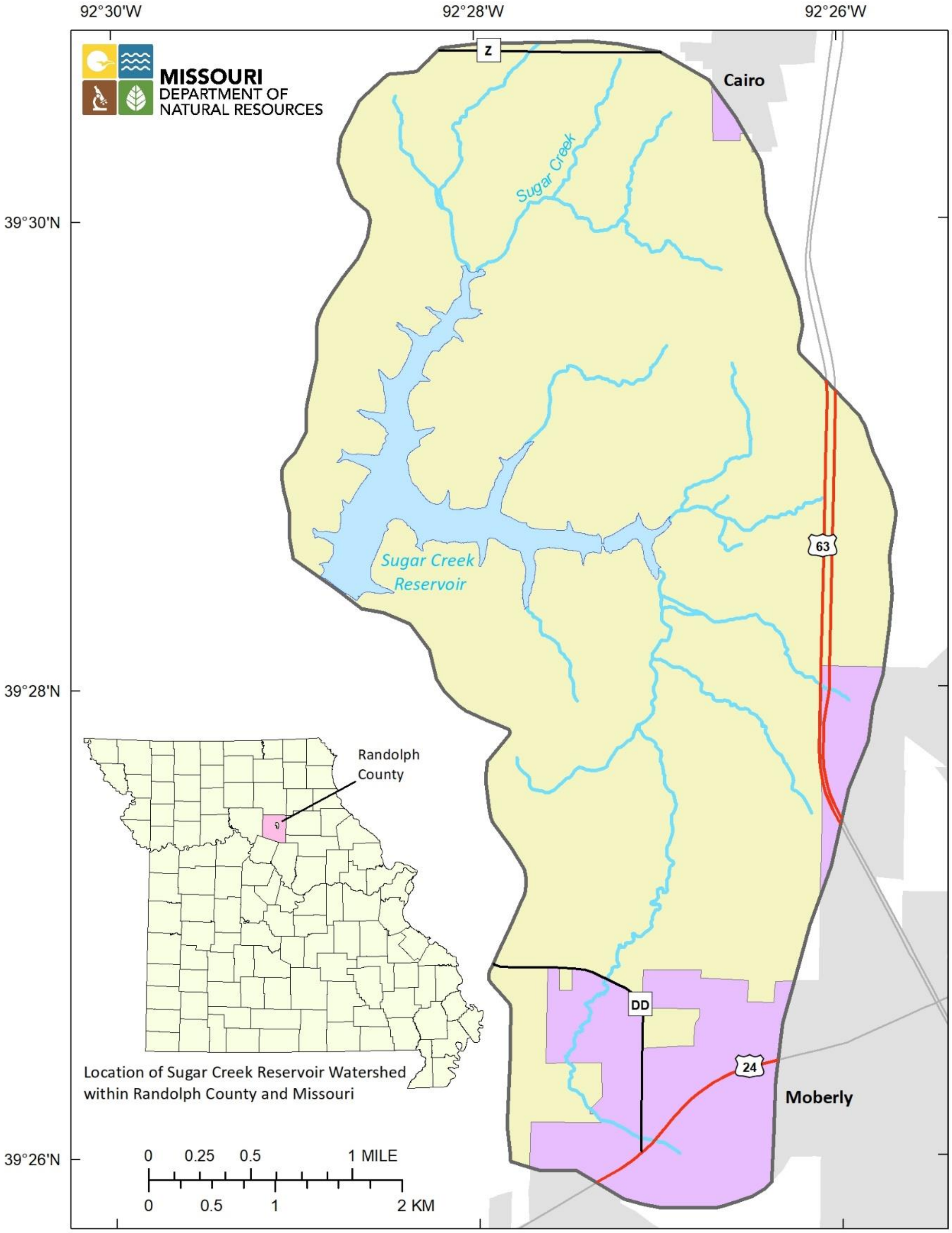


Figure 1. Sugar Creek Lake and Watershed. The reservoir and its drainage area in relation to the City of Moberly.

Introduction

Sugar Creek Lake is a 333-acre reservoir with a drainage area of 11 square miles and is the sole source of water for the City of Moberly (Figure 1). A 2005 study of Sugar Creek Lake (Edwards, Chen, & McIntosh, 2005) determined that the reservoir would not be able to meet the City's water demand should conditions similar to the drought of record (1951-1960) recur. In 2018, City of Moberly water managers requested an update to the 2005 study to determine Sugar Creek Lake's available yield for water supply planning purposes.

Surface Water Supplies in Missouri

Most surface water supplies in Missouri are located north of the Missouri River in areas of glacial till. Groundwater resources in this region are poor due to high mineral content and insufficient pumping yields.

Following the 1999-2000 drought, the Missouri Department of Natural Resources prepared an analysis of 44 communities' water systems. Included were 40 drinking water reservoirs and four systems that utilize streams as their main water supply source. The study analyzed reservoir storage volumes and water demand against drought of record conditions in Missouri and found that many communities would need supplemental inflows to maintain water service to customers should a similar drought occur (Edwards, Chen, & McIntosh, 2005).

Hydrologic Setting

Mean annual precipitation in Missouri varies from a low of 34 inches in northwest Missouri to a high of 50 inches in the southeast. The City of Moberly of Randolph County, Missouri is approximately two miles south of Sugar Creek Lake and receives an average of 43 inches of rainfall each year. Between 1936 and 2019 the area had a historical high of 65 inches of precipitation in 2008 and a historical low of 22 inches in 1988 (Midwestern Regional Climate Center, 2019). Sugar Creek Lake, the primary water source for the City of Moberly, has a drainage area of 11.05 square miles and is fed by Sugar Creek and a few small, unnamed tributaries. Discharges from Sugar Creek Lake flow into the East Fork Chariton River approximately 4.6 miles downstream from the dam. Reservoir levels are manually monitored with a staff gage located on the adjustable intake in the southeast corner of the reservoir (Figure 2).

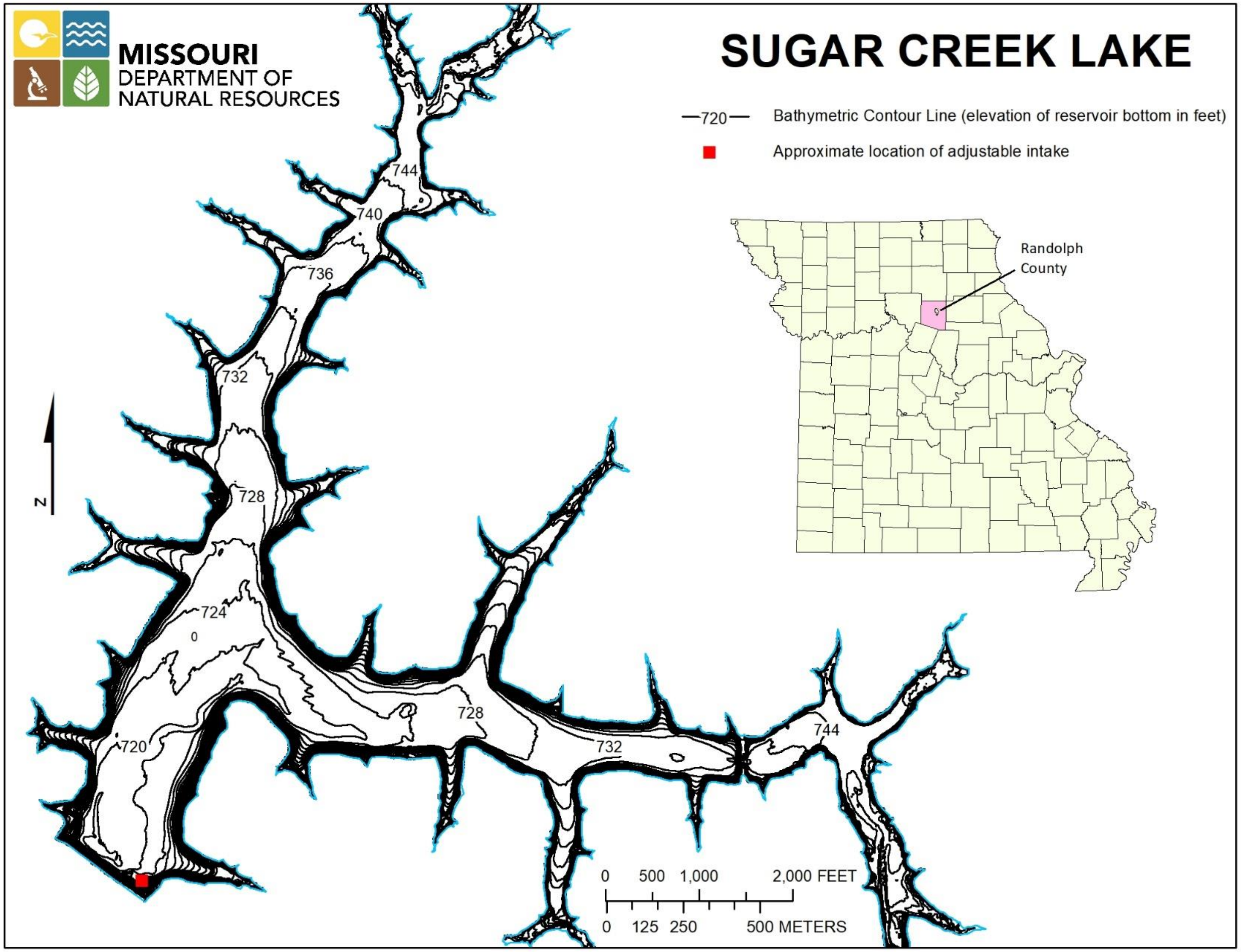


Figure 2. Bathymetric Map of Sugar Creek Lake. Contours indicate the elevation of the bottom of the reservoir as surveyed by the USGS in September of 2018. Contours are at 2-foot intervals.

The City of Moberly serves a population of approximately 12,174 with an annual water demand of 1.15 million gallons per day according to the 2019 Census of Missouri Public Water Systems (Missouri Department of Natural Resources, 2019). The City of Moberly's water demand has gradually decreased from 2.4 MGD to 1.1 MGD since 1987 (Figure 3) likely due to the loss of customers and improvements in water efficient appliances and fixtures. For example, the City of Moberly supplied water to a public water district until 1992. In 1992 the City stopped supplying water to that district, decreasing its water demand. From 1992 to 2017, the City's 26-year average water demand was 1.33 million gallons per day (MGD).

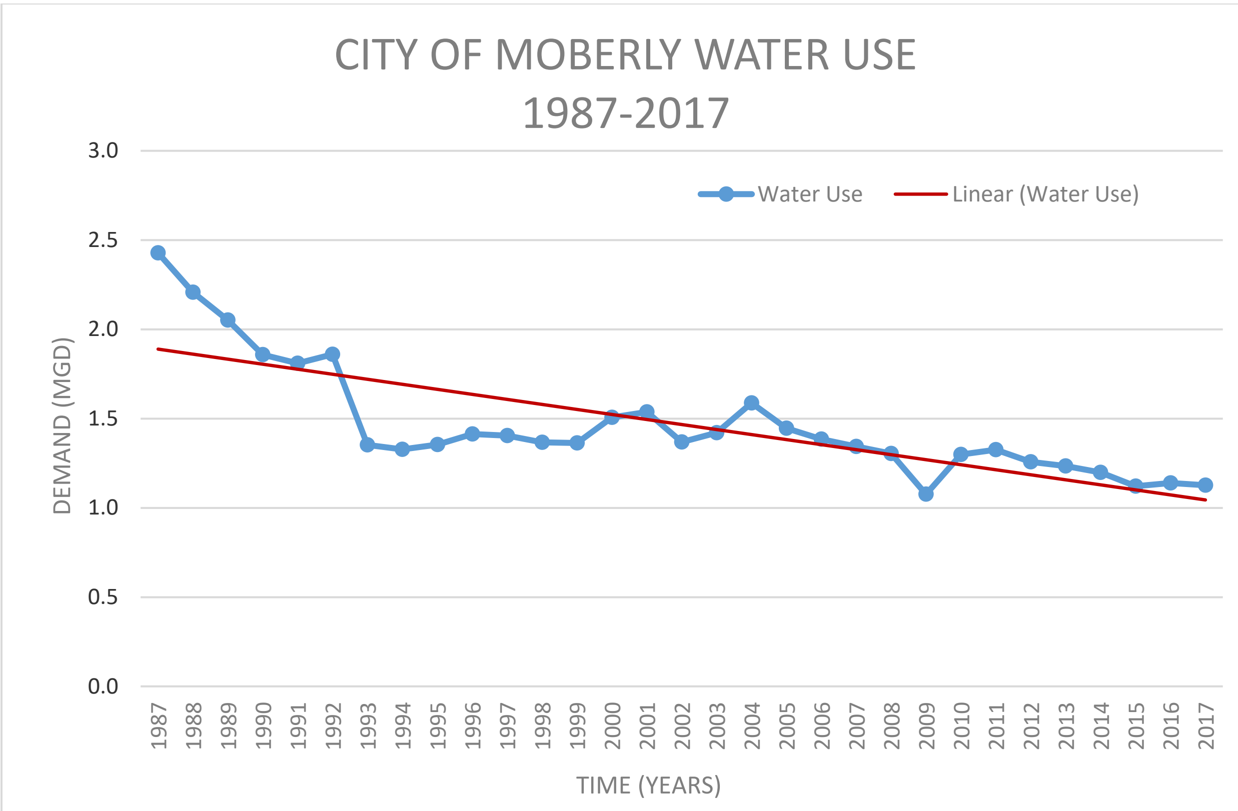


Figure 3. The City of Moberly's water use has declined since 1987 likely due to the loss of water customers and improvements in water efficient appliances and fixtures.

Methods

The USGS bathymetric survey of Sugar Creek Lake was conducted using a multi-beam echo sounder from September 4-6, 2018. Areas of the reservoir too shallow to be surveyed by boat were either supplemented with LIDAR data or interpolated from the 2003 bathymetric survey (Richards & Huizinga, 2019).

The bathymetric survey was not only instrumental in understanding the current volume of the reservoir but also in understanding the impact of sedimentation on water supply intakes. The City has two intakes: an adjustable intake that could withdraw water between elevations 752.28 and 729.78 feet, and a lower, fixed intake set at 717.78 feet. The intakes are located in the southeast corner of the reservoir, near the dam. The bathymetric survey showed sufficient sedimentation in the area of the reservoir near the intakes to render the lower, fixed intake unusable without removing the sediment. Therefore, with the concurrence of City water operators, the effective minimum operational elevation for this study is 729.78 feet.

Data from the area-capacity table (Table 1) generated from the USGS bathymetric data was used to perform a yield analysis using Reservoir System Simulation (HEC-ResSim). HEC-ResSim is a simulation program developed by the US Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center. HEC-ResSim is a tool with the capability to model large complex reservoir systems as well as small, relatively simple systems (HEC-ResSim, 2019). Once a model is created in HEC-ResSim, operational conditions can be defined and simulations run to study how systems will react in different scenarios. In this situation HEC-ResSim was utilized to simulate drought conditions.

Sugar Creek Lake Area-Capacity			
Elevation (feet)	Storage (acre-feet)	Area (acre)	Notes
716.46	0	0	Lowest elevation in reservoir
718	0.4	1.5	
720	18.0	18.2	
721	44.5	35.0	
722	86.3	48.3	
724	211	77.5	
726	393	104	
728	627	129	
729	762	142	Minimum Operational Storage Elevation
730	910	155	
732	1245	181	
734	1631	206	
736	2065	227	
738	2536	243	
740	3036	257	
742	3566	275	
744	4133	291	
746	4746	326	
746.8	5010	333	Spillway Elevation

Table 1. Reservoir elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 746.8 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88). Note: Volumes calculated from surface testing 0.91 feet vertical accuracy at 95 percent confidence level

Inflow Data

The Sugar Creek Lake watershed lacks the necessary instrumentation to directly determine the volume of water flowing into the reservoir. Therefore, it was necessary to obtain streamflow data from a watershed of similar soil type and topography. The U.S. Geological Survey (USGS) operates a streamgage on Moniteau Creek near Fayette, MO (USGS 06909500). Observations from this gage were used during the 2005 study and were again used in this analysis. The drainage area for the streamgage’s location is 75.1 square miles which is considerably larger than the 11 square mile drainage area of Sugar Creek Lake. To account for the difference in drainage area, the runoff data for USGS 06909500 was proportionately reduced to apply to Sugar Creek Lake’s watershed.

Example: On March 5, 1948 the mean runoff recorded at USGS 06909500 was 38 cubic feet per second (cfs). The model input data for Sugar Creek was therefore 5.7 cfs (38 cfs x 0.15 = 5.7 cfs).

Seepage

Sugar Creek Lake Dam is a regulated dam (MO10005) and has a history of a seepage issues first documented in 1979 when Burns & McDonnell conducted a dam inspection. Based on the Dam Inspection Report, Sugar Creek Lake Dam was found to have seepage issues in the east and west abutments. Burns & McDonnell recommend a grouting program to alleviate the situation (Burns & McDonnell, 1979). In 1983, the Land Reclamation Commission requested that the MoDNR conduct an inspection focusing on the impacts of mining operations in the area. Despite grouting programs carried out as suggested in the 1979 Burns & McDonnell inspection, MoDNR found that there was still a seepage issue in one of the abutments (Howe, 1983).

For this study City of Moberly provided numbers quantifying the seepage flow rate at varies reservoir elevations. It is estimate that there is a seepage rate of 720 gallons per minute (GPM) when the reservoir is at full pool (elevation of 746.8 feet) and a seepage rate of 150 gpm when the reservoir is 25 inches below full pool (elevation 744.72 feet). The information provided was plotted on a scatter plot and a line of best fit was assigned to the data. Points generated from the line of best fit were entered into the simulation program where it interpolated a relationship between seepage flow rate and elevation.

Evaporation

Monthly pan evaporation rates recorded at the Lakeside gage near Lake of the Ozarks from 1951 to 1960 were used to estimate the evaporation While Lakeside gage had the most extensive data points for evaporation during the drought of record there were two locations closer to Sugar Creek Lake. When values were available from Columbia, Missouri or New Franklin, Missouri the Lakeside data was replaced. The pan values were multiplied by 0.76 to convert from pan evaporation to lake evaporation. Monthly averages were calculated for the 10 year period and the following values were used in the simulation:

Month	Evaporation (inches)
January	0.75
February	1.41
March	2.26
April	3.95
May	4.84
June	5.47
July	6.03
August	5.40
September	4.48
October	3.05
November	1.81
December	0.91

Table 2. Evaporation Table. Average monthly values from 1951 to 1960.

Scenario Analyses

Two scenarios were modeled using HEC-ResSim to determine if the reservoir has sufficient yield to meet current water demands under drought of record conditions. The first scenario analyzed current demand and yield without seepage. Current demand was considered to be 1.33 million gallons per day (MGD) which is the 25-year average of recorded water demand between 1993 and 2017. The demand was then applied to the drought of the 1950s to determine the available yield. Seepage was accounted for in the second scenario with the same demand and drought parameters as the first scenario.

The scenarios represent two categories of demand and yield: without seepage and with seepage. Without seepage demand is defined as the amount of water the community requires in order to meet water demands. Yield is how much water can be withdrawn from the reservoir before the water surface reaches the minimum operational elevation. In scenario 2, when seepage is included, the definitions of demand and yield change. With seepage demand is defined as the amount of water the community requires plus the maximum amount of water that could be lost to seepage. Yield has the same definition as before, however, the amount available to be withdrawn will be less in this scenario because the reservoir surface elevation will be lower due to seepage outflow.

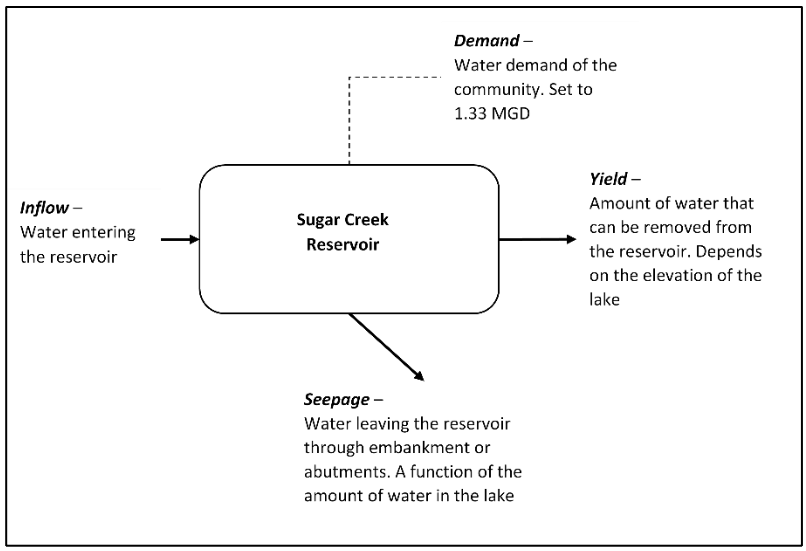


Figure 4. Schematic of water balance for Sugar Creek Lake.

Results

Current Demand	1.33 MGD
Current Demand With Seepage	2.58 MGD
Yield	1.44 MGD
Yield With Seepage	1.17 MGD

Table 3. Results from the HEC-ResSim models

Scenario 1 – No Seepage

Scenario 1 model results indicate that Sugar Creek Lake, with a demand of 1.33 MGD, could yield 1.44 MGD over 10 years as shown in Figure 6. Under these conditions there would be sufficient yield to meet demand during an extended drought. However, there was a period of time in which the reservoir nears insufficient water supply conditions. For a total of 300 days out of 3,560 days the reservoir was less than 3 feet above operational elevation and less than 0.5 feet above operational elevation for 14 days (Figure 8).

Scenario 2 - Seepage

Scenario 2 models conditions over the same period as Scenario 1 with the inclusion of seepage. Under this scenario, Sugar Creek Lake would yield 1.17 MGD (Table 3) when applying the current demand of 2.58 MGD (demand + seepage). The results indicate the yield is insufficient to meet the current demand resulting in three periods of supply deficiency (Table 4).

Period 1	November 24, 1954 January 4, 1955	41 Days	1.37 Months
Period 2	February 12, 1955 February 15, 1955	3 Days	0.10 Months
Period 3	December 13, 1956 March 25, 1957	102 Days	3.40 Months

Table 4. Periods of deficiency. Where yield was insufficient to meet demand during Scenario 2 - With Seepage

Sedimentation

The effects of sedimentation on reservoir volume were calculated by comparing the results of the two bathymetric surveys conducted in 2003 and 2018. The difference in the elevations of the reservoir bottoms between surveys represents sediment depth. There has been sediment deposition of 1 to 1.5 feet throughout the reservoir (Figure 9). Storage-elevation curves were calculated from both surveys. Figure 10 shows that sedimentation has resulted in a 240 acre-foot reduction in water storage volume at full pool over 15 years, representing a decrease of 4.6%.

To better understand the impacts of the sedimentation noted from 2003 to 2015 in Sugar Creek Lake, a simulation was run using the storage curves from 2003, 2018, and 2033. The 2033 storage curve was generated assuming the 4.6% loss in storage from 2003 to 2018 would occur in the next 15 years. The storage curves can be seen in Figure 8. As the focus of this analysis was to see the impact from sedimentation on yield assuming seepage was still occurring the only factor changed from simulation to simulation was the storage curve. The results shown in Tables 5-7. Over 30 years the sedimentation increased the number of insufficient yield days by 12 days.

2003 - Storage of 5250 ac-ft			
Period 1	30-Nov-1955 4-Jan-1955	35 Days	1.17 Months
Period 2	13-Feb-1955 15-Feb-1955	2 Days	0.07 Months
Period 3	9-Dec-1956 25-Mar-1957	106 Days	3.53 Months
Total Days of Insufficient Yield			**143**
Total Days of Simulation Period			**3560**

2018 - Storage of 5010 ac-ft			
Period 1	24-Nov-1954 4-Jan-1955	41 Days	1.37 Months
Period 2	12-Feb-1955 15-Feb-1955	3 Days	0.10 Months
Period 3	13-Dec-1956 25-Mar-1957	102 Days	3.40 Months
Total Days of Insufficient Yield			**146**
Total Days of Simulation Period			**3560**

2033 - Storage of 4781 ac-ft			
Period 1	6-Nov-1954 4-Jan-1955	49 Days	1.63 Months
Period 2	5-Feb-1955 6-Feb-1955	1 Day	0.03 Months
Period 3	9-Feb-1955 15-Feb-1955	6 Days	0.20 Months
Period 4	16-Dec-1956 25-Mar-1957	99 Days	3.30 Months
Total Days of Insufficient Yield			**155**
Total Days of Simulation Period			**3560**

Tables 5-7. The series of tables show the periods of yield for 2003, 2018 , and 2033. Each year assumes 1.33 MGD of demand with seepage factored in. The total storage for each year is listed in the table header.

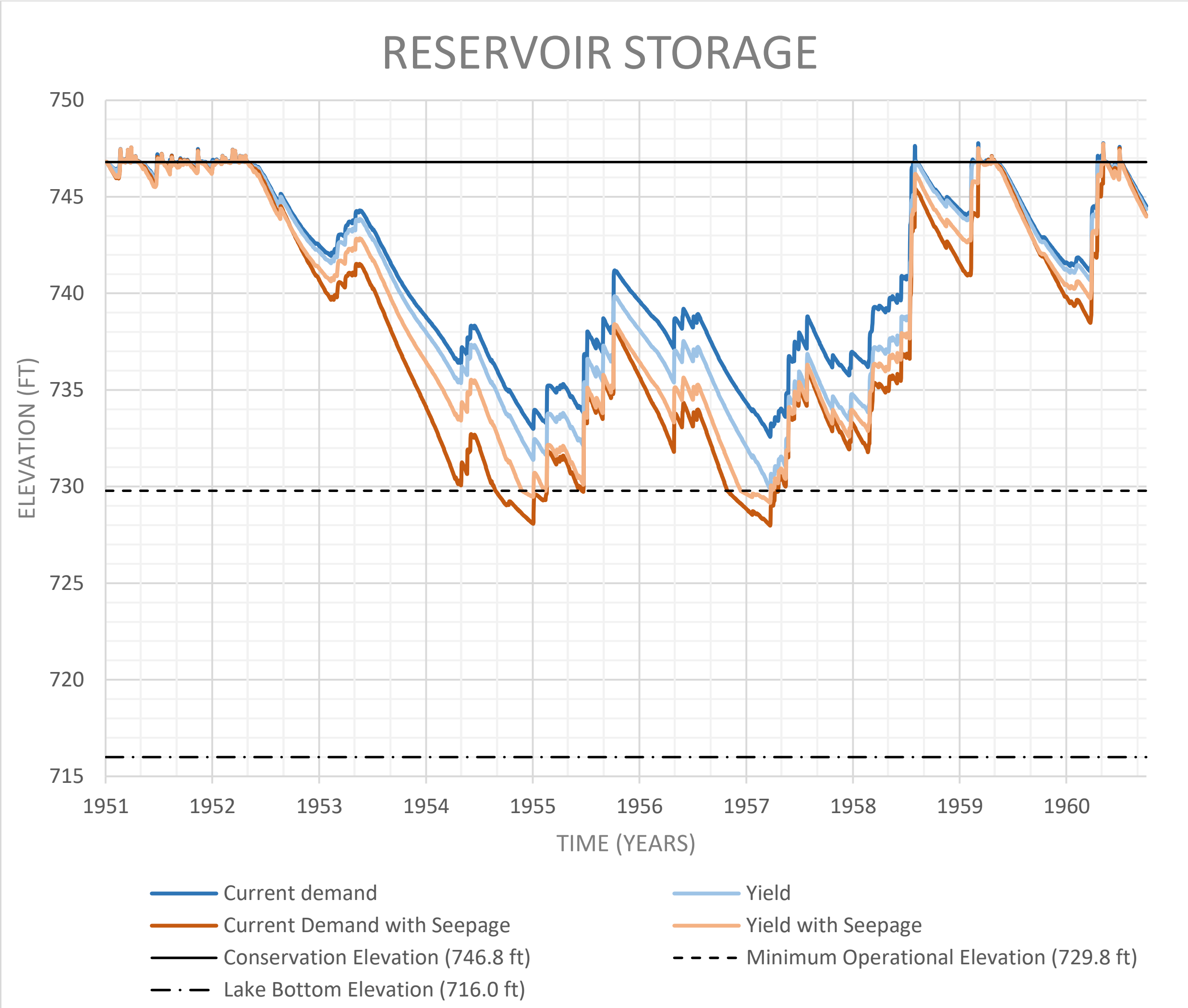


Figure 5. Reservoir Surface Elevation from Scenarios 1 and 2. HEC-ResSim results from 1951-1960, the drought of record period. The elevations of the bottom of the reservoir, the minimum operational level, and the conservation level are marked. The blue lines represent Scenario 1 – Without Seepage and the orange lines represent Scenario 2 – With Seepage.

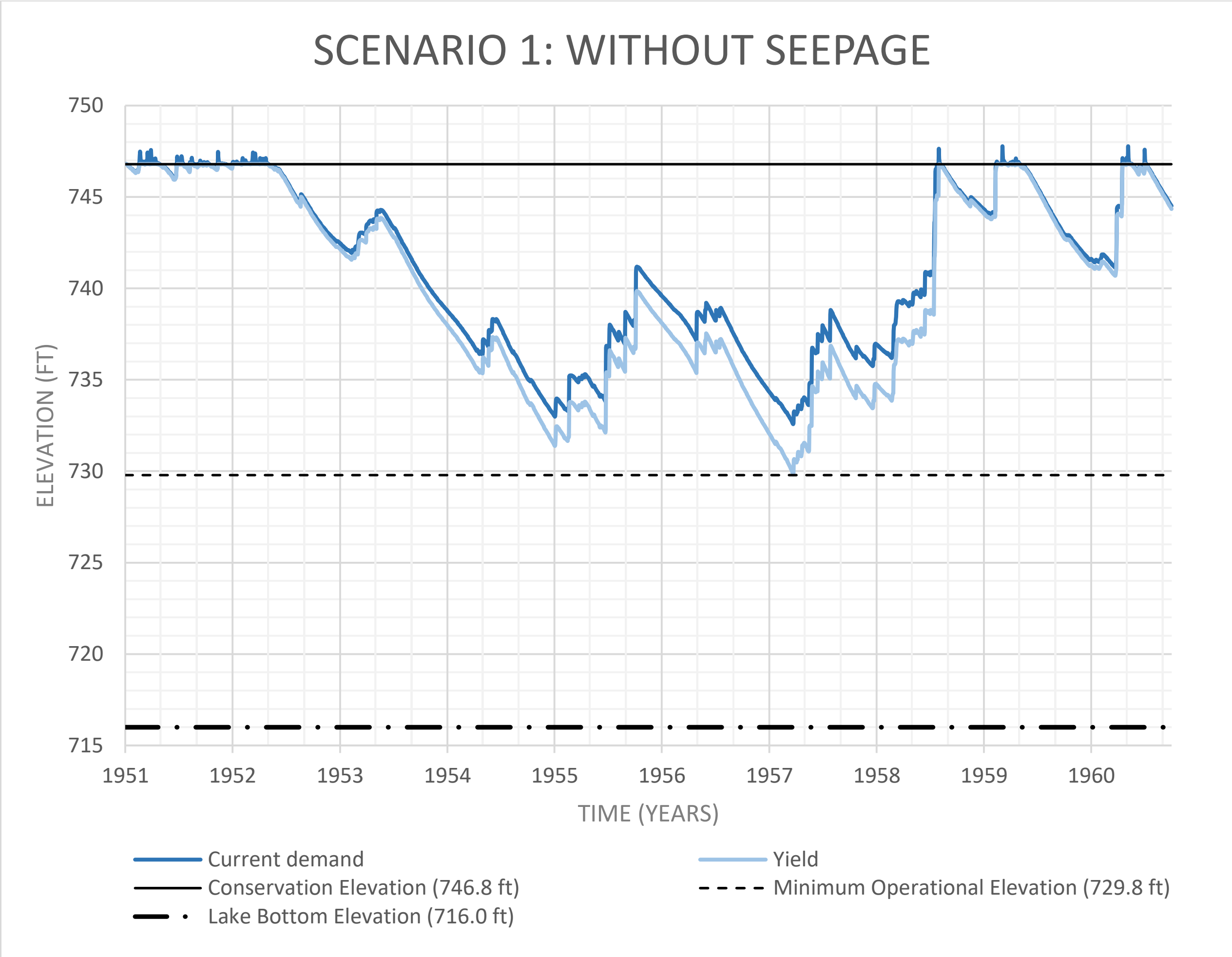


Figure 6. Scenario 1 – Without Seepage HEC-ResSim Results. Results from 1951-1960, the drought of record period. The elevations of the bottom of the reservoir, the minimum operational level, and the conservation level are marked. The dark blue line represents the demand and the light blue line represents the yield.

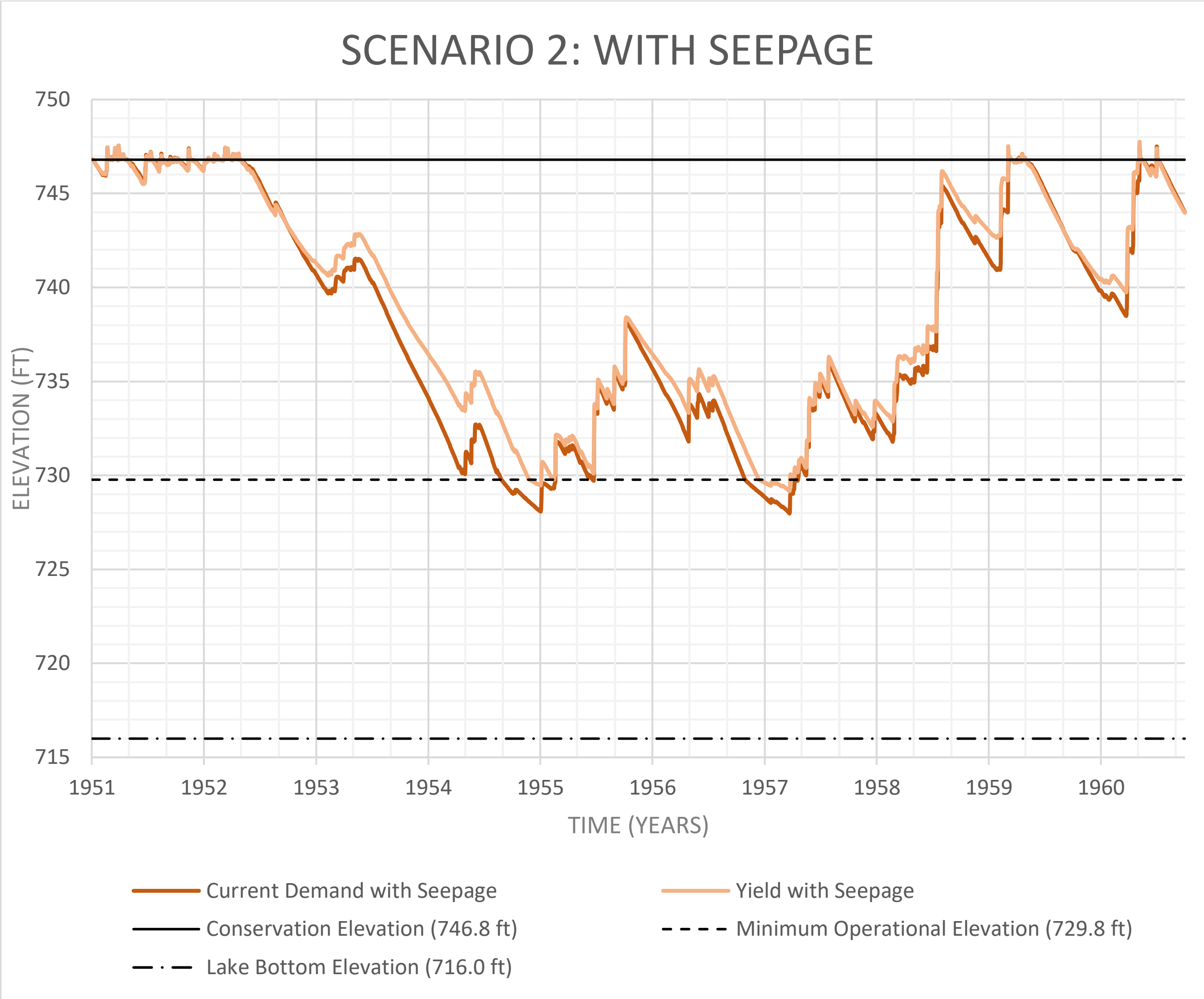


Figure 7. Scenario 2 – With Seepage HEC-ResSim Results. Results from 1951-1960, the drought of record period. The elevations of the bottom of the reservoir, the minimum operational level, and the conservation level are marked. The dark orange line represents the demand and the light orange line represents the yield.

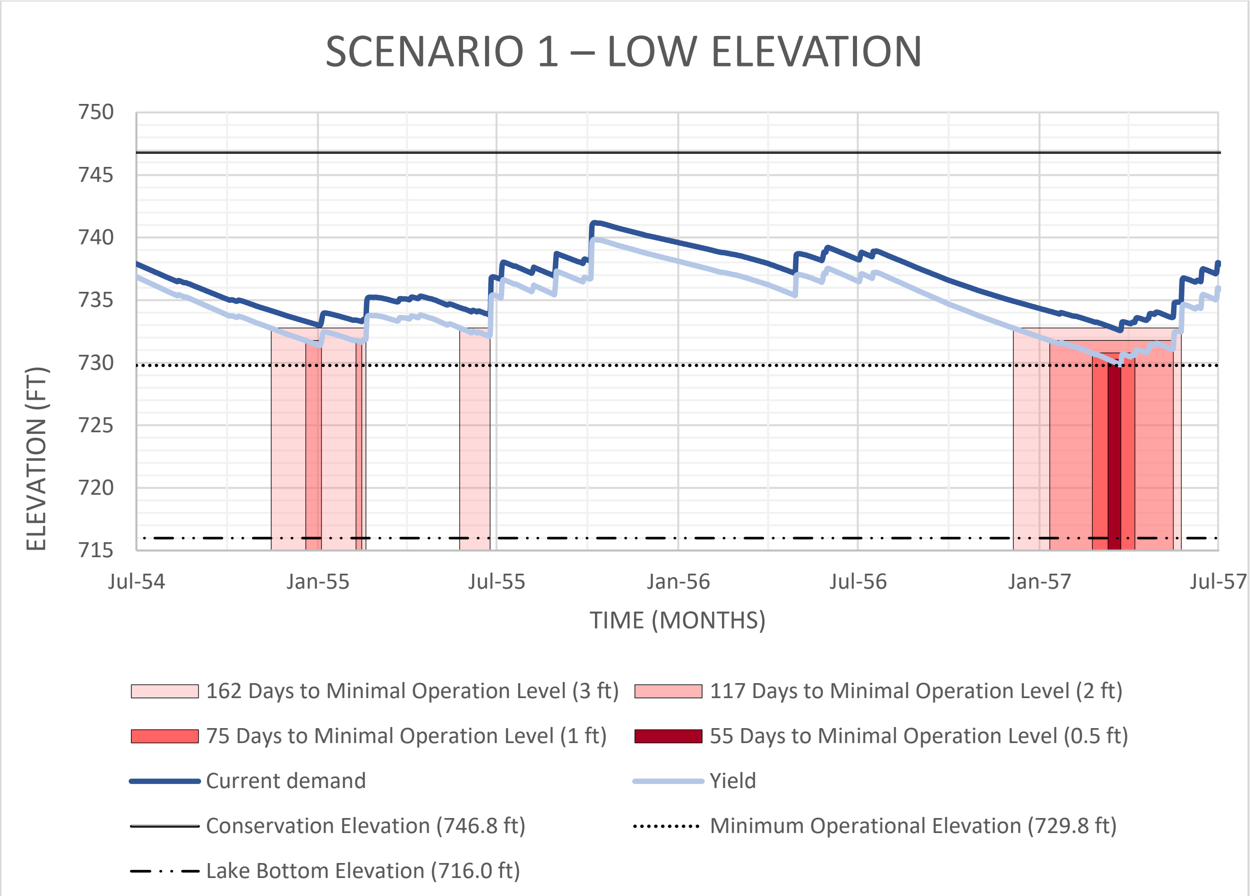


Figure 8. Scenario 1 – Without Seepage Low Elevation Warnings. While the simulation period is from 1951-1960, from 1954 to 1957 there were 3 periods where low elevations in the reservoir were noted. The feet listed next to the number of days indicated how many feet the yield was from the minimum operational elevation.

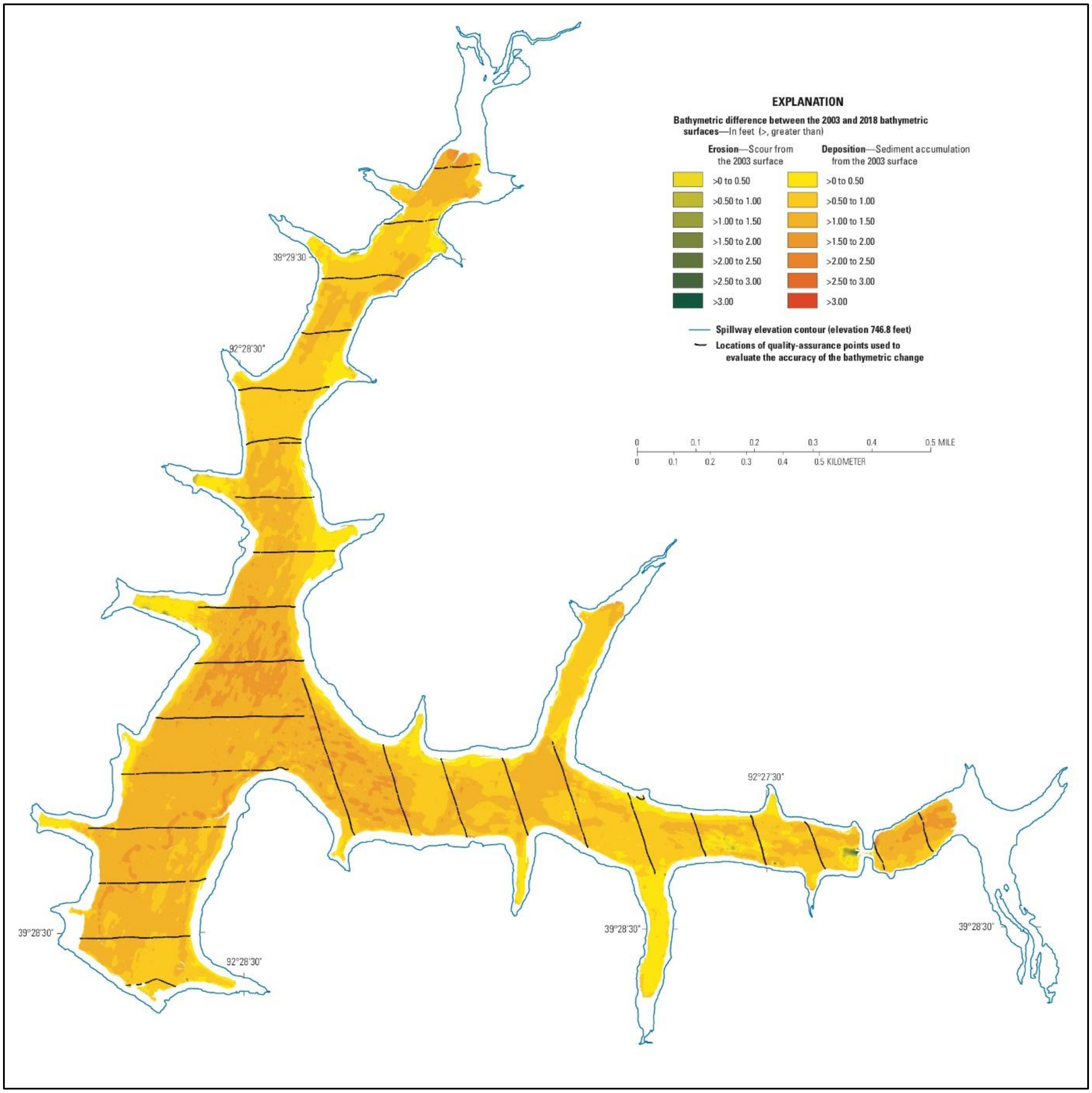


Figure 9. Bathymetric survey change since 2003 study. Change can represent either sediment deposition or erosion. Source: USGS

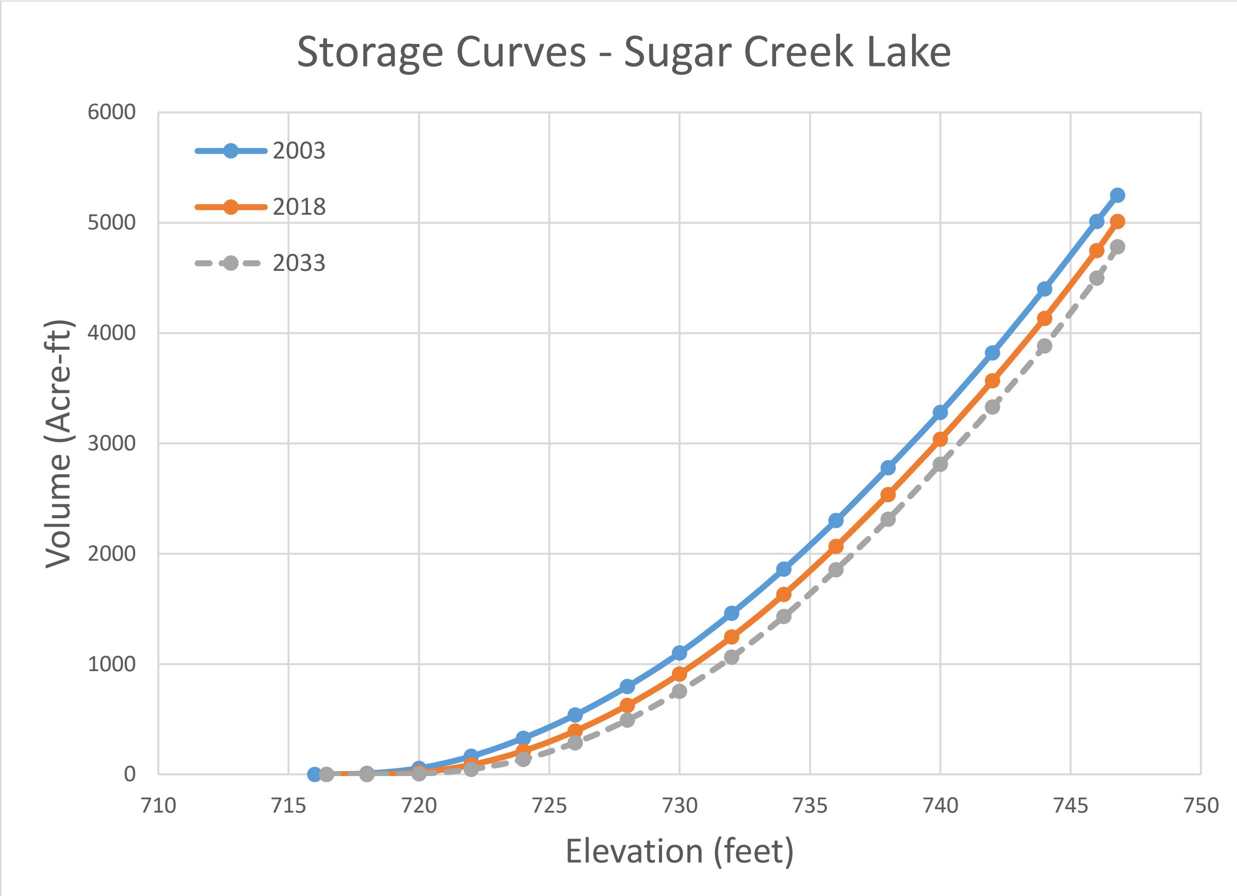


Figure 10. Storage-Elevation curves calculated from bathymetric surveys for the years 2003 and 2018. 2033 is a projected storage curve developed assuming a 4.6% loss of storage would occur from 2018 to 2033. Storage volume was lost at all elevations of the lake between surveys.

Discussion

At full pool, approximately 1 MGD of water is being lost to seepage, which would be critical to the City's water supply if a sustained drought were to occur. Seepage is not necessarily a structural concern for the dam itself, but the City is losing water that would be valuable during drought. It is recommended that the City take steps to reduce the volume of water lost to seepage.

Sedimentation is also a key contributor to the decrease in yield since the 2003 bathymetric survey. A 240 acre-foot reduction is equivalent to 78 million gallons or approximately 58 days of supply, which could assist in meeting demand during an extreme drought. The location of deposited sediment is also of concern since it is likely that the bottom, fixed intake is inaccessible. The intake is located in the southeast corner of the reservoir at elevation 717.78 feet. According to the 2018 USGS bathymetry survey, that section of the reservoir has a bottom elevation of 730 feet. Therefore, the intake is likely under approximately 12 feet of sediment. It is recommended that the City create a management plan to ensure access to available water should the need arise to use the lower, fixed intake.

The City currently has to visually estimate the level of the reservoir (Figure 11) by the use of bars attached to the intake platform at one-foot intervals above and below normal pool. This method of measuring reservoir levels has limited precision. Installing a USGS lake gage would enable the City to monitor reservoir levels with much greater precision. Such USGS lake gages are located in Montgomery City, Concordia, Stanberry, and Marceline.

Furthermore, it would be beneficial to install a streamgage on Sugar Creek upstream of the reservoir. A gage in this location would provide more accurate information on the amount of inflow to the reservoir, improving data inputs for future yield studies.

Figure 11. The City currently has to visually estimate the level of the reservoir by the use of bars (example circled) attached to the intake platform at one-foot intervals above and below normal pool.

Acknowledgements

We gratefully acknowledge the indispensable assistance of Russ Errett, Cory Tabbert, and Joan Stemler with the St. Louis District of the U.S Army Corps of Engineers, and the help of the US Geological Survey.

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Appendix B

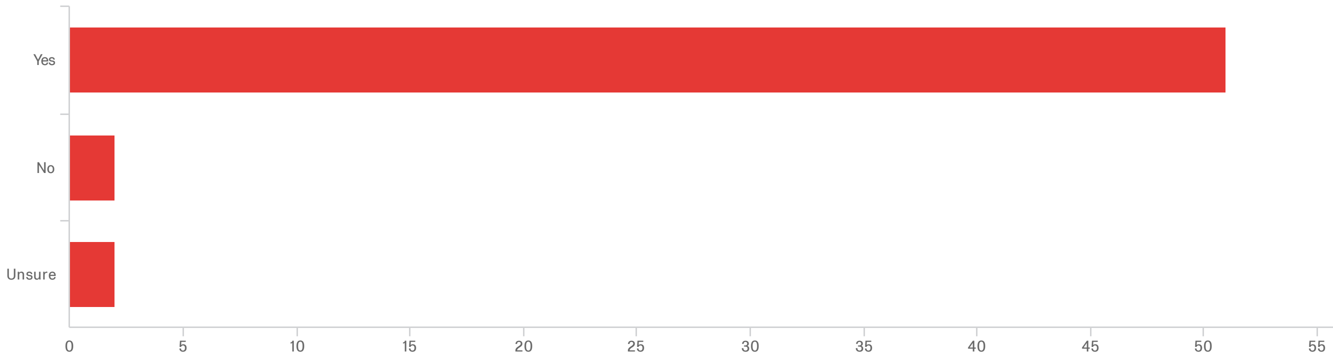
2019 Stakeholder Survey Results

Default Report

Sugar Creek Lake Community Water Plan: Public Input Survey

March 21, 2019 11:37 AM CDT

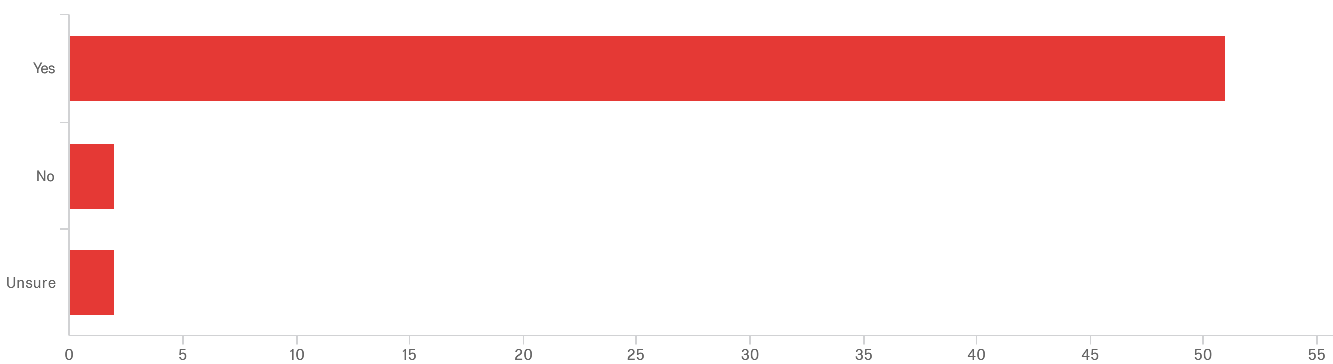
Q1 - To the best of your knowledge, is Sugar Creek Lake a source of drinking water?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	To the best of your knowledge, is Sugar Creek Lake a source of drinking water?	1.00	3.00	1.11	0.41	0.17	55

#	Field	Choice Count	
1	Yes	92.73%	51
2	No	3.64%	2
3	Unsure	3.64%	2
			55

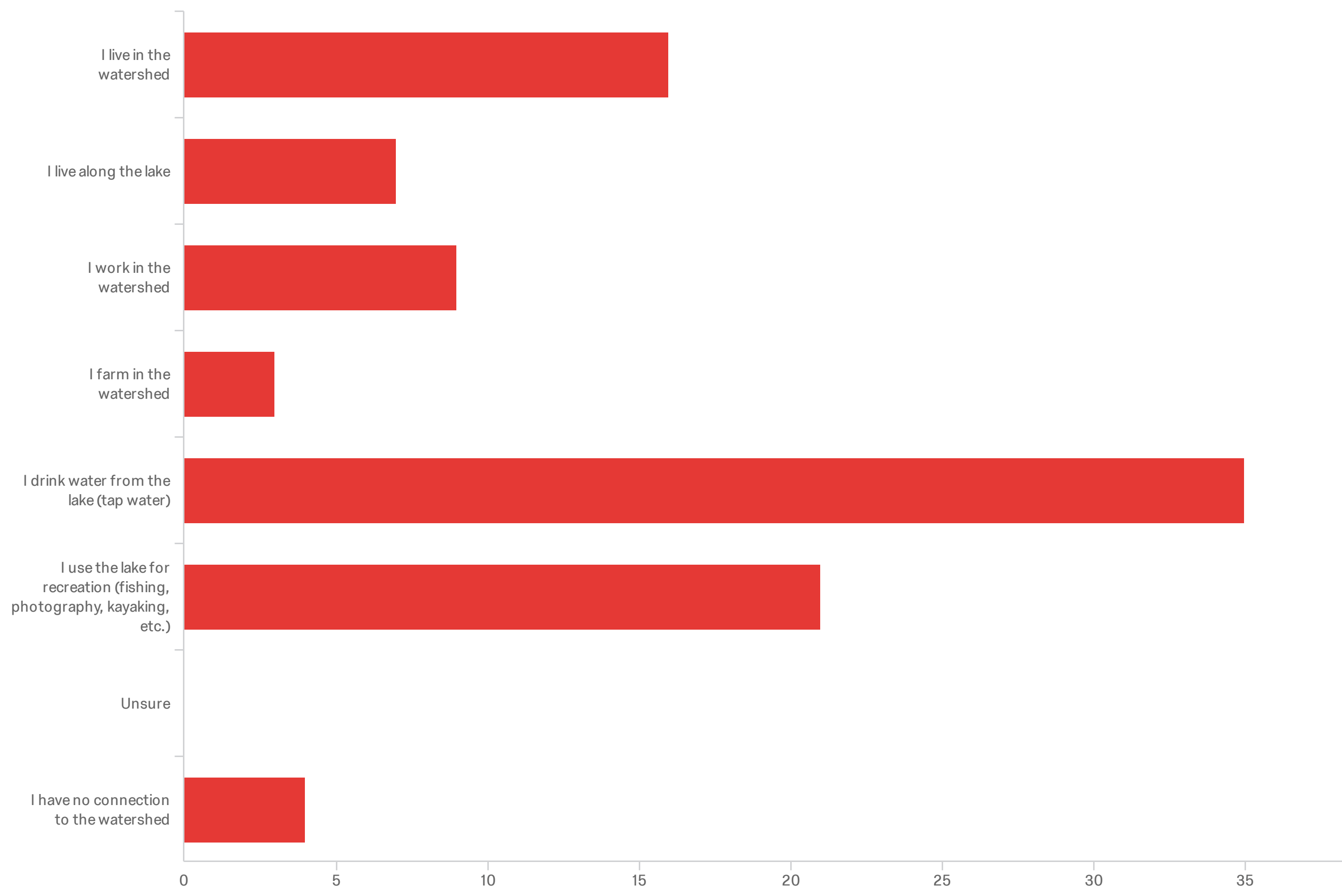
Showing rows 1 - 4 of 4



Q2 - What is your connection to the Sugar Creek Lake watershed? Check all that apply.

See map below. The watershed is an area of land that channels rain and snowmelt into drainage ways, ditches, creeks, and eventually into Sugar Creek Lake. To view a map of the watershed, copy and paste this link into a separate page on your browser:

http://extension.missouri.edu/boone/ced.aspx

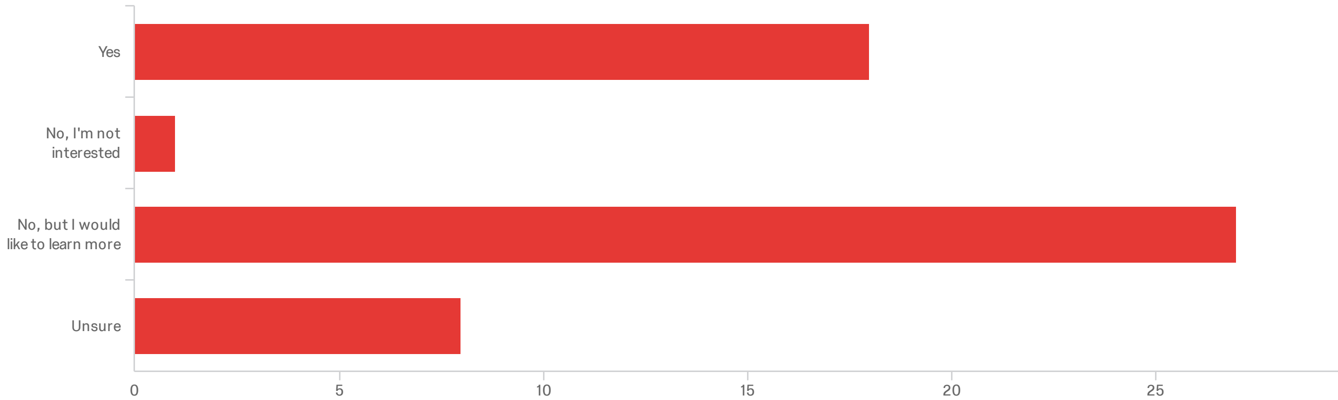


#	Field	Choice Count	
1	I live in the watershed	16.84%	16
2	I live along the lake	7.37%	7
3	I work in the watershed	9.47%	9
4	I farm in the watershed	3.16%	3
5	I drink water from the lake (tap water)	36.84%	35

#	Field	Choice Count	
6	I use the lake for recreation (fishing, photography, kayaking, etc.)	22.11%	21
7	Unsure	0.00%	0
8	I have no connection to the watershed	4.21%	4
			95

Showing rows 1 - 9 of 9

Q3 - Do you feel you have enough information to know if there are any concerns with Sugar Creek Lake?

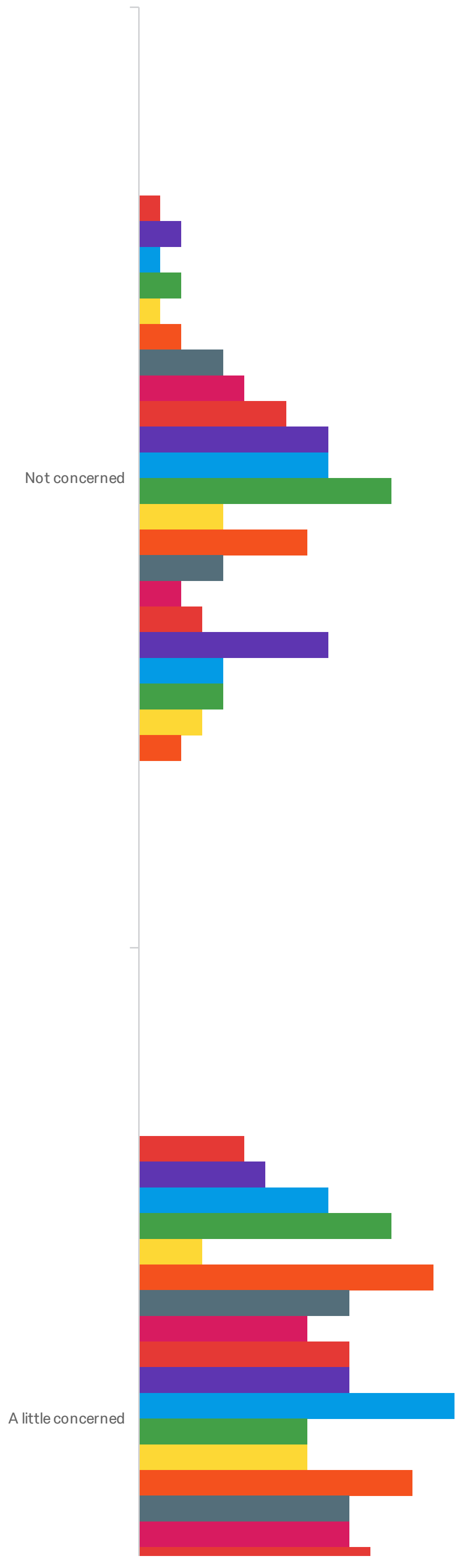


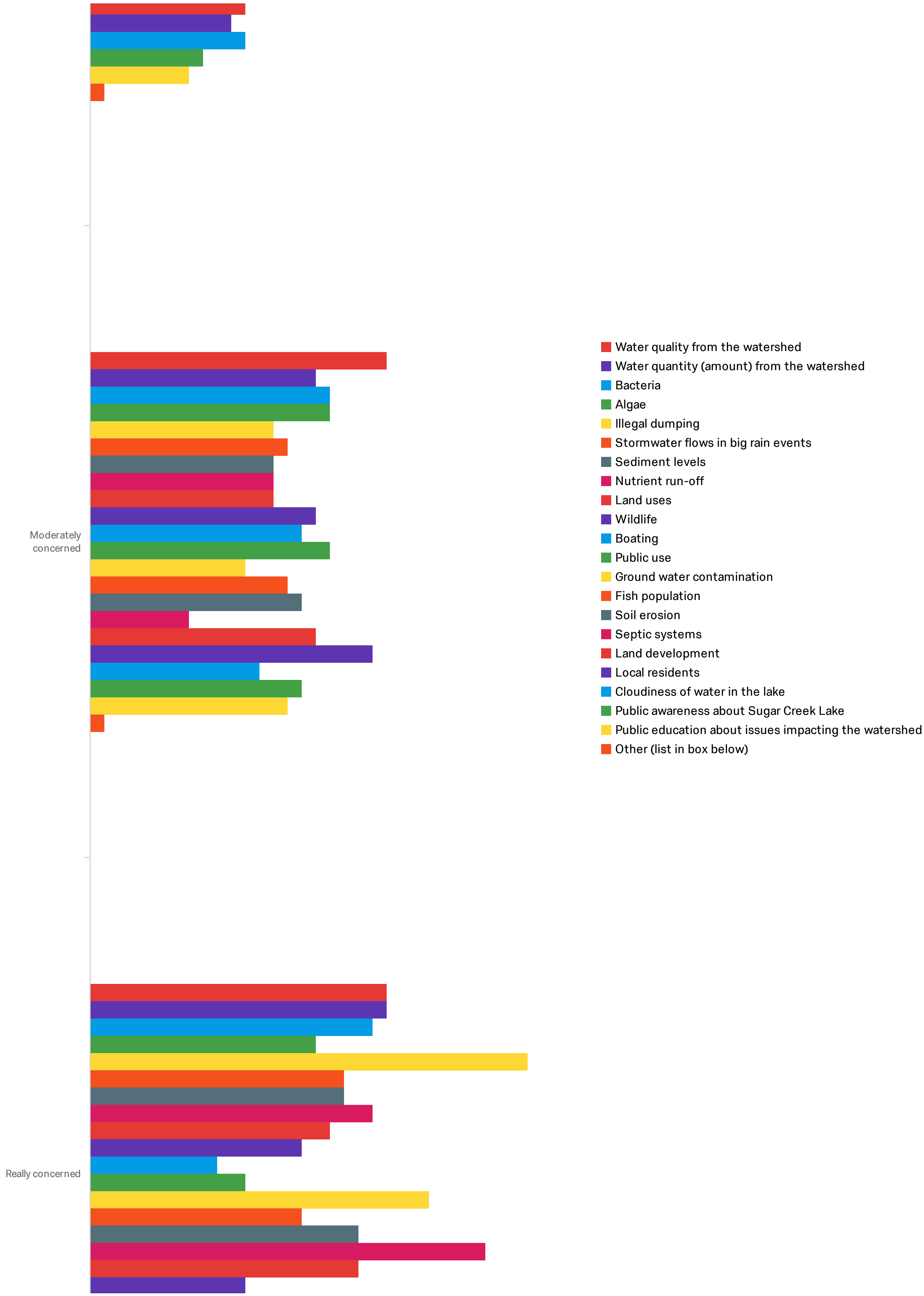
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Do you feel you have enough information to know if there are any concerns with Sugar Creek Lake?	1.00	4.00	2.46	1.10	1.21	54

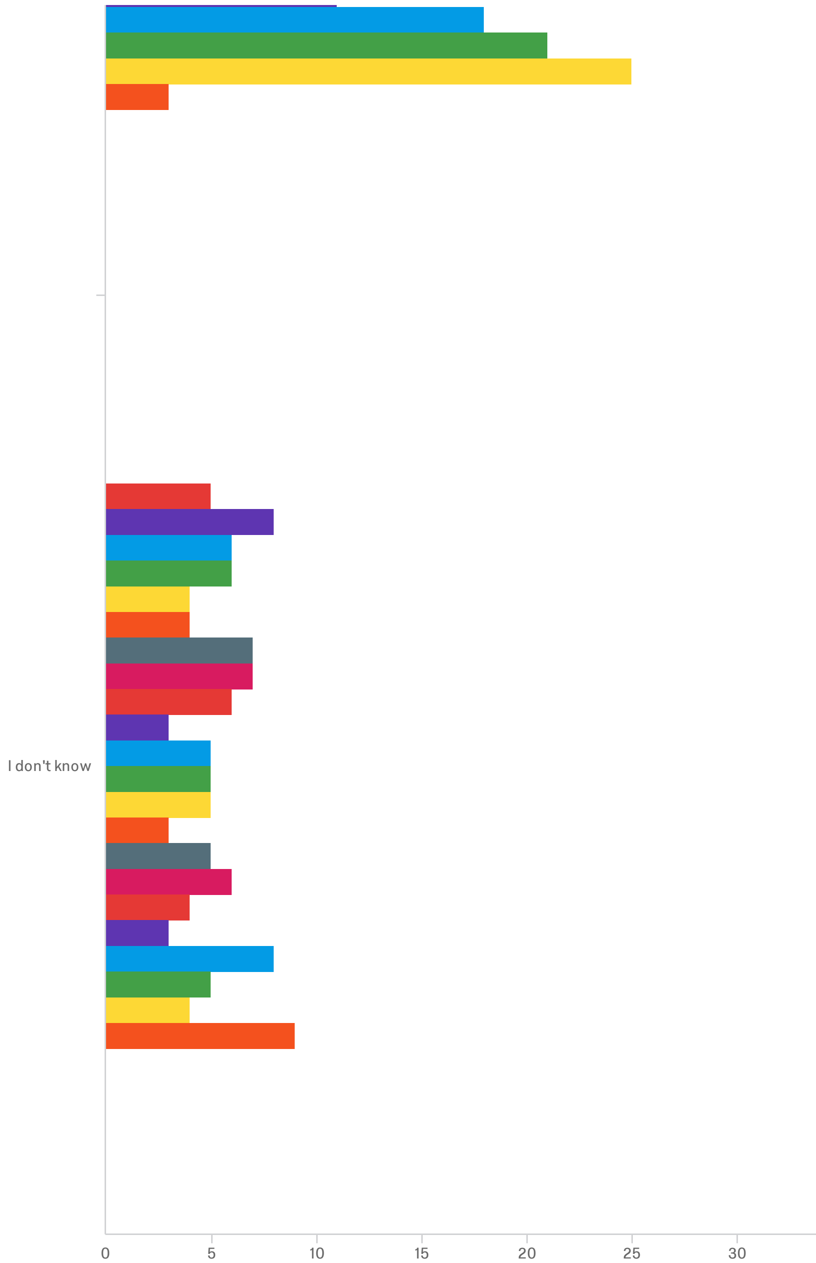
#	Field	Choice Count	
1	Yes	33.33%	18
2	No, I'm not interested	1.85%	1
3	No, but I would like to learn more	50.00%	27
4	Unsure	14.81%	8
			54

Showing rows 1 - 5 of 5

Q4 - From your own perspective, how concerned are you about the following potential issues or items at Sugar Creek Lake? (Note: items listed may not reflect actual current conditions). Please select one dot in each line.




Moderately concerned
Really concerned
Water quality from the watershed
Water quantity (amount) from the watershed
Bacteria
Algae
Illegal dumping
Stormwater flows in big rain events
Sediment levels
Nutrient run-off
Land uses
Wildlife
Boating
Public use
Ground water contamination
Fish population
Soil erosion
Septic systems
Land development
Local residents
Cloudiness of water in the lake
Public awareness about Sugar Creek Lake
Public education about issues impacting the watershed
Other (list in box below)



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Water quality from the watershed	1.00	5.00	3.45	0.86	0.74	53
2	Water quantity (amount) from the watershed	1.00	5.00	3.51	1.00	1.00	53
3	Bacteria	1.00	5.00	3.40	0.96	0.92	53
4	Algae	1.00	5.00	3.23	1.04	1.08	53
5	Illegal dumping	1.00	5.00	3.65	0.78	0.61	52
6	Stormwater flows in big rain events	1.00	5.00	3.15	1.03	1.05	52
7	Sediment levels	1.00	5.00	3.27	1.15	1.31	52

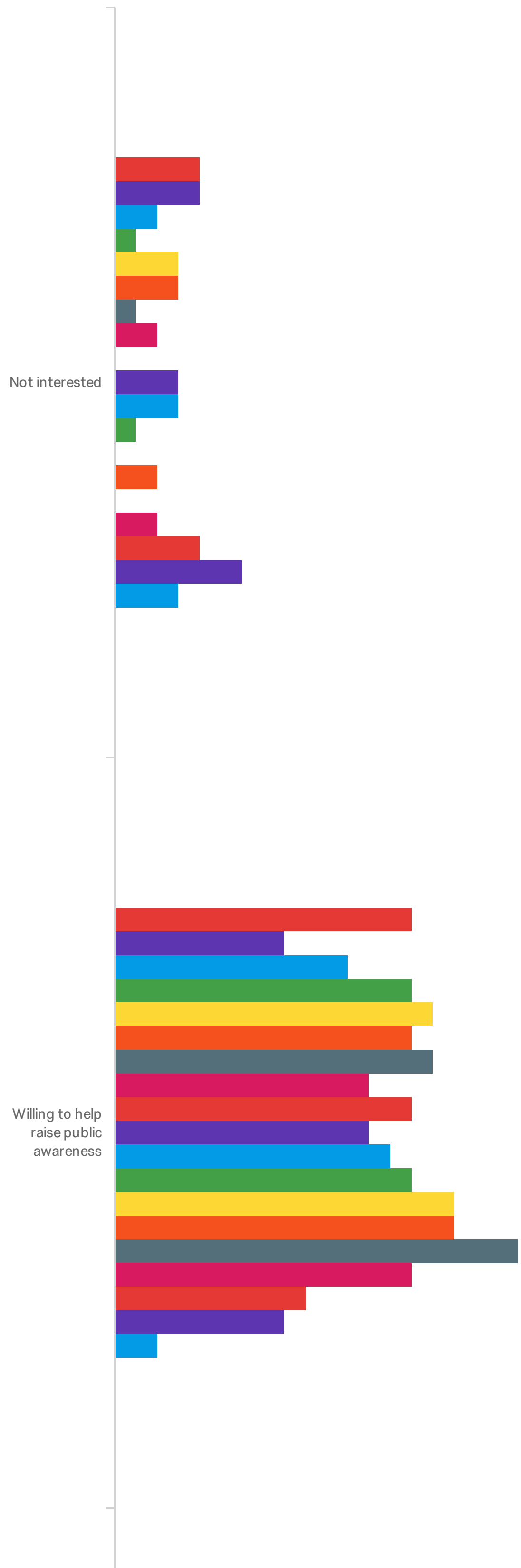
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
8	Nutrient run-off	1.00	5.00	3.30	1.16	1.34	53
9	Land uses	1.00	5.00	3.09	1.22	1.48	53
10	Wildlife	1.00	5.00	2.87	1.17	1.36	53
11	Boating	1.00	5.00	2.74	1.20	1.44	53
12	Public use	1.00	5.00	2.79	1.26	1.60	53
13	Ground water contamination	1.00	5.00	3.35	1.09	1.19	52
14	Fish population	1.00	5.00	2.85	1.16	1.34	53
15	Soil erosion	1.00	5.00	3.21	1.09	1.18	53
16	Septic systems	1.00	5.00	3.49	1.04	1.08	53
17	Land development	1.00	5.00	3.19	1.03	1.06	53
18	Local residents	1.00	5.00	2.79	1.12	1.26	53
19	Cloudiness of water in the lake	1.00	5.00	3.28	1.17	1.37	53
20	Public awareness about Sugar Creek Lake	1.00	5.00	3.28	1.07	1.15	53
21	Public education about issues impacting the watershed	1.00	5.00	3.38	0.99	0.99	53
22	Other (list in box below)	1.00	5.00	4.00	1.41	2.00	16

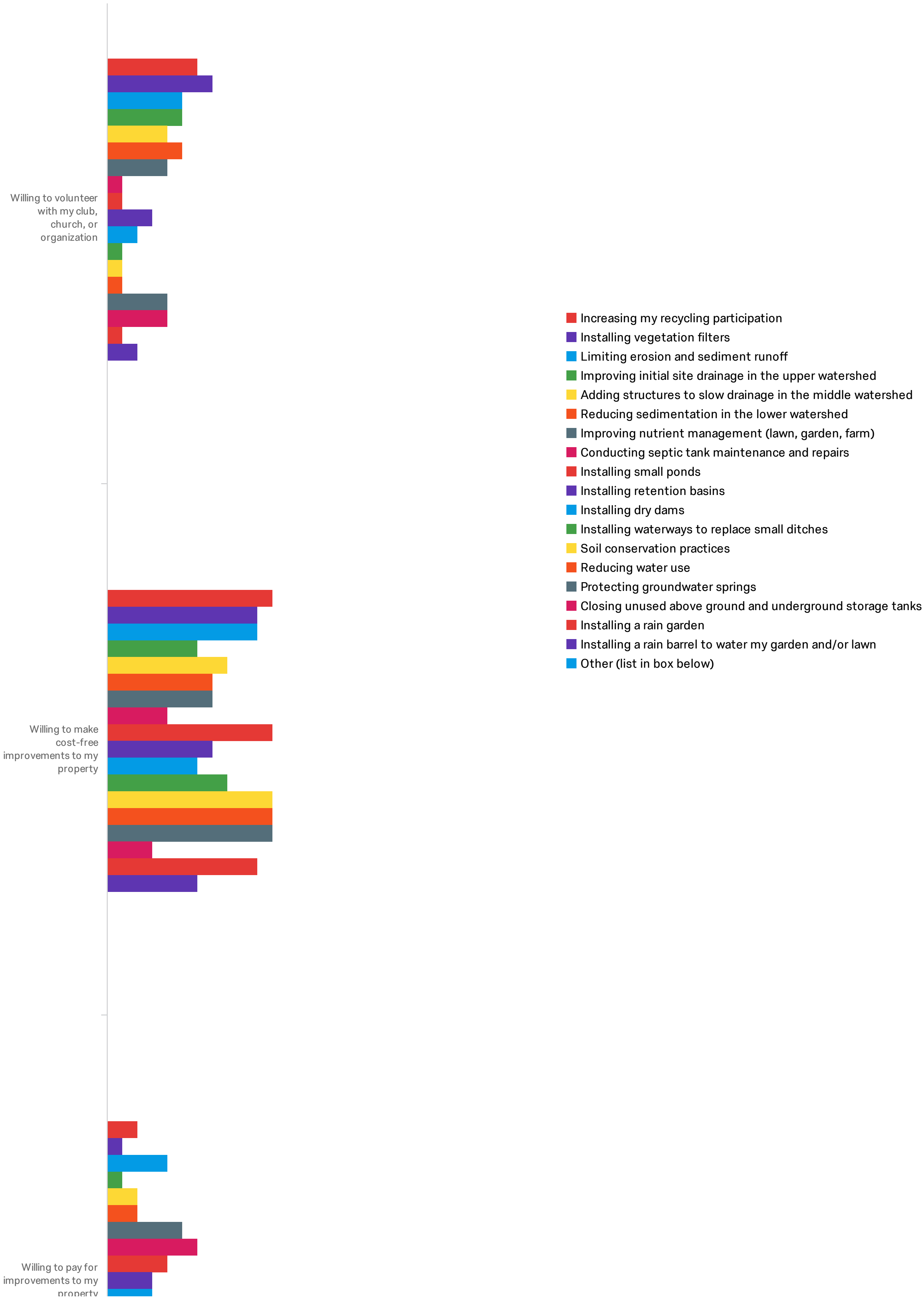
#	Field	Not concerned		A little concerned		Moderately concerned		Really concerned		I don't know		Total
1	Water quality from the watershed	1.89%	1	9.43%	5	39.62%	21	39.62%	21	9.43%	5	53
2	Water quantity (amount) from the watershed	3.77%	2	11.32%	6	30.19%	16	39.62%	21	15.09%	8	53
3	Bacteria	1.89%	1	16.98%	9	32.08%	17	37.74%	20	11.32%	6	53
4	Algae	3.77%	2	22.64%	12	32.08%	17	30.19%	16	11.32%	6	53
5	Illegal dumping	1.92%	1	5.77%	3	25.00%	13	59.62%	31	7.69%	4	52
6	Stormwater flows in big rain events	3.85%	2	26.92%	14	26.92%	14	34.62%	18	7.69%	4	52
7	Sediment levels	7.69%	4	19.23%	10	25.00%	13	34.62%	18	13.46%	7	52
8	Nutrient run-off	9.43%	5	15.09%	8	24.53%	13	37.74%	20	13.21%	7	53

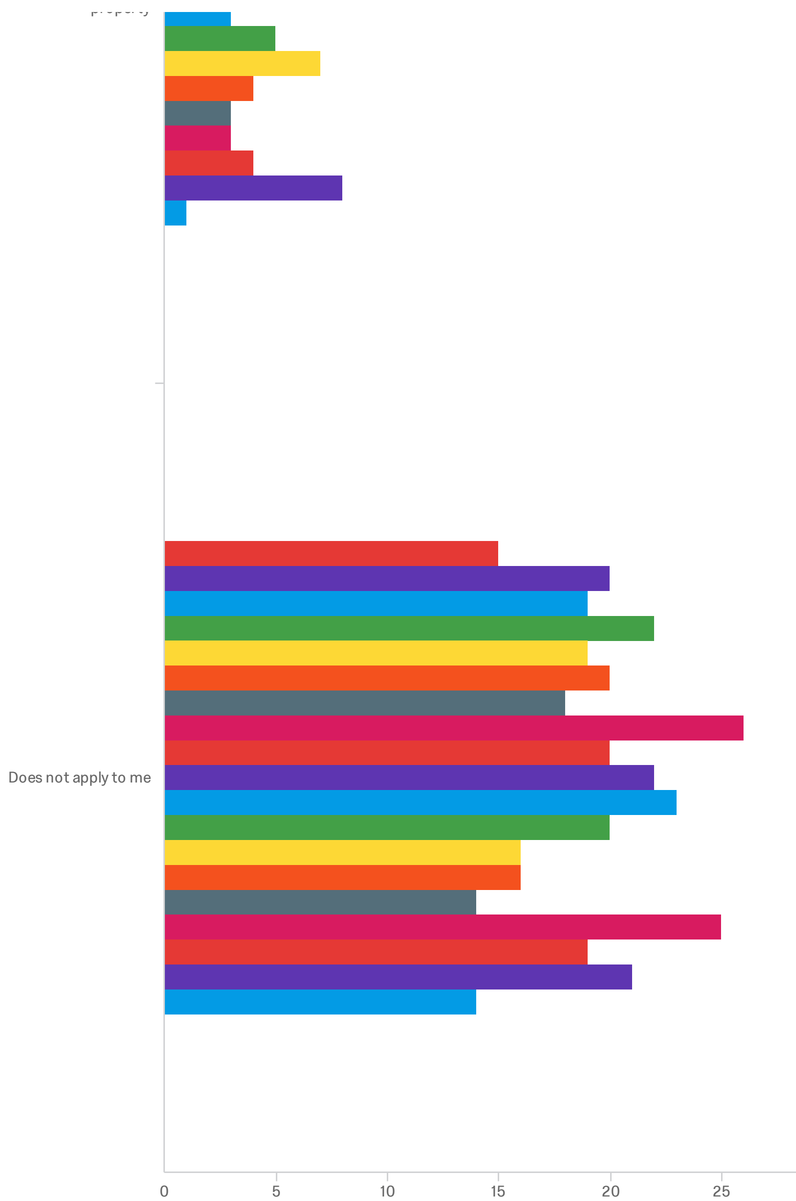
#	Field	Not concerned		A little concerned		Moderately concerned		Really concerned		I don't know		Total
9	Land uses	13.21%	7	18.87%	10	24.53%	13	32.08%	17	11.32%	6	53
10	Wildlife	16.98%	9	18.87%	10	30.19%	16	28.30%	15	5.66%	3	53
11	Boating	16.98%	9	28.30%	15	28.30%	15	16.98%	9	9.43%	5	53
12	Public use	22.64%	12	15.09%	8	32.08%	17	20.75%	11	9.43%	5	53
13	Ground water contamination	7.69%	4	15.38%	8	21.15%	11	46.15%	24	9.62%	5	52
14	Fish population	15.09%	8	24.53%	13	26.42%	14	28.30%	15	5.66%	3	53
15	Soil erosion	7.55%	4	18.87%	10	28.30%	15	35.85%	19	9.43%	5	53
16	Septic systems	3.77%	2	18.87%	10	13.21%	7	52.83%	28	11.32%	6	53
17	Land development	5.66%	3	20.75%	11	30.19%	16	35.85%	19	7.55%	4	53
18	Local residents	16.98%	9	18.87%	10	37.74%	20	20.75%	11	5.66%	3	53
19	Cloudiness of water in the lake	7.55%	4	20.75%	11	22.64%	12	33.96%	18	15.09%	8	53
20	Public awareness about Sugar Creek Lake	7.55%	4	15.09%	8	28.30%	15	39.62%	21	9.43%	5	53
21	Public education about issues impacting the watershed	5.66%	3	13.21%	7	26.42%	14	47.17%	25	7.55%	4	53
22	Other (list in box below)	12.50%	2	6.25%	1	6.25%	1	18.75%	3	56.25%	9	16

Showing rows 1 - 22 of 22

Q5 - The following actions could lead to improvements in the water quality of Sugar Creek Lake. In what ways are you willing to be involved? Check one per line.




Willing to volunteer with my club, church, or organization
Willing to make cost-free improvements to my property
Willing to pay for improvements to my property
Increasing my recycling participation
Installing vegetation filters
Limiting erosion and sediment runoff
Improving initial site drainage in the upper watershed
Adding structures to slow drainage in the middle watershed
Reducing sedimentation in the lower watershed
Improving nutrient management (lawn, garden, farm)
Conducting septic tank maintenance and repairs
Installing small ponds
Installing retention basins
Installing dry dams
Installing waterways to replace small ditches
Soil conservation practices
Reducing water use
Protecting groundwater springs
Closing unused above ground and underground storage tanks
Installing a rain garden
Installing a rain barrel to water my garden and/or lawn
Other (list in box below)



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Increasing my recycling participation	1.00	6.00	3.73	1.73	3.00	52
2	Installing vegetation filters	1.00	6.00	4.12	1.76	3.11	50
3	Limiting erosion and sediment runoff	1.00	6.00	4.18	1.69	2.85	51
4	Improving initial site drainage in the upper watershed	1.00	6.00	4.18	1.79	3.21	49
5	Adding structures to slow drainage in the middle watershed	1.00	6.00	3.94	1.82	3.31	51
6	Reducing sedimentation in the lower watershed	1.00	6.00	4.00	1.83	3.33	51
7	Improving nutrient management (lawn, garden, farm)	1.00	6.00	4.08	1.73	2.99	50
8	Conducting septic tank maintenance and repairs	1.00	6.00	4.53	1.79	3.19	51

#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
9	Installing small ponds	2.00	6.00	4.30	1.65	2.73	50
10	Installing retention basins	1.00	6.00	4.22	1.83	3.33	50
11	Installing dry dams	1.00	6.00	4.24	1.86	3.46	50
12	Installing waterways to replace small ditches	1.00	6.00	4.27	1.74	3.01	49
13	Soil conservation practices	2.00	6.00	4.12	1.63	2.65	51
14	Reducing water use	1.00	6.00	3.94	1.74	3.02	50
15	Protecting groundwater springs	2.00	6.00	3.78	1.64	2.68	51
16	Closing unused above ground and underground storage tanks	1.00	6.00	4.29	1.86	3.46	51
17	Installing a rain garden	1.00	6.00	4.23	1.79	3.20	47
18	Installing a rain barrel to water my garden and/or lawn	1.00	6.00	4.27	1.86	3.45	51
19	Other (list in box below)	1.00	6.00	4.80	1.99	3.96	20

#	Field	Not interested		Willing to help raise public awareness		Willing to volunteer with my club, church, or organization		Willing to make cost-free improvements to my property		Willing to pay for improvements to my property		Does not apply to me		Total
1	Increasing my recycling participation	7.69%	4	26.92%	14	11.54%	6	21.15%	11	3.85%	2	28.85%	15	52
2	Installing vegetation filters	8.00%	4	16.00%	8	14.00%	7	20.00%	10	2.00%	1	40.00%	20	50
3	Limiting erosion and sediment runoff	3.92%	2	21.57%	11	9.80%	5	19.61%	10	7.84%	4	37.25%	19	51
4	Improving initial site drainage in the upper watershed	2.04%	1	28.57%	14	10.20%	5	12.24%	6	2.04%	1	44.90%	22	49
5	Adding structures to slow drainage in the middle watershed	5.88%	3	29.41%	15	7.84%	4	15.69%	8	3.92%	2	37.25%	19	51
6	Reducing sedimentation in the lower watershed	5.88%	3	27.45%	14	9.80%	5	13.73%	7	3.92%	2	39.22%	20	51

#	Field	Not interested		Willing to help raise public awareness		Willing to volunteer with my club, church, or organization		Willing to make cost-free improvements to my property		Willing to pay for improvements to my property		Does not apply to me		Total
7	Improving nutrient management (lawn, garden, farm)	2.00%	1	30.00%	15	8.00%	4	14.00%	7	10.00%	5	36.00%	18	50
8	Conducting septic tank maintenance and repairs	3.92%	2	23.53%	12	1.96%	1	7.84%	4	11.76%	6	50.98%	26	51
9	Installing small ponds	0.00%	0	28.00%	14	2.00%	1	22.00%	11	8.00%	4	40.00%	20	50
10	Installing retention basins	6.00%	3	24.00%	12	6.00%	3	14.00%	7	6.00%	3	44.00%	22	50
11	Installing dry dams	6.00%	3	26.00%	13	4.00%	2	12.00%	6	6.00%	3	46.00%	23	50
12	Installing waterways to replace small ditches	2.04%	1	28.57%	14	2.04%	1	16.33%	8	10.20%	5	40.82%	20	49
13	Soil conservation practices	0.00%	0	31.37%	16	1.96%	1	21.57%	11	13.73%	7	31.37%	16	51
14	Reducing water use	4.00%	2	32.00%	16	2.00%	1	22.00%	11	8.00%	4	32.00%	16	50
15	Protecting groundwater springs	0.00%	0	37.25%	19	7.84%	4	21.57%	11	5.88%	3	27.45%	14	51
16	Closing unused above ground and underground storage tanks	3.92%	2	27.45%	14	7.84%	4	5.88%	3	5.88%	3	49.02%	25	51
17	Installing a rain garden	8.51%	4	19.15%	9	2.13%	1	21.28%	10	8.51%	4	40.43%	19	47
18	Installing a rain barrel to water my garden and/or lawn	11.76%	6	15.69%	8	3.92%	2	11.76%	6	15.69%	8	41.18%	21	51
19	Other (list in box below)	15.00%	3	10.00%	2	0.00%	0	0.00%	0	5.00%	1	70.00%	14	20

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Appendix C

USGS 2018 Bathymetric Map for Sugar Creek Lake

Prepared in cooperation with the
Missouri Department of Natural Resources and the City of Moberly, Missouri

Scientific Investigations Map 3431

Introduction

Managers of water-supply lakes need an accurate estimate of the lake capacity to ensure that enough water is available for uses such as: providing consistent recreation pool levels, preserving downstream aquatic habitat, flood abatement, water supply, and power generation. Lake capacity is particularly important for managers of water-supply lakes during periods of drought, unexpected population growth, or exceptionally high water use in the area supplied by the lake. Sedimentation, primarily from runoff into the lake, will cause a loss of storage capacity as a lake ages; as a result, the capacity table for the lake (if one exists) will overestimate the actual capacity. Lake bathymetric changes can be demonstrated through periodic surveying, and rates of sediment accumulation can be calculated so that managers can better regulate the water supply.

In cooperation with several Federal, State, and local agencies, the U.S. Geological Survey (USGS) completed bathymetric surveys of several water-supply lakes in Missouri in the early 2000s (Richards, 2013) to determine the capacity of the lakes. The USGS, in cooperation with the Missouri Department of Natural Resources, completed one such survey of Sugar Creek Lake in December 2003 using a boat-mounted survey-grade singlebeam echosounder and differentially corrected global positioning system equipment. Sugar Creek Lake (fig. 1), constructed in 1922, is about 4 miles northwest of Moberly, Missouri, in Randolph County and has a surface area of about 330 acres at the spillway elevation of 746.8 feet (ft) above North American Vertical Datum of 1988. Additional construction details of the lake and dam were provided in Wilson and Richards (2006). The lake primarily is used for recreation and drinking-water supply for the town of Moberly, Mo.

In September 2018, the USGS, in cooperation with the Missouri Department of Natural Resources and the City of Moberly, Mo., surveyed the bathymetry of Sugar Creek Lake to prepare an updated bathymetric map and a surface area and capacity table. The 2003 survey was compared with the 2018 survey to document the changes in the bathymetric surface of the lake and produce a bathymetric change map.

Methods

A bathymetric survey was done from September 4 to 6, 2018, at Sugar Creek Lake using similar methods to the previous survey completed in 2003 (Wilson and Richards, 2006; Richards, 2013). The average water-surface elevation of the lake during the 2018 survey was 745.75 ft and was 746.8 ft during the 2003 survey. A bathymetric surface, a bathymetric contour map, and a bathymetric change map were created from the survey data.

Bathymetric Data Collection

Bathymetric data (water depths and positions) were collected (fig. 2) using a high-resolution multibeam mapping system (MBMS). The various components of the MBMS used for this study are described in more detail in reports about studies on the Missouri and Mississippi Rivers in Missouri (for example, see Huizinga, 2010, 2017; Huizinga and others, 2010), and for the City of Cameron water-supply lakes (Huizinga, 2014). The survey methods used to obtain the data for Sugar Creek Lake were similar to these other studies, as were the methods used to ensure data quality. A brief description of the equipment and methods follows.

An MBMS is an integration of several individual components: the multibeam echosounder (MBES), an inertial navigation system (INS), and a data-collection and data-processing computer. The INS (Applanix OceanMaster) provides position in three-dimensional space and measures the heave, pitch, roll, and heading of the vessel (and, thereby, the MBES) to accurately position the data received by the MBES. The MBES that was used is the Norbit iWBMSh, operated at a frequency of 400 kilohertz. The iWBMSh is similar in operation to the MBES systems used in other previous studies in Missouri. The iWBMSh has a curved receiver array that enables bathymetric data to be collected throughout a swath range of 210 degrees. Optimum data usually are collected in a swath of less than 160 degrees (80 degrees on each side of nadir, or straight down below the MBES); nevertheless, the swath can be electronically rotated to either side of nadir, enabling data to be captured along sloping banks up to a depth just below the water surface.

Base from OpenStreetMap, 2019
Universal Transverse Mercator Projection, zone 15
North American Datum of 1983

Figure 1. Location of Sugar Creek Lake near Moberly, Missouri.

Real-time navigation during the survey used a differential global positioning system solution; however, the navigation information from the Sugar Creek Lake survey was post-processed using the POS-Pac Mobile Mapping Suite (MMS) software (Applanix Corporation, 2009) to mitigate the effects of the degraded positional accuracy of the vessel from the differential global positioning system solution. POS-Pac MMS provides tools to identify and compensate for sensor and environmental errors and computes an optimally blended navigation solution from the Global Navigation Satellite Systems (GNSS) and inertial-measurement unit raw data from the INS. The location solution was further enhanced by collecting static GNSS data with a GNSS base receiver set up over a temporary reference mark near the lake; the coordinates for which were determined using techniques detailed in Rydlund and Densmore (2012). The blended navigation solution (called a "smoothed best estimate of trajectory" or "SBET" file) generated by postprocessing the daily navigation data was applied to the corresponding daily survey data.

Most of the bathymetric survey data within Sugar Creek Lake (fig. 2) were collected with the swath range limited to 140 degrees, 70 degrees on each side of nadir. Along the banks and in the shallow areas at the upstream ends of the lake arms, however, the swath range was widened to 160 degrees to cover a wider swath of the bottom. In these areas the receiver array also was electronically tilted to port or starboard as needed to enhance acquisition of bathymetric data in the shallow areas near the banks, in coves, and in the upper reaches of the lake arms. The electronically tilted swath generally was about 120 degrees wide, extending from about 10 degrees above horizontal on the bankward side of the survey vessel to about 20 degrees past nadir below the vessel.

The bathymetric data were collected along transect lines oriented longitudinally in the main lake area. In the main body of the lake, the transect lines were spaced to create about 10- to 25-percent overlap of the survey swaths to attempt to ensure complete coverage of the lake bottom and minimize sonic shadows. Data along the shoreline were collected by navigating the boat parallel to the shore while overlapping the data collected in the main body of the lake. Cove data were collected by navigating into a cove along the approximate centerline of the cove as far as practical (usually, the point at which forward progress was blocked by vegetation, or water depth decreased to less than about 3 ft), pivoting the boat 180 degrees, and egressing the cove along the ingress line.

In a lake, it is not unusual for the speed of sound in the water to change over time and to vary spatially. The speed of sound also can vary over the water column because of water temperature variations with depth. Although sound velocity data are collected at the MBES head throughout the survey to mitigate these variations near the water surface, the changes in the speed of sound with depth needs to be known to accurately determine the depths acquired by the MBES. Sound velocity profiles, therefore, were measured with a sound velocity probe at various locations throughout each survey day and applied during postprocessing in the HYPACK/HYSWEEP software.

Preparation for the bathymetric survey was done in HYPACK/HYSWEEP software (HYPACK, Inc., 2015). To collect the survey data, a computer onboard the survey vessel ran HYPACK/HYSWEEP data acquisition software. After completing the survey, the acquired depth data were processed further to apply sound velocity profiles and to remove data spikes and other spurious points, often caused by fish and submerged woody debris, in the MBES swath trace. The data were georeferenced using the navigation and position solution data from the SBET file from POS-Pac MMS and visualized in HYPACK/HYSWEEP as a triangulated irregular network (TIN) surface or a point cloud. The georeferenced data were output to a comma-delimited file that was filtered and reduced to a 1.64-ft data resolution.

Bathymetric Surface and Contour Map Creation

About 4,500,000 data points, spaced 1.64-ft horizontally, were exported from the raw data collected in the 2018 survey and are available as a USGS data release (Richards and Huizinga, 2019). The vertical datum for the survey was the North American Vertical Datum of 1988 using the geoid model GEOID12b, and the horizontal datum was the North American Datum of 1983. Geographic information system (GIS) software was used to filter the 1.64-ft spaced bathymetric data points so that the points would be no closer than about 3.28 ft apart. The data reduction retained about 1,100,000 surveyed data points from the 2018 MBES survey.

Data outside the MBES survey extent (fig. 2) and greater than 745 ft in elevation were obtained from 1/9 arc-second National Elevation Dataset data that were derived from data collected in 2012 using light detection and ranging (lidar) equipment (https://viewer.nationalmap.gov/basic/). These data points were resampled to a linear distance of about 3.28 ft (576,135 points) using GIS software and define the upland areas of the lake.

Using the linear enforcement techniques described in Wilson and Richards (2006), about 1,700 points were created based on surrounding 2018 data values and were used as additional data in bathymetric surface creation. These data were added to anchor the bathymetric surface in areas of sparse data in the upper ends of coves where the water was too shallow for the MBES equipment.

Data outside the MBES survey extent, but below 745 ft in elevation in the upper ends of the main and east arms of the lake, where the water was too shallow for the MBES equipment (fig. 2), were obtained from a 3.28-ft grid of points (46,310 points) interpolated from the 2003 bathymetric surface. These data were adjusted by adding 1 ft to the 2003 elevation value to account for the approximate vertical difference observed between the 2003 and 2018 bathymetric surfaces in the nearby areas where the surfaces were coincident.

The preceding point datasets were used to produce a three-dimensional TIN surface of the lake-bottom elevations. A surface area and capacity table was produced from the three-dimensional TIN surface showing surface area and capacity at specified lake water-surface elevations (table 1). The surface was contoured at a 2-ft interval using GIS software, and the contours were cartographically smoothed and edited to create a bathymetric contour map (fig. 2) using the techniques of Wilson and Richards (2006).

Table 1. Surface area and capacity at specified water surface elevations for Sugar Creek Lake near Moberly, Missouri, September 4–6, 2018.

[Spillway elevation is about 746.8 feet (fig. 2); the average water-surface elevation during the survey was 745.75 feet]

Water surface elevation[1], in feet	Surface area, in acres	Capacity[2], in acre-feet
716.0	0.00	0.00
718.0	1.51	0.37
720.0	18.2	18.0
722.0	48.3	86.3
724.0	77.5	211
726.0	104	393
728.0	129	627
730.0	155	910
732.0	181	1,250
734.0	206	1,630
736.0	227	2,070
738.0	243	2,540
740.0	257	3,040
742.0	275	3,570
744.0	294	4,140
746.0	325	4,750
746.8	332	5,020

[1]Elevations are referenced to the North American Vertical Datum of 1988 using geoid model GEOID12b.

[2]Capacities were calculated from surface testing at 0.12-foot vertical accuracy at a 95-percent confidence level. An explanation of the vertical accuracy calculation can be found in the "Bathymetric Surface, Contour, and Bathymetric Change Quality Assurance" section of this report.

Bathymetric Change Map Creation

The bathymetric change map (fig. 3) was generated from the difference between the 2003 and 2018 bathymetric survey data points where they were coincident. The data points between the two surveys were considered coincident if a 2018 raw survey data point was within a horizontal distance of 0.16 ft from a 2003 survey data point. Of the possible 258,865 survey points collected along transects spaced about 49 ft apart in 2003 (Richards, 2013), there were 147,051 coincident locations found in the survey points collected in 2018. A bathymetric change TIN was generated using the coincident point data. The TIN was converted to a raster surface with a spacing of 3.28 ft for use in further analysis and creation of the map. The bathymetric change map was limited to the intersection of the 2003 and 2018 MBES survey extents so that only data that were surveyed by the MBES were compared. In areas of steeper slope, observed in figure 2 as areas where the contours are closely spaced, raster cells that had a 2018 slope greater than 6 degrees were removed from the bathymetric change raster because sediment deposition was assumed to be relatively minor in these areas.

Bathymetric Data Collection Quality Assurance

For the MBMS, the principal quality-assurance measures were assessed in real time during the survey. The MBMS operator continuously assessed the quality of the data collected during the survey by making observations of across-track swaths (such as convex, concave, or skewed bed returns in flat, smooth bottoms), noting data-quality flags and alarms from the MBES and the INS, and inspecting comparisons between adjacent overlapping swaths. In addition to the real-time quality-assurance assessments during the survey, beam-angle checks and a suite of patch tests were done on September 5 during the survey to ensure quality data were acquired from the MBMS. These tests were completed in the deepest part of the lake near the dam (fig. 2).

Beam-Angle Check

A beam-angle check is used to determine the accuracy of the depth readings obtained by the outer beams (greater than 25 degrees from nadir [vertical]) of the MBES (U.S. Army Corps of Engineers, 2013), which may change with time because of inaccurate sound velocities, physical configuration changes, and water depth. A beam-angle check was done on September 5, and the results were within the recommended performance standards used by the U.S. Army Corps of Engineers for hydrographic surveys for all the representative angles below 70 degrees (U.S. Army Corps of Engineers, 2013), permitting the use of the central 140 degrees of the sound navigation and ranging (sonar) swath with confidence.

Patch Tests

Patch tests are a series of dynamic calibration tests that are used to check for subtle variations in the orientation and timing of the MBES with respect to the INS and real-world coordinates. The patch tests are used to determine timing offsets caused by latency between the MBES and the INS, and angular offsets to roll, pitch, and yaw caused by the alignment of the transducer head (Huizinga, 2017). These offsets have been observed to be essentially constant for a given survey, barring an event that causes the mount to change such as striking a floating or submerged object (see Huizinga, 2017). The offsets determined in the patch test are applied when processing the data collected during a survey. Patch tests were completed on September 5, at Sugar Creek Lake, and angular offsets were updated in the data collection software as appropriate. For this study, there was no measured timing offset, which is consistent with latency test results for this boat and similar equipment configurations used in other surveys (Huizinga, 2010, 2017; Huizinga and others, 2010).

Uncertainty Estimation

Similar to the previous studies of bathymetry in Missouri (Huizinga, 2010, 2017), uncertainty in the survey was estimated by computing the total propagated uncertainty (TPU) for each 1.64-ft survey-grid cell in the surveyed area using the Combined Uncertainty and Bathymetric Estimator (CUBE) method (Calder and Mayer, 2003). The CUBE method allows all random system component uncertainties and resolution effects to be combined and propagated through the data processing steps, which provides a robust estimate of the spatial distribution of possible uncertainty within the survey area (Czuba and others, 2011). Thus, the TPU of a point is a measure of the accuracy to be expected for such a point when all relevant error sources are considered (Czuba and others, 2011).

Most of the TPU values (more than 95 percent) were less than 0.20 ft, which is within the specifications for a "Special Order" survey, the most-stringent survey standard of the International Hydrographic Organization (International Hydrographic Organization, 2008). The median TPU value of the data was about 0.07 ft. The largest TPU in this survey was about 15.9 ft; however, TPU values of this magnitude typically are near high-relief features, such as near vertical surfaces such as bridge abutments or submerged cliffs that may exist on some parts of the lake (fig. 2). The TPU values were larger near moderate-relief features (steep banks and submerged channels and ridges; fig. 2). The TPU values also were sometimes larger in the outermost beam extents of the MBES swath in the overlap with an adjacent swath, particularly when the swath was tilted for the survey lines along the banks or widened in the upper extent of the lake (fig. 4).

Bathymetric Surface, Contour, and Bathymetric Change Quality Assurance

Accuracy of the bathymetric surface and contours is a function of the survey data accuracy, density of the survey data, and the processing steps involved in the surface and contour creation. The process of data reduction done to obtain the 1.64-ft gridded dataset from the raw survey data likely degraded the accuracy of the 1.64-ft gridded dataset relative to the raw data. Four areas of the lake were surveyed twice (fig. 2) to collect a dataset that could be used to estimate the accuracy of the 1.64-ft gridded dataset used to produce the bathymetric surface. The four areas had a combined total of about 8,680,000 raw survey points (Richards and Huizinga, 2019). Raw points that were within a horizontal distance of 0.16 ft of a 1.64-ft gridded point were selected as quality-assurance data points, and the elevation values of these points were compared to the 1.64-ft gridded points. The 59,903 selected raw points were compared to 1.64-ft gridded points, and the data tested at a vertical accuracy of 0.25 ft at a 95-percent confidence level; the median absolute vertical error was about 0.09 ft.

The quality-assurance dataset used to evaluate the bathymetric surface included about 179,580 data points selected at random from the about 4,500,000, 1.64-ft data points. Points that were used to create the bathymetric surface were not included as quality-assurance points. The three-dimensional bathymetric surface was tested against the quality-assurance dataset to determine the vertical accuracy of the surface using methods described in Wilson and Richards (2006). The surface tested at a vertical accuracy of 0.12 ft at the 95-percent confidence level; the median absolute vertical error was about 0.02 ft. A map of the vertical accuracy of the bathymetric surface is shown in figure 5. The three-dimensional bathymetric surface was used as the source for the computation of the surface area and capacity values in table 1, the source for the development of the bathymetric contour map (fig. 2), and the source for the bathymetric change map (fig. 3).

The process of smoothing and cartographic editing of the bathymetric contours to produce an aesthetic map degrades the positional and vertical accuracy of the contours; however, the contours are used primarily for visualization of the surface in an illustration, so some accuracy degradation is expected. The bathymetric contours (fig. 2) were tested with the same quality-assurance dataset used to evaluate the bathymetric surface. A point was considered a contour elevation evaluation point if it was within a horizontal distance of 0.33 ft of a given contour line. Of the about 179,580 quality-assurance points, 2,693 points were selected as evaluation points for the contour lines, and the contour vertical accuracy was computed to be 0.35 ft at the 95-percent confidence level; the median absolute vertical error was about 0.03 ft.

Quality assurance data (21,647 points) that were used to evaluate the bathymetric surface accuracy of the 2003 survey (Wilson and Richards, 2006) were used to estimate the accuracy of the bathymetric change raster. The differences between the elevations of the 2003 quality-assurance data points and the 2018 raw bathymetric points at coincident locations, as defined in the "Bathymetric Change Map Creation" section, were compared at 10,041 locations (fig. 3). The bathymetric change raster tested at 0.55-ft accuracy at the 95-percent confidence level; the median absolute error was 0.16 ft.

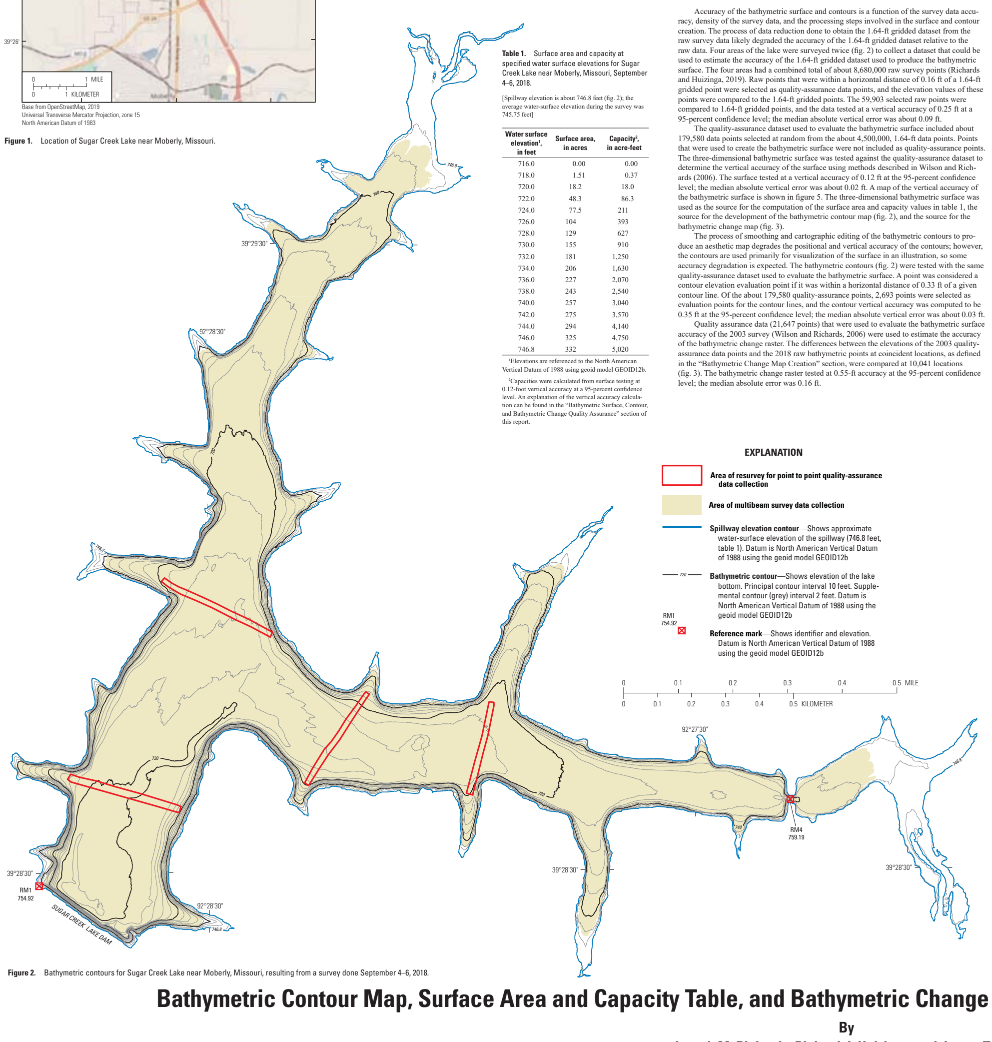

Figure 2. Bathymetric contours for Sugar Creek Lake near Moberly, Missouri, resulting from a survey done September 4–6, 2018.

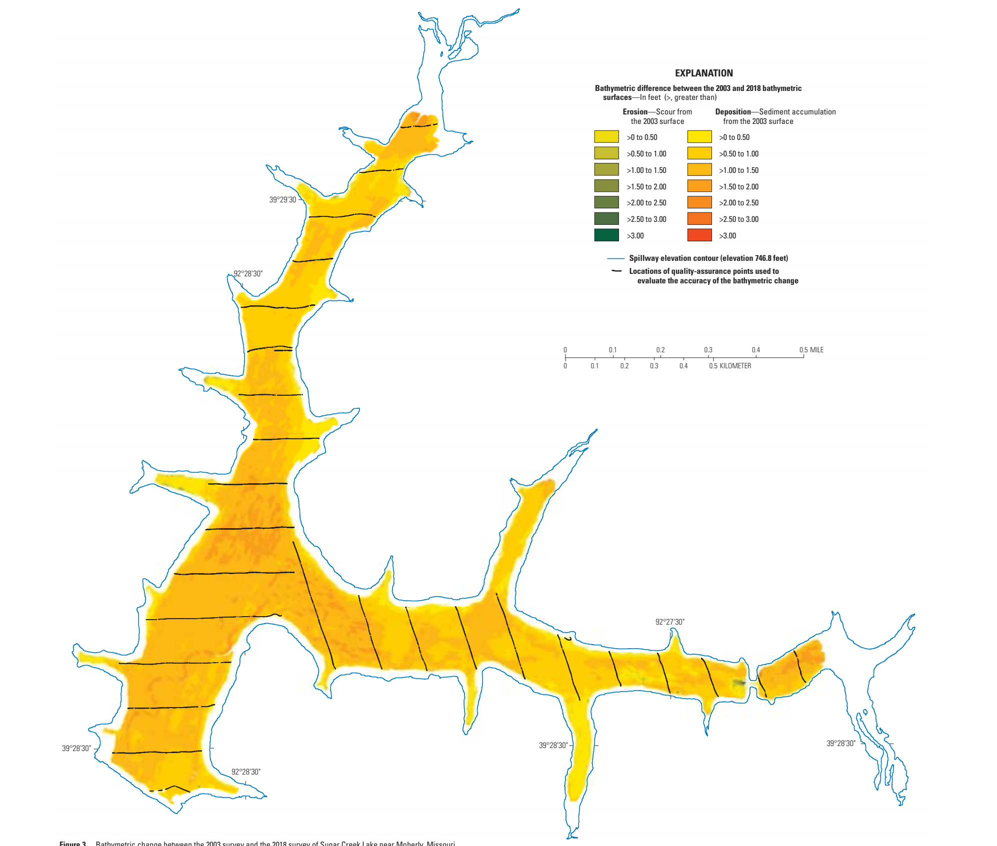

Figure 3. Bathymetric change between the 2003 survey and the 2018 survey of Sugar Creek Lake near Moberly, Missouri.

Bathymetry, Capacity, and Bathymetric Change

A bathymetric surface was created from the current (2018) surveyed data and used to produce a bathymetric contour map (fig. 2). The 2018 bathymetric map is similar to the map produced from the 2003 survey (Wilson and Richards, 2006; appendix of Richards, 2013) in that evidence of the submerged river channel is still present in some areas (fig. 2), but a clearly defined channel is not observed in most of the lake. There is evidence of the river channel, although somewhat muted, all the way to Sugar Creek Lake Dam (fig. 2).

A surface area and capacity table (table 1) was computed from the bathymetric surface TIN. At the spillway elevation of 746.8 ft, the surface area of the lake is 332 acres, and the capacity is 5,020 acre-feet (table 1). The surface area and capacity table is similar to the table prepared for the previous 2003 survey (Wilson and Richards, 2006; appendix of Richards, 2013); however, the capacity is less in the 2018 table compared to the 2003 table for the 50-ft transect interval at each corresponding elevation. At the spillway elevation of 746.8 ft, the capacity of the lake in 2018 is 230 acre-feet less than the capacity of the lake in 2003, which represents a capacity loss of about 4.4-percent during a period of about 14.7 years. The average capacity loss per year is about 15.6 acre-feet for the period between the 2003 and 2018 surveys.

The bathymetric change map indicates some erosional and depositional areas. Erosion seems to have occurred downstream from the bridge opening on the east arm of the lake, presumably where the water velocity, and the sediment carrying capacity, increased as water flowed through the bridge. Deposition seems to be relatively uniform across the lake area. The mean bathymetric change computed from the bathymetric change raster is about 0.96 ft, and the surface area of the bathymetric change raster is about 241 acres. Multiplying these values gives a total volume of sediment of 231 acre-feet, which is consistent with the change in the lake capacity between the 2003 survey and the 2018 survey.

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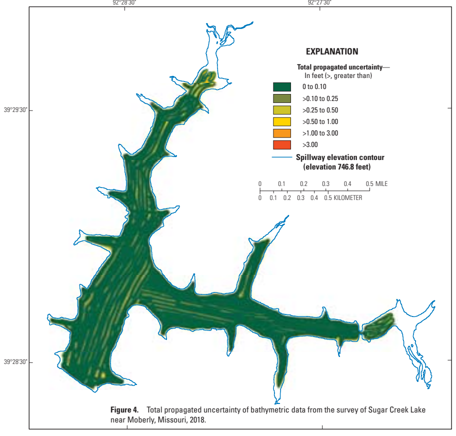

Figure 4. Total propagated uncertainty of bathymetric data from the survey of Sugar Creek Lake near Moberly, Missouri, 2018.

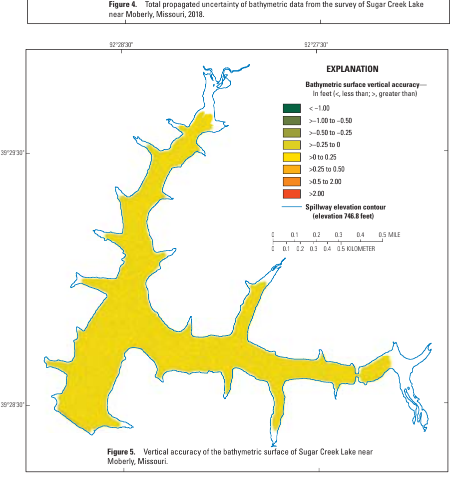

Figure 5. Vertical accuracy of the bathymetric surface of Sugar Creek Lake near Moberly, Missouri.

Bathymetric Contour Map, Surface Area and Capacity Table, and Bathymetric Change Map for Sugar Creek Lake near Moberly, Missouri, 2018

By
Joseph M. Richards, Richard J. Huizinga, and Jarrett T. Ellis
2019

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For more information about this publication, contact
Director, USGS Central Midwest Water Science Center
1400 Independence Road
Rolla, MO 65401
(573) 308–3667
For additional information visit https://www.usgs.gov/centers/cm-water

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Appendix D

USLE and SPI Equations

$$\boldsymbol{A} = \boldsymbol{R} \times \boldsymbol{K} \times \boldsymbol{LS} \times \boldsymbol{C}$$ **Equation 1**

where:

A = annual soil loss (tons/acres)

R = rainfall erosivity factor (unitless)

K = soil erodability factor (unitless)

LS = length and steepness of slope factor (unitless)

C = vegetation or crop factor (unitless)

$$\boldsymbol{SPI} = \boldsymbol{ln}(\boldsymbol{DA} \times \tan \boldsymbol{G})$$ **Equation 2**

where:

SPI = stream power index (unitless)

Q_o = upstream drainage area (flow accumulation at grid cell multiplied by grid cell area (unitless)

G = slope at the grid cell (radians)

Appendix E

MDNR Nutrient Criteria Implementation Plan

Nutrient Criteria Implementation Plan

July 27, 2018

Table of Contents

Purpose

Section 304(a) of the federal Clean Water Act provides the framework for states to develop Water Quality Standards (WQS) that protect the physical, chemical, and biological integrity of their waters. The Missouri Department of Natural Resources (Department) is fully delegated by the US Environmental Protection Agency (EPA) to conduct WQS revisions pursuant to the federal Clean Water Act. Changes to Missouri's WQS [10 Code of State Regulations (CSR) 20-7.031] were published on March 31, 2018. One major revision to the WQS is the incorporation of numeric nutrient criteria for lakes.

This plan describes how the Department intends to implement nutrient criteria in accordance with the newly revised WQS. This plan does not prohibit establishing alternative methods of analysis, permit limits, or requirements provided that the alternatives are technically sound, consistent with state and federal regulations, and are protective of water quality. All permitting will be consistent with federal and state requirements.

Background

Eutrophication is the process by which a body of water becomes enriched in nutrients, such as nitrogen and phosphorus, which stimulate the excessive growth of algae and other plants. Eutrophication may be accelerated by human activities. It is well documented that enrichment of nutrients can lead to increased production of algae and aquatic plants in freshwater systems. This increased production may result in nonattainment of beneficial uses under certain environmental conditions. Aquatic life protection uses can be negatively impacted by excess nutrient loading, which may increase the likelihood of fish kills caused by the depletion of dissolved oxygen. Aquatic diversity can be undermined by creating conditions favorable to fast-growing species, such as carp and other benthivores, at the expense of other species (Edgertson and Downing, 2004).

The Department utilizes regulatory and incentive-based approaches to ensure excessive nutrients do not impair or degrade beneficial uses. Regulatory approaches such as nutrient effluent limitations and nutrient WQS are implemented by the Department's Water Protection Program. Incentive-based approaches to nutrient reduction through education, outreach, and the execution of best management practices are implemented by the Department's Soil and Water Conservation Program using federal and state funds.

Missouri's Nutrient Criteria

Missouri Lakes and Reservoirs

For the purposes of Missouri's nutrient criteria and this document, all lakes and reservoirs are referred to as "lakes." [10 CSR 20-7.031(5)(N)1.A.]. Missouri's lakes are more appropriately classified as impoundments and have very different physical, chemical, and biological characteristics when compared to naturally-formed glacial or mountainous lakes found in other states. Many of Missouri's major lakes were constructed primarily for flood control, hydroelectric power, and water supply. The riverine habitats and species that existed before impoundment over time transitioned into the current state of aquatic life dominated by self-sustaining populations of sport and non-sport fishes. The numeric nutrient criteria and implementation methods proposed by the Department are structured to ensure the deleterious impacts of nutrient enrichment to Missouri's lakes are mitigated without adverse impacts to the health and vitality of the self-sustaining populations of aquatic life that live there.

Missouri's nutrient criteria apply to all lakes that are waters of the state and have an area of at least ten (10) acres during normal pool condition, except the natural lakes (oxbows) in the Big River Floodplain ecoregion [10 CSR 20-7.031(5)(N)2.]. The criteria apply to, and assessments will be conducted for, the entire water body as found in Missouri's WQS regulation. As noted in the *Rationale for Missouri Lake Nutrient Criteria* (DNR, 2017), the Department has structured Missouri's nutrient criteria as a decision framework that applies at an ecoregional basis. This decision framework integrates causal and response parameters into one water quality standard that accounts for uncertainty in linkages between causal and response parameters. The decision framework includes response impairment thresholds, nutrient screening thresholds, and response assessment endpoints. This framework appropriately integrates causal and response parameters and is based on the bioconfirmation guiding principles that EPA (2013) has suggested as an approach for developing nutrient criteria.

Numeric Criteria for Lakes [10 CSR 20-7.031(5)(N)]

Missouri's WQS contain numeric response impairment threshold values for chlorophyll-a (Chl-a) and screening threshold values for total nitrogen (TN), total phosphorus (TP), and Chl-a, all of which vary by the dominant watershed ecoregion. Lakes are determined to be impaired if the geometric mean of samples taken between May and September in a calendar year exceeds the Chl-a response impairment threshold value more than once in three years' time. A duration of three or more years is necessary to account for natural variations in nutrient levels due to climatic variability (Jones and Knowlton, 2005). If a lake exceeds a screening threshold value, it will be designated as impaired if any of five response assessment endpoints are also identified in the same calendar year.

Lake Ecoregion	Chl-a Response Impairment Thresholds (µg/L)	Nutrient Screening Thresholds (µg/L)		
		TP	TN	Chl-a
Plains	30	49	843	18
Ozark Boarder	22	40	733	13
Ozark Highland	15	16	401	6

The five response assessment endpoints are:

- Occurrence of eutrophication-related mortality or morbidity events for fish and other aquatic organisms
- Epilimnetic excursions from dissolved oxygen or pH criteria
- Cyanobacteria counts in excess of 100,000 cells/mL
- Observed shifts in aquatic diversity attributed to eutrophication
- Excessive levels of mineral turbidity that consistently limit algal productivity during the period of May 1 – September 30

All scientific references used for numeric nutrient criteria derivation are contained in the *Rationale for Missouri Lake Nutrient Criteria* (DNR, 2017) and supplemental materials maintained by the Department. The Department will maintain a copy of these references and make them available to the public for inspection and copying at no more than the actual cost of reproduction.

Narrative Criteria [10 CSR 20-7.031(4)]

Missouri's WQS contain general (narrative) water quality criteria that are used to protect waters from nutrient enrichment caused by excessive nitrogen and/or phosphorous loading. Missouri's general criteria protect waters from "unsightly or harmful bottom deposits" and "unsightly color or turbidity," which is a potential consequence of excess nutrients in freshwater systems. Narrative criteria do not provide numeric thresholds or concentrations above which impacts to designated uses are likely to occur. However, because the bioconfirmation approach integrates causal and response variables to ensure attainment of the aquatic habitat protection use, the proposed numeric nutrient criteria and screening thresholds serve as an enforceable interpretation of Missouri's general criteria at 10 CSR 20-7.031(4). Additionally, implementation of the numeric nutrient criteria and screening thresholds also will ensure protection of downstream waters as required by 10 CSR 20-7.031(4)(E) and 40 CFR 131.10(b).

Site-Specific Numeric Criteria [10 CSR 20-7.031(5)(N)]

Missouri's WQS also contain numeric nutrient criteria for specific lakes. Each of the lakes listed in Table N of the WQS have site-specific criteria for TN, TP, and Chl-a, based on the annual geometric mean of a minimum of three years of data and characteristics of the lake. Additional site-specific criteria may be developed to account for the unique characteristics of a water body.

Part I. Monitoring and Assessment

Monitoring Efforts

The Department currently has data on approximately 12% of Missouri lakes, representing 83% of lake acres. Based on past resources and progress, the Department expects to have data on most lakes that are subject to the WQS within ten years. The Department will prioritize data collection on lakes without sufficient data by identifying relevant bodies of water that, because of location or activity, are most likely to have an impairment or are most vulnerable to the impacts of nutrients. Missouri has identified this gap (GAP 5.2) in our Monitoring Strategy Document found at https://dnr.mo.gov/env/wpp/waterquality/303d/docs/2015-monitoring-strategy-final.pdf. The Department coordinates with EPA to update the Monitoring Strategy Document every five years.

The Department has a cooperative agreement with the University of Missouri (MU) to collect data on lakes statewide. This cooperative agreement utilizes Section 319 funds, as well as match funds from MU, to collect data sufficient to characterize and assess lake water quality in accordance with Sections 303(d) and 305(b) of the federal Clean Water Act. MU operates two programs that are funded through the cooperative agreement: 1) the Statewide Lake Assessment Program, and 2) the Lakes of Missouri Volunteer Program. MU has been collecting and analyzing data on lakes throughout the state since 1989.

As part of the cooperative agreement, these programs submit, and the Department approves, Quality Assurance Project Plans (QAPPs) that detail the following:

- Parameters – data to be collected
- Sampling Methods – how the data are collected
- Personnel – who collects the data
- Analytical Methods – how the data are analyzed
- Laboratory – who analyzes the data
- Quality Assurance Review – who quality assures the data
- Reporting – to whom the data are reported

Lakes of Missouri Volunteer Program (LMVP)

The LMVP works to identify volunteers to assist MU in collecting information on lakes across Missouri. Volunteers are trained by MU staff and follow the approved protocols in the QAPP. The samples collected are analyzed by the MU laboratory. Volunteer data are checked through MU audits to ensure their data are of the same quality as data collected by MU staff. These data typically are collected 4-8 times per year from April through September.

The samples collected by LMVP volunteers are analyzed for:

- Total Nitrogen
- Total Phosphorus
- Total Chlorophyll
- Chlorophyll-a
- Pheophytin-a
- Inorganic Suspended Solids
- Organic Suspended Solids
- Total Suspended Solids
- Microcystin
- Cylindrospermopsin

*Water temperature and Secchi depth also are recorded with each sample.

Statewide Lake Assessment Program (SLAP)
The SLAP is composed of MU staff who collect water samples, as well as depth profiles, on lakes across the state.

The samples collected by SLAP staff are analyzed for:

- Total Nitrogen
- Total Phosphorus
- Total Chlorophyll
- Chlorophyll-a
- Pheophytin-a
- Inorganic Suspended Solids
- Organic Suspended Solids
- Total Suspended Solids
- Microcystin*
- Cylindrospermopsin*
- Anatoxin-a*
- Saxitoxin*

*Algal toxins started in summer of 2018.

The depth profiles consist of a composite sample of the epilimnion and include continuous sonde measurements for:

- Depth
- Temperature
- Dissolved Oxygen % Saturation
- Dissolved Oxygen Concentration
- Conductivity
- pH
- Turbidity
- Phycocyanins
- Chlorophyll
- Oxidizing/Reducing Potential

In addition to these parameters, in 2018 MU will begin collecting light-availability data through the use of a Li-Cor quantum sensor. Data collected with this equipment consist of light attenuation and photosynthetically active radiation (PAR).

The SLAP collects long-term data on 38 lakes throughout the state to assess water quality and to conduct long-term trend analysis. The SLAP also collects data on approximately 40 lakes which can be rotated every 3-4 years. Starting in 2019, the Department will work with the SLAP to expand monitoring or add priority lakes for additional data collection needs. See Assessment Methodology Section for identification of priorities during assessment.

Data Requirements for Assessment

In order to assess a lake against the lake numeric nutrient criteria in 10 CSR 20-7.031(5)(N), the following data requirements must be met:

1. At least four samples collected between May 1 and September 30 under representative conditions;
2. Each sample must have been analyzed for at least Chl-a, TN, TP, and Secchi depth;
3. At least three years of samples (years do not have to be consecutive). Data older than seven years will not be considered, consistent with the Department's Listing Methodology (see Appendix B);
4. Data collected under a Quality Assurance Project Plan (QAPP).

If these requirements are not met, the lake will be placed into Category 3 of Missouri's Integrated Water Quality Report (i.e., Missouri's 305(b) Report) until further information can be collected. In the case of lakes that have some data, but not enough to make an assessment, these lakes will be prioritized for additional sampling. Lakes with limited data where water quality trends or field observations point to possible impairment will receive the highest priority.

Criteria for Assessment

Each lake will be evaluated against the appropriate ecoregional or site-specific criteria located in Tables L, M, and N of 10 CSR 20-7.031 (reproduced below).

Table L: Lake Ecoregion Chl-a Response Impairment Threshold Values (µg/L)

Lake Ecoregion	Chl-a Response Impairment Thresholds
Plains	30
Ozark Border	22
Ozark Highland	15

Table M: Lake Ecoregion Nutrient Screening Threshold Values (µg/L)

Lake Ecoregion	Nutrient Screening Thresholds		
	TP	TN	Chl-a
Plains	49	843	18
Ozark Border	40	733	13
Ozark Highland	16	401	6

Table N: Site-Specific Nutrient Criteria

Lake Ecoregion	Lake	County	Site-Specific Criteria (µg/L)		
			TP	TN	Chl-a
Plains	Bowling Green Lake	Pike	21	502	6.5
	Bowling Green Lake (old)	Pike	31	506	5
	Forest Lake	Adair	21	412	4.3
	Fox Valley Lake	Clark	17	581	6.3
	Hazel Creek Lake	Adair	27	616	6.9
	Lincoln Lake – Cuivre River State Park	Lincoln	16	413	4.3
	Marie, Lake	Mercer	14	444	3.6
	Nehai Tonkaia Lake	Chariton	15	418	2.7
	Viking, Lake	Daviess	25	509	7.8
	Waukomis Lake	Platte	25	553	11
	Weatherby Lake	Platte	16	363	5.1
Ozark Border	Goose Creek Lake	St Francois	12	383	3.2
	Wauwanoka, Lake	Jefferson	12	384	6.1
Ozark Highland	Clearwater Lake	Wayne-Reynolds	13	220	2.6
	Council Bluff Lake	Iron	7	229	2.1
	Crane Lake	Iron	9	240	2.6
	Fourche Lake	Ripley	9	236	2.1
	Loggers Lake	Shannon	9	200	2.6
	Lower Taum Sauk Lake	Reynolds	9	203	2.6
	Noblett Lake	Douglas	9	211	2
	St. Joe State Park Lakes	St Francois	9	253	2
	Sunnen Lake	Washington	9	274	2.6
	Table Rock Lake	Stone	9	253	2.6
	Terre du Lac Lakes	St Francois	9	284	1.7
	Timberline Lakes	St Francois	8	276	1.5

Assessment Methodology

The Department requests and actively seeks out readily available data on all waters within the state. These data are reviewed for proper quality assurance and quality control measures, and then the data are compiled by the Department into Missouri's Water Quality Assessment database.

Every two years, the Department assesses the designated uses of all waters protected under 10 CSR 20-7.031. Once assessments have been completed, the Department creates spreadsheets of data for all impaired (303(d) List) and delisted waters. The Department then places the spreadsheets, as well as the list of impaired waters, on the Department's website for a 90-day public notice period. After the public notice period ends, the Department responds to any public comments and makes any applicable changes to the spreadsheets or the list of impaired waters. The Department then asks the Missouri Clean Water Commission for approval of the impaired waters list. After the Commission's approval, the Department submits all of the information used in the assessment decision process to the EPA for approval.

1. <u>Site-Specific Lake Nutrient Criteria</u>
   Lakes with site-specific numeric nutrient criteria (see Table N of 10 CSR 20-7.031) will be assessed using the current listing methodology. Missouri has a state regulation 10 CSR 20-7.050 which requires a methodology be created and followed for the development of an impaired waters list. Missouri develops and provides public notice of the methodology every two years concurrently with the 303(d) list. The methodology is approved by the Missouri Clean Water Commission before the Department can use it for assessments. The Department currently assesses against the existing site specific lake nutrient criteria in the water quality standards (now Table N of 10 CSR 20-7.031). See the Department's 2020 Listing Methodology in Appendix B for details. Table 1 below shows the current list of impaired lakes assessed according to the site specific criteria.

Table 1. List of Impaired Lakes with Site Specific Criteria

Year	WBID	Waterbody	WB Size	Units	IU	Pollutant
2014	7003	Bowling Green Lake - Old	7	Acres	AQL	Chl-a
2012	7003	Bowling Green Lake - Old	7	Acres	AQL	TN
2012	7003	Bowling Green Lake - Old	7	Acres	AQL	TP
2014	7326	Clearwater Lake	1635	Acres	AQL	Chl-a
2016	7326	Clearwater Lake	1635	Acres	AQL	TP
2016	7334	Crane Lake	109	Acres	AQL	Chl-a
2016	7334	Crane Lake	109	Acres	AQL	TP
2010	7151	Forest Lake	580	Acres	AQL	Chl-a
2010	7151	Forest Lake	580	Acres	AQL	TN
2010	7151	Forest Lake	580	Acres	AQL	TP
2018	7324	Fourche Lake	49	Acres	AQL	Chl-a
2018	7324	Fourche Lake	49	Acres	AQL	TN
2014	7008	Fox Valley Lake	89	Acres	AQL	Chl-a
2014	7008	Fox Valley Lake	89	Acres	AQL	TN
2010	7008	Fox Valley Lake	89	Acres	AQL	TP
2010	7152	Hazel Creek Lake	453	Acres	AQL	Chl-a
2018	7152	Hazel Creek Lake	453	Acres	AQL	TN
2018	7049	Lake Lincoln	88	Acres	AQL	Chl-a
2018	7301	Monsanto Lake	18	Acres	AQL	Chl-a
2016	7301	Monsanto Lake	18	Acres	AQL	TN
2018	7301	Monsanto Lake	18	Acres	AQL	TP
2014	7316	Noblett Lake	26	Acres	AQL	Chl-a
2014	7316	Noblett Lake	26	Acres	AQL	TP
2002	7313	Table Rock Lake	41747	Acres	AQL	Chl-a
2002	7313	Table Rock Lake	41747	Acres	AQL	TN
2012	7071	Weatherby Lake	185	Acres	AQL	Chl-a
2010	7071	Weatherby Lake	185	Acres	AQL	TN
2014	7071	Weatherby Lake	185	Acres	AQL	TP

2. Ecoregional Lake Nutrient Criteria
Lakes with ecoregional nutrient criteria (see Tables L and M of 10 CSR 20-7.031) will be assessed using the following methodology:

 a. For lakes with ecoregional criteria, a yearly geometric mean for Chl-a, TN, and TP will be calculated for the period of record. The latest three years (years do not have to be consecutive) of data will be used for assessment. These data are collected by the SLAP and the LMVP under a cooperative agreement with the Missouri Department of Natural Resources.

 b. If the geometric mean of Chl-a exceeds the response impairment threshold in more than one of the latest three years of available data, the lake will be placed into Category 5 of Missouri's IR and go on the 303(d) List for Chl-a. If only two years of data are available and the geometric mean of Chl-a exceeds the response impairment threshold in both years, the lake will be placed into Category 5 of Missouri’s IR and go on the 303(d) List for Chl-a.

c. If the geometric mean of Chl-a, TN, or TP exceeds the nutrient screening threshold, then additional response assessment endpoints will be evaluated (see Assessment Methodology Section #3 “Additional Lake Response Assessment Endpoints” below). If data for any of the response assessment endpoints indicates impairment in the same year that Chl-a, TN, or TP exceeds the nutrient screening threshold, the lake will be placed into Category 5 of Missouri’s IR. If sufficient data are not available to assess the response assessment endpoints or they do not show impairment, then the water will be placed into Category 3B or 2B, respectively (assuming other uses are attaining) and prioritized for additional monitoring and ongoing evaluation of response assessment endpoints (see Monitoring Efforts Section). If a lake that is sampled in the LMVP is placed in Category 3b or 2B, then it may be moved to the SLAP to ensure all nutrient screening threshold data needed to complete a full assessment are available. The Department is committed to providing the data needed to complete the full assessment.

d. If the geometric mean of Chl-a, TN, or TP does not exceed the nutrient screening threshold, the water will be placed into the appropriate IR category based on the attainment of the other uses.

e. The period of record for the lake will be reviewed for the purpose of determining long-term trends in water quality. If a lake is determined to be trending towards potential impairment, the lake will be further scrutinized and prioritized for additional monitoring (see Monitoring Efforts and Trend Analysis Sections).

f. The Department’s Listing Methodology Document will be updated to reflect the methodology outlined in this implementation plan as soon as possible after approval of the ecoregional lake nutrient criteria.

3. <u>Additional Lake Response Assessment Endpoints</u>

For lakes where the geometric mean of Chl-a, TN, or TP exceeds the ecoregional nutrient screening thresholds, the additional response assessment endpoints listed below will be evaluated. Each of these endpoints is linked to the protection of the aquatic habitat designated use and will be used to assess compliance with the numeric nutrient criteria when screening values are exceeded. When one of these endpoints indicate a eutrophication impact in the same year as a nutrient screening threshold exceedance, the lake will be placed into category 5 and on the 303(d) list.

Response assessment endpoints observed in lakes without sufficient data for Chl-a, TP, or TN will be prioritized highest for additional sampling of Chl-a, TP, and TN.

a. 10 CSR 20-7.031(5)(N)6.A. – Occurrence of eutrophication-related mortality or morbidity events for fish and other aquatic organisms (i.e., fish kills)

- Following the Department's Listing Methodology Document (see Appendix B), two or more fish kills within the last three years of available data will result in the water being placed into category 5 as well as the 303(d) list.

- Fish kills as a result of nutrient enrichment (eutrophication) in a lake indicate that current water quality may not be protective of the aquatic habitat designated use. The Missouri Department of Natural Resources maintains contact with the Missouri Department of Conservation (MDC) on fish kills that occur throughout the state. The MDC, as well as the Department's Environmental Emergency Response and Water Protection Program, receive notifications of observed fish kills. The MDC investigates all reported fish kills and provides a summary report of the species, size, and number of fish and other aquatic organisms killed. These reports are provided shortly after the investigation. Annual fish kill reports are compiled and provided to the Department.

  One such example of a fish kill annual report is MDC's Missouri Pollution and Fish Kill Investigations 2017 (published April 2018). The Missouri Department of Natural Resources will continue to request these data and annual reports from MDC. This document includes fish kill data and causes as well as describes the methods used by MDC to assess fish kills.

- The Department will review reports for information pertaining to the cause of death as well as the potential sources. Fish populations can have seemingly random small die offs related to disease, virus, or other natural causes. The Department will focus on die-offs related to dissolved oxygen, temperature, pH, algal blooms, and the toxins associated with algal blooms. More than one fish kill within ten years or one large (>100 fish and covering more than ten percent of the lake area) fish kill documented to be caused by dissolved oxygen excursions, pH, algal blooms, or the toxins associated with algal blooms will constitute evidence of impairment.

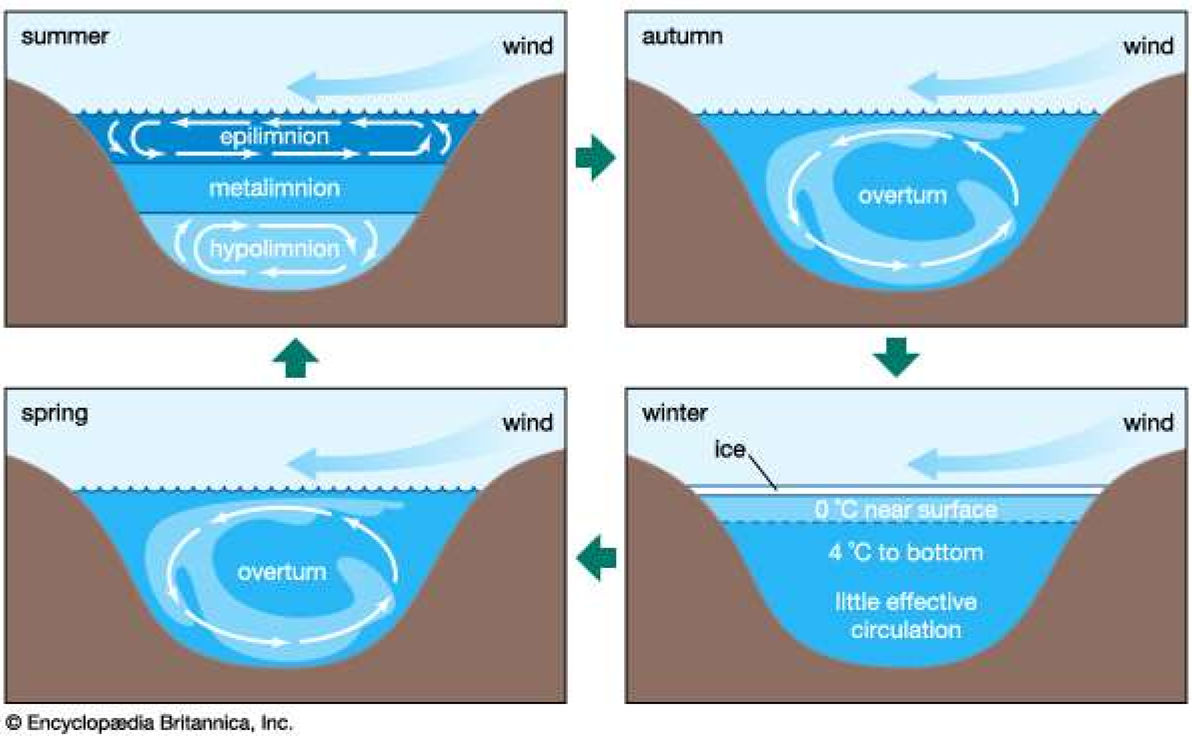
b. 10 CSR 20-7.031(5)(N)6.B. – Epilimnetic excursions from dissolved oxygen or pH criteria

In lakes, DO is produced by atmospheric reaeration and the photosynthetic activity of aquatic plants and consumed through respiration. DO production by aquatic plants (primarily phytoplankton in Missouri reservoirs) is limited to the euphotic zone where sufficient light exists to support photosynthesis. In some lakes, reaeration and photosynthesis may be sufficient to support high DO levels throughout the water column during periods of complete mixing. However, Missouri lakes do not stay completely mixed and thermally stratify during the summer (Figure 1). The duration, depth, and areal extent of stratification in any lake is a function of site-specific lake variables and environmental factors. During the stratified period, the epilimnion (surface water layer) receives oxygen from the atmosphere and is dominated by primary production from phytoplankton and other aquatic plants. In contrast, the hypolimnion (deep, cool water zone) is largely separated from the epilimnion (surface layer) and is dominated by respiratory processes that use organic matter derived from autochothonous (in-lake) and allochthonous (watershed) sources. The strong temperature gradient between the epilimnion and hypolimnion generally restrict gas and nutrient circulation and limits the movement of phytoplankton between the layers. As a result, respiration in the hypolimnion creates hypoxic conditions during the stratification period.

Data collected by the MU demonstrates that hypoxic hypolimnetic conditions (absent of DO) consistently occur during the summer in Missouri lakes regardless of trophic condition. Further, anoxic hypolimnetic conditions have even been measured in Missouri's high quality oligotrophic lakes. It is apparent from the science and available data that low hypolimnetic DO conditions are the result of natural processes and should be expected in all lakes across the state. Thermal stratification and resulting anoxic hypolimnia limits the area where some more sensitive fish species thrive to the epilimnion. Assessment of dissolved oxygen in the epilimnion of lakes will ensure the protection of aquatic life and aquatic habitat designated use and the maintenance of a robust aquatic community. Therefore, it would be inappropriate to apply the 5.0 milligrams per liter DO criterion throughout the entire water column.

DO and pH criterion will apply only to the epilimnion during thermal stratification. DO and pH criteria will apply throughout the water column outside of thermal stratification.

Figure 1. Diagram of Typical Lake Stratification in Missouri



Excess nutrient input into lakes causes an increase in primary productivity of a lake. This increase in productivity comes with an increasing demand for dissolved oxygen through both the living and the decaying portions of aquatic life. Increased productivity also causes algal populations to have exponential growth and decay rates that can cause swings in dissolved oxygen concentrations. Sudden drops in dissolved oxygen concentrations or low levels of dissolved oxygen concentrations can cause fish kills.

Similar to DO, water column pH levels are linked to photosynthesis and impacted by thermal stratification. During periods of high photosynthesis, carbon dioxide (CO_2) is removed from the water column and pH increases. Conversely, when respiration and decomposition is high, CO_2 levels increase and pH decreases. As described above, the natural temperature gradients during the summer growing season create conditions whereby the epilimnion is dominated by primary production and the hypolimnion is dominated by respiration. Therefore, the pH levels will typically be higher in the epilimnion and lower in the hypolimnion. Because the nutrient criteria are focused on the biological response variable Chl-a, which is highest in the epilimnion in the summer, it is appropriate to also limit pH assessments to the epilimnion.

Excessive algal production can cause the pH of the epilimnion to rise above 9.0 in some cases. When pH falls outside of this range due to algal blooms and their eventual decomposition, aquatic life which requires a stable range of pH conditions to survive can suffer. As mentioned for dissolved oxygen, assessment of pH in the epilimnion of lakes against WQS will ensure the protection of aquatic life and aquatic habitat designated use and the maintenance of a robust aquatic community.

- At the time of sample collection, dissolved oxygen, water temperature, and pH will be measured near the surface as well as via sonde probe throughout the depth of the epilimnion (water surface to the thermocline). The sonde probe continuously collects data for a short period of time as it is lowered through the water column. This data is currently collected by the SLAP under a cooperative agreement with the Missouri Department of Natural Resources.

- Following the Listing Methodology Document procedure for dissolved oxygen: If more than 10% of the measurements are below 5.0 mg/L minimum to protect aquatic life, the binomial probability will be used for determining if the criterion has been exceeded.

- Following the Listing Methodology Document procedure for pH: If more than 10% of the measurements are outside the 6.5 to 9.0 range to protect aquatic life, the binomial probability will be used for determining if the criterion has been exceeded.

c. 10 CSR 20-7.031(5)(N)6.C. – Cyanobacteria counts in excess of one hundred thousand (100,000) cells per milliliter (cells/mL)

Cell counts of cyanobacteria (blue-green algae) greater than one hundred thousand can be indicative of a harmful algal bloom (HAB) and the increased probability of algal toxins in the lake. Certain species of blue-green algae can produce toxins which are harmful to both aquatic life and terrestrial life (including humans and pets). *Microcystis* can produce microcystin (liver toxin) and anatoxin-a (neurotoxin). *Dolichospermum*, in addition to producing microcystin and anatoxin-a, can also produce cylindrospermopsin (liver toxin) and saxitoxin (nerve toxin). These toxins can cause adverse effects on aquatic life, as well as humans recreating on surface waters. The Oregon Health Authority has developed recreational guidelines for issuing public health advisories in relation to algal toxins (Oregon Health Authority, 2018). Until EPA develops Section 304(a) criteria for algal toxins, the values contained in the Oregon Health Authority document will serve as a surrogate indicator that Section 101(a) uses (i.e., aquatic habitat protection and recreational uses) are not being met. Direct measurement of cyanobacteria cell counts is limited and currently prohibitively expensive. Until this method becomes more widely adopted or technology improves to reduce the cost, the Department will collect data on algal toxin concentrations as a surrogate indicator for cyanobacteria counts.

- Cyanobacteria counts greater than 100,000 cells per milliliter suggest the presence and impact of a harmful algal bloom (HAB) in the water body. HABs and the algal toxins that are produced as a result pose a threat to the aquatic habitat protection and recreational designated uses (Oregon Health Authority, 2018). This data may be collected by agencies or county governments and when available the Department will request and use this information. The cyanobacteria cell count is based on the threat of unacceptable levels of algal toxins, which are currently being collected by the SLAP and the LMVP under a cooperative agreement with the Department.

- Any algal toxin values exceeding the following thresholds during the same year one of the nutrient screening levels was exceeded will constitute evidence of impairment. Two of these toxins are currently collected by the SLAP and the LMVP. The SLAP will begin collecting all four in 2018 under a cooperative agreement with the Department.

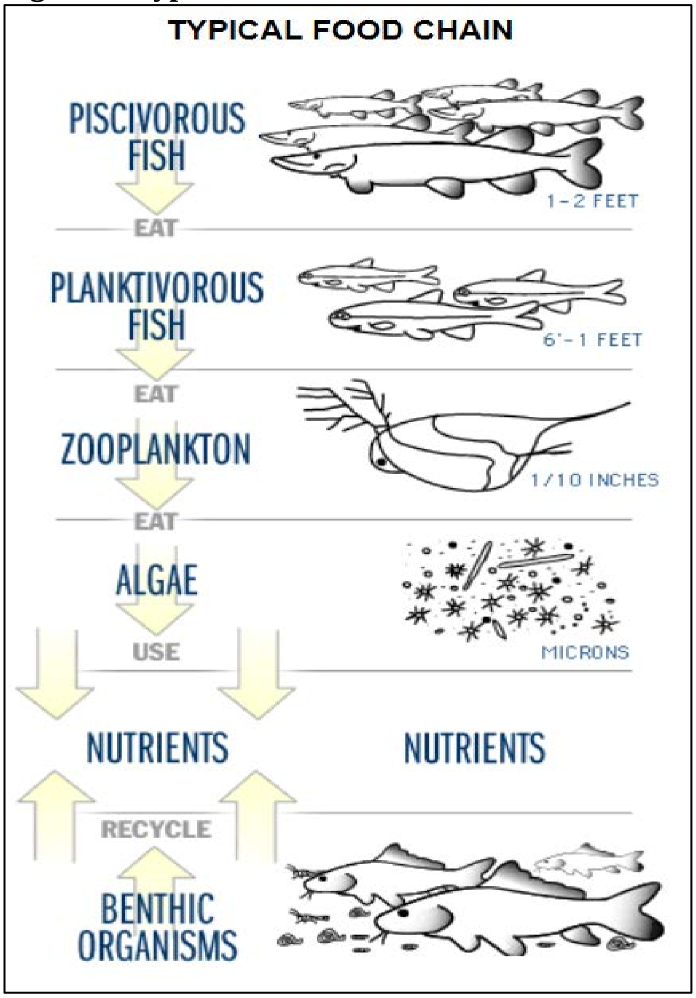
Microcystin	4.0 µg/L
Cylindospermopsin	8.0 µg/L
Anatoxin-a	8.0 µg/L
Saxitoxin	4.0 µg/L

These toxin levels are associated with a total toxigenic algal species cell count greater than or equal to 100,000 cell/mL. They are also associated with an algal cell count of greater than or equal to 40,000 cells/mL of Microcystis or Planktothrix species.

d. 10 CSR 20-7.031(5)(N)6.D. – Observed shifts in aquatic diversity attributed to eutrophication

The health of an ecosystem can be assessed by looking at different aspects, one of which is the food web or chain (Figure 2). Chemical measurements can be taken to assess the nutrients and chlorophyll (as a surrogate for algae). Relative abundances of fish at the various levels of the food chain can be surveyed to see if it is in balance. High nutrient inputs along with high levels of suspended solids can cause a decrease in the number of sight feeding predators and an increase in the number of the prey that the predators are unable to catch. More numerous prey puts a strain on the resources available, resulting in smaller prey and smaller, less numerous predators. This imbalance in the number and/or size of fish, or a shift to less sight-feeding fish in favor of bottom feeding fish such as carp, due to eutrophication is a cause for concern.

Figure 2. Typical Food Chain in Missouri Lakes



http://www.lakeaccess.org

As the state agency responsible for the protection and management of fish, forest, and wildlife resources in the state, the Missouri Department of Conservation regularly monitors fish populations of primary sport fishes (black bass, crappie, catfish) in major reservoirs (typically annually) to ensure the agency has appropriate regulations in place to manage these fish populations for today and into the future. These populations of piscivorous (i.e., fish eating) sport-fish, and the many planktivorous (i.e., plankton eating) non-sportfish that are their prey, are self-sustaining in Missouri's major reservoirs. Correspondence with MDC Fisheries Division confirms the agency does not conduct supplemental stocking for primary sport fishes (i.e., apex predators) nor does the agency conduct supplemental stocking of non-sportfish lower down the food chain (MDC, 2018).

Although MDC does not stock the primary sport and non-sport fishes noted above, MDC does stock additional fish species to provide a "bonus" or "specialty" sport fishing opportunity. Species included in the bonus or specialty fishing opportunities include (but are not limited to) paddlefish, rainbow trout, brown trout, striped bass, hybrid striped bass, walleye, and muskellunge. Many of these fish species are non-native and would not be capable of reproducing or sustaining populations in Missouri lakes.

MDC uses various sampling techniques including electrofishing, netting, creel surveys, and angler surveys to collect information related to fish populations and angler satisfaction over time. These data help to inform MDC's regulations for the capture of fish within Missouri lakes to ensure self-sustaining populations of sport- and non-sport fishes. The Department, in consultation with MDC, will use these data to determine whether shifts in aquatic diversity attributed to eutrophication are occurring in a lake. These data are contained within MDC's Fisheries Information Network System (FINS) and annual reports of fish stocking activities such as the "Fish Stocking for Public Fishing and Aquatic Resource Education." In support of this approach, the last eight calendar year reports (CY 2010 – 2017) generated by MDC and supporting data have been included with this submittal.

- The Department will request any available information on the potential biological shifts in fish or invertebrate communities related to eutrophication. This includes data from other agencies (such as the U.S. Fish and Wildlife Service) that monitor the populations of game fish.
- The MDC regularly monitors fish populations of primary sport fishes (black bass, crappie, and catfish) in major reservoirs (typically annually) to ensure the agency has appropriate regulations in place to manage these fish populations for today and into the future. These populations of sport-fish, and the non-sportfish that are their prey, are self-sustaining in Missouri's major reservoirs.
- The MDC uses various sampling techniques including electrofishing, netting, creel surveys, and angler surveys to collect information related to fish populations and angler satisfaction over time. These data in consultation with MDC will be used to determine whether shifts in aquatic diversity attributed to eutrophication are occurring in a lake.
- The MDC produces annual fishery management reports for Missouri's major lakes and reservoirs that detail the health of the fishery and includes number of species, catch per unit effort, relative density of fish and measures of fish condition and population size structure. One such example of an annual fishery management report is the Stockton Reservoir 2017 Annual Lake Report (published March 2018). The data supporting MDC's annual fishery management reports can also be made available to the Department. The Missouri Department of Natural Resources will request these annual reports and data from MDC.

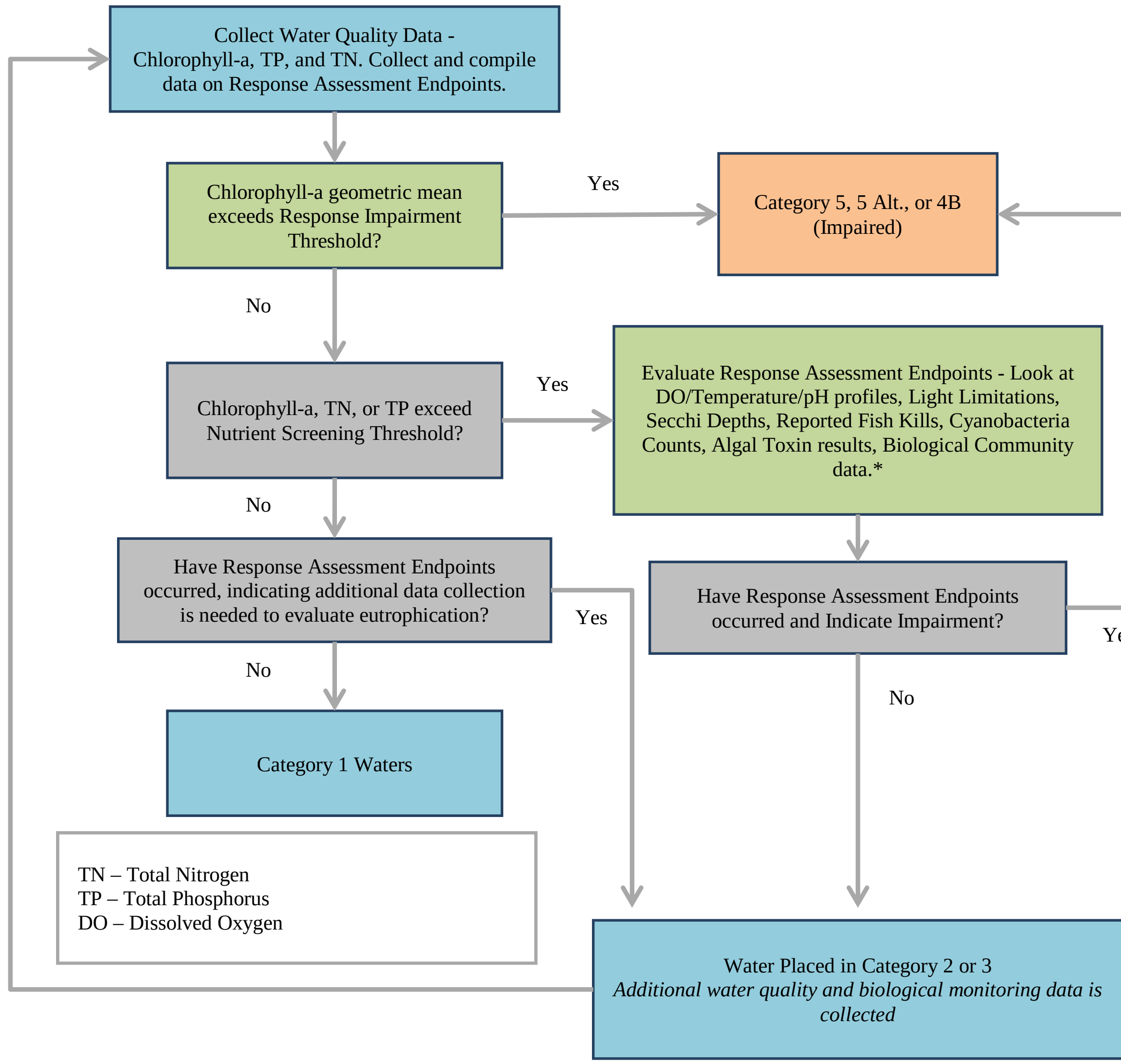
e. 10 CSR 20-7.031(5)(N)6.E. – Excessive levels of mineral turbidity that consistently limit algal productivity during the period May 1 – September 30 (i.e., light limitations)

It is widely recognized that mineral turbidity reduces transparency and thereby limits algal production (Jones and Hubbart, 2011). Excessive mineral turbidity and reduced water column transparency can suppress Chl-a levels despite high levels of nutrients. Pronounced and extended turbidity events could have the effect of reducing Chl-a on an average annual basis but still allow for periodically high peaks or algal blooms after sedimentation of mineral turbidity and increased transparency. Under such conditions, waterbodies experiencing harmful algal blooms may go undetected when assessed as an average annual geomean. The intent of this response variable is to identify such waterbodies that might otherwise go unidentified as impaired.

There are several ways to determine light availability in a lake. Some examples include: Secchi depth, light attenuation and photosynthetically active radiation (PAR), Chl-a/TP ratios, and measurements for turbidity and suspended sediments. All of these methods can provide additional information on the amount of light available in the epilimnion and how deep it penetrates into the lake. These data will be used to determine whether the lake has excess sediment in relation to nutrients for eutrophication impacts to occur.

- Excessive mineral turbidity can reduce light penetration within the photic zone of lakes and limit algal productivity due to the lack of sunlight. Water clarity can be expressed through measurements such as Secchi depth, turbidity, and suspended solids. These data are collected by the SLAP and the LMVP under a cooperative agreement with the Department.
- Measured lake Secchi depths less than 0.6 meters in the Plains, 0.7 meters in the Ozark Border, and 0.9 meters in the Ozark Highlands is likely an indicator of excessive mineral turbidity that limits algal productivity in the water body (MDC 2012). This data is collected by the SLAP and the LMVP under a cooperative agreement with the Department. Yearly average Secchi depths below the applicable ecoregional value may constitute evidence of impairment. Additional analysis of average Chl-a/TP ratios will also be conducted before determining impairment status, as described below.
- The ratio of the average Chl-a to the average TP is an additional indicator of chlorophyll suppression in lakes due to mineral turbidity. A mean Chl-a/TP ratio less than or equal to 0.15 and a mean inorganic suspended solids value greater than or equal to 10 mg/L is suggestive of excessive mineral turbidity which limits algal productivity (Jones and Hubbart, 2011). Unless attributed to other physical factors, Chl-a/TP ratios at or below 0.15 and an ISS value greater than or equal to 10 mg/L as determined by yearly means will serve as an indicator of excessive mineral turbidity and constitute evidence of impairment. Assessment threshold values for Secchi depth, Chl-a/TP ratio, and ISS shall all be exceeded before determining a water is impaired.
- The Department will use data collected using a Li-Cor quantum sensor. Data collected with this equipment consists of light attenuation and photosynthetically active radiation (PAR). Until scientific literature on this new technology can be developed, the Department will rely on best professional judgment for when the data indicate light availability is limiting algal production to the point that if there were less or no limitation then the Chl-a values would be likely to exceed the criterion. This data will be collected by the SLAP starting in 2018 under a cooperative agreement with the Department.

Figure 3. Missouri Ecoregional Numeric Nutrient Criteria Decision Framework based on the Bioconfirmation Approach.



Trend Analysis

The Department currently reports on physiographic region trends in Missouri's 305(b) Report. The latest version as well as past versions can be found on Missouri's 303(d) website: https://dnr.mo.gov/env/wpp/waterquality/303d/303d.htm. These trends have been reported every cycle in the 305(b) Report since 1990. Trends for the physiographic regions are calculated based on at least 20 years of data. Trends are developed for Secchi depth, total phosphorus, total nitrogen, total chlorophyll, nonvolatile suspended solids, and volatile suspended solids.

The Department will evaluate individual lake trends for total phosphorus, total nitrogen, and Chl-a. Nutrients and chlorophyll can be seasonally variable, as well as wet and dry weather dependent. A minimum of ten years of data will be necessary to confidently evaluate water quality trends in Missouri lakes due to significant annual variability and differing hydrologic conditions. Longer time periods are needed for more accurate predictions of impairment.

- When evaluating trends, confounding, or exogenous variables, such as natural phenomena (e.g., rainfall, flushing rate and temperature), must be controlled for.
- The trend must be statistically significant. This process involves standard statistical modeling, such as least squares regression or Locally Weighted Scatterplot Smoothing (LOWESS) analysis. To be considered statistically significant, the p value associated with the residuals trend analysis must be less than 0.05.
- Impairment decisions based on trend analysis should, at a minimum, demonstrate that the slope of the projected trend line is expected to exceed the chlorophyll criterion within 5 years and that there is evidence of anthropogenic nutrient enrichment. If the slope of the projected trend line is expected to exceed the chlorophyll criterion in greater than 5 years, the lake will be prioritized for additional monitoring and identified as a potential project for a 319 protection plan. A list of lakes that have increasing trends of nutrients or Chl-a will be added as an appendix to Missouri's future 305(b) Reports.

The Department will look for statistically significant trends in the DO/pH profile of lakes throughout the entire water column. Areas the Department will look at may include, but are limited to: mixing volumes, mixing depths, and severity of anoxia in the hypolimnion.

Examples of Assessments

<u>Example 1</u>
Lake Girardeau is in the Ozark Border ecoregion of Missouri. The Chl-a response impairment threshold for the Ozark Border is 22µg/L. The nutrient screening thresholds for the Ozark Border are: Chl-a = 13µg/L; TP =40µg/L; and TN = 733µg/L. Lake Girardeau was sampled in 1994, 2004, 2005, 2008, and 2015. The geometric means for Chl-a, TN, and TP are in Table 2. The Chl-a geometric mean was higher than the response impairment threshold in 2015. The nutrient screening thresholds for TN and TP were also exceeded that year.

- The sample data do not show any excursions of the DO and pH criteria
- The average Secchi depths during both years of nutrient screening threshold exceedance are greater than 0.7 meters
- Chl-a/TP ratio is above 0.15 and inorganic suspended solids/nonvolatile suspended solids (ISS/NVSS) is less than or equal to 10 mg/L

There is not enough data to evaluate a trend. Therefore, Lake Girardeau would be placed into category 2B and would be placed into the high priority list for additional data collection.

Table 2. Lake Girardeau Yearly Geometric Means

Year	Chl-a Geomean (µg/L)	TN Geomean (µg/L)	TP Geomean (µg/L)	Avg. Secchi Depth (m)
1994		1266	68	0.6
2004	21.5	582	30	0.89
2005	10.5	541	24	1.58
2008	18.5	528	28	1.27
2015	34.2	853	40	0.87

Example 2

Lake DiSalvo is in the Ozark Highlands ecoregion of Missouri. The Chl-a response impairment threshold for the Ozark Highlands is 15µg/L. The nutrient screening thresholds for the Ozark Highlands are: Chl-a = 6µg/L; TP =16µg/L; and TN = 401µg/L. Lake DiSalvo was sampled in 2011, 2012, 2014, 2015, and 2016. The geometric means for Chl-a, TN, and TP are in Table 3. The geometric mean for Chl-a exceeded the response impairment threshold every year since 2011.

Lake DiSalvo would be placed into category 5 and the 303(d) list for Chl-a.

Table 3. Lake DiSalvo Yearly Geometric Means

Year	Chl-a Geomean (µg/L)	TN Geomean (µg/L)	TP Geomean (µg/L)
2011	47.7	768	77
2012	58.7	941	107
2014	105.8	1508	119
2015	82.8	1079	82
2016	44.1	928	77

Example 3

Henry Sever Lake is in the Plains ecoregion of Missouri. The Chl-a response impairment threshold for the Plains is 30µg/L. The nutrient screening thresholds for the Plains are: Chl-a = 18µg/L; TP =49µg/L; and TN = 843µg/L. Henry Sever Lake was sampled in 2011, 2012, 2014, 2015, and 2016. The geometric means for Chl-a, TN, and TP are in Table 4. The geometric mean for Chl-a did not exceed the response impairment threshold in any of these years. Some or all of the nutrient screening thresholds were exceeded in 2012 and 2014. Figure 4 shows the scatter plot, trend line, Mann-Kendall trend test and the Theil-Sen Slope for Chl-a in Henry Sever Lake.

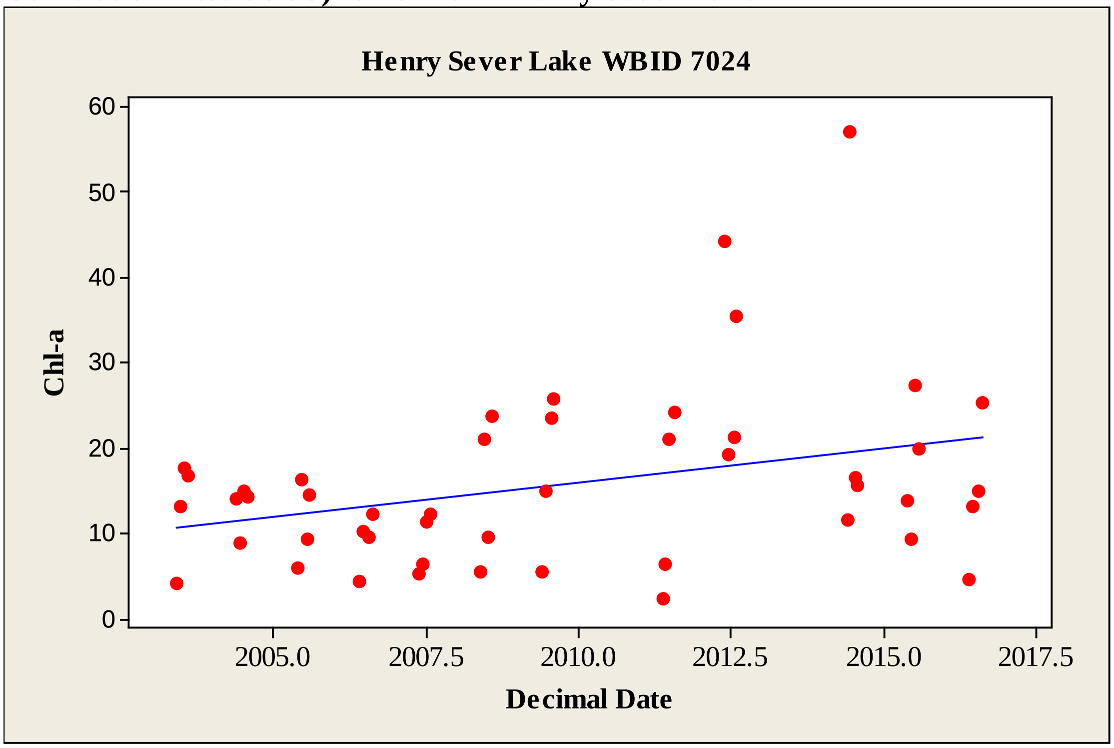
- Half of the pH values in 2012 exceed the pH criteria. None of the DO values exceed the criteria.
- The average Secchi depth during the years of nutrient screening threshold exceedance is 1.12 meters (2012) and 1.11 (2014) meters
- Chl-a/TP ratio is above 0.15
- Mann-Kendall Trend test is significant
- Trend data (Figure 4) shows a scatter plot with a trendline. The Theil-Sen slope of 0.6223 µg/L per year shows it is estimated to reach 30 µg/L theoretically in 2034.

Therefore, Henry Sever Lake would go into category 2B and will be placed into the priority list for additional data collection.

Table 4. Henry Sever Lake Yearly Geometric Means

Year	Chl-a Geomean (µg/L)	TN Geomean (µg/L)	TP Geomean (µg/L)
2003	11.19	742	43
2004	12.79	966	37
2005	10.70	1079	51
2006	8.47	871	43
2007	8.22	725	66
2008	12.61	1354	75
2009	14.90	838	65
2011	9.15	957	42
2012	28.30	898	41
2014	20.28	854	49
2015	16.21	772	36
2016	12.29	737	31

Figure 4. Scatter Plot Trend Line and Mann-Kendall Trend Test (Kendall's Tau Correlation Test USGS) for Chl-a in Henry Sever Lake



Kendall's tau Correlation Test, US Geological Survey, 2005

Data set: Henry Sever Lake Chl-a - Mann-Kendall test, input type 4
The tau correlation coefficient is 0.222
S = 250.0, z = 2.213, p = 0.0269

The relation may be described by the equation (Theil-Sen Slope estimator):
Y = -1235.9 + 0.6223 * X

Total Maximum Daily Load Development for Nutrient Impaired Waters

The Department will address water quality impairments of the numeric nutrient criteria or violations of narrative criteria where evidence shows excess nutrients to be a cause through the development of total maximum daily loads (TMDLs). TMDL development will occur in accordance with the schedules and priority rankings required as part of the biennial submittal of the state's 303(d) list of impaired waters per federal regulations at 40 CFR 130.7(b)(4). When developing TMDL priorities of 303(d)-listed waters, the Department will also consider alternative approaches that may result in attainment of water quality standards more quickly than a TMDL.

As with all TMDLs and in accordance with federal regulations at 40 CFR 130.7(c)(1), TMDLs developed by the Department to address nutrient impairments will be written to meet water quality standards, including narrative criteria or applicable numeric nutrient criteria. TMDLs developed to meet applicable numeric nutrient criteria will consider targets appropriate for attaining chlorophyll-a response impairment thresholds with consideration given to other causal and response parameter concentrations to ensure water quality standards are met and maintained. Depending upon the nature and source of impairment, TMDLs developed to address exceedances of narrative criteria may also target site-specific or reference chlorophyll-a response thresholds or a combination of other factors to ensure water quality standards are met, such as phosphorus, pH, and dissolved oxygen. Such factors and numeric translators used for developing TMDL targets to address a narrative criteria impairment will only be applicable to water bodies for which TMDLs have been developed and approved. As required by Section 303(d)(1)(C) of the Clean Water Act and federal regulations at 40 CFR 130.7(c)(1), all TMDLs will include an implicit and/or explicit margin of safety to provide additional certainty that the calculated TMDL allocations to point and nonpoint sources of nutrients will result in attainment of water quality standards.

During the development of nutrient TMDLs, the Department will evaluate available datasets and other relevant information to determine appropriate modeling approaches for calculating loading targets and estimating existing loads. One such model to be considered is BATHTUB, which was developed by the U.S. Army Corps of Engineers, and is currently in use for nutrient TMDL development by states within EPA Regions 5 and 7 to address lake eutrophication issues. Other models may be considered depending upon complexity and data needs. Estimates of upstream nutrient loading may be calculated directly where nutrient data is available or may be estimated through models, such as the Spreadsheet Tool for Estimating Pollutant Load (STEPL).

In conjunction with TMDL development, the Department also develops supplemental implementation plans for all TMDLs. These plans provide detailed strategies and actions that will achieve the established goals and water quality targets. TMDL implementation should follow an adaptive implementation approach that makes progress towards achieving water quality goals while using new data and information to reduce uncertainty and adjust implementation activities. The Department recognizes that technical guidance and support are critical to achieving the goals of most TMDLs. While a TMDL calculates the maximum loading that an impaired water body can assimilate and still meet water quality standards, the supplemental implementation plan provides additional information regarding best management practices, funding, and potential stakeholders in the watershed. These implementation plans serve to provide a general guide to permit writers, nonpoint source program coordinators, and other department staff, as well as soil and water conservation districts, local governments, permitted entities, regional planning commissions, watershed managers, and citizen groups for achieving the calculated wasteload and load allocations. Although not required by EPA, TMDL implementation plans will be placed on public notice and made available for public comment along with the corresponding draft TMDLs, which are made available for public review as described in the State Continuing Planning Process as required by federal regulations at 40 CFR 130.7.

Part II. Permit Implementation

The Department is fully delegated by EPA through Section 402(b) of the Clean Water Act to administer its National Pollutant Discharge Elimination System Permitting Program. The "Missouri's Nutrient Criteria" section of this document describes each part of Missouri's WQS that contain nutrient criteria. Notwithstanding, all permitting will be consistent with federal and state requirements. The following are additional regulations that the Department uses to implement point source nutrient reductions.

Effluent Regulation [10 CSR 20-7.015(3)]

The Effluent Regulation requires dischargers to the Table Rock Lake watershed and Lake Taneycomo and its tributaries between Table Rock Dam and Power Site Dam to not exceed 0.5 mg/L of phosphorus as a monthly average.

Exemptions to this requirement:

- Facilities discharging to Lake Taneycomo and its tributaries between Table Rock Dam and Power Site Dam permitted prior to May 9, 1994, and with a design flow less than 22,500 gallons per day (GPD) that have not had an increase in capacity.
- Facilities discharging to the Table Rock Lake watershed permitted prior to November 30, 1999, and with a design flow less than 22,500 GPD that have not had an increase in capacity.

All dischargers to the White River basin are required to monitor for phosphorus.

Effluent Regulation [10 CSR 20-7.015(9)(D)7.]

The Effluent Regulation requires facilities that typically discharge nutrients with a design flow greater than 100,000 GPD to monitor discharges for TN and TP quarterly. Soon the Department will be proposing an amendment to the regulation that would expand the monitoring requirements in various ways. First, facilities with a design flow greater than 1,000,000 GPD will be required to monitor monthly instead of quarterly. Second, instead of reporting TN, facilities will need to report nitrogen's constituents as: total Kjeldahl nitrogen, nitrate plus nitrite, and ammonia. Third, the facility will need to monitor influent for a period of time, in addition to effluent. The Department notes that many publicly-owned treatment works have voluntarily performed nutrient sampling at greater frequencies than required in the regulation.

Implementing a Three-Phase Nutrient Reduction Approach

The following implementation procedures for point source nutrient reduction are divided into three phases: Data Collection and Analysis, Plant Optimization, and Final Effluent Limitations. The three-phase approach is applicable for facilities that discharge to a lake watershed where the new numeric nutrient criteria apply; however, there are exceptions:

- Missouri's effluent regulation [10 CSR 20-7.015(3)] requires phosphorus effluent limitations or monitoring requirements in permits for facilities discharging to the Table Rock Lake and Lake Taneycomo watersheds. The effluent regulation supersedes the implementation procedures of this plan except in situations where this plan is more stringent.
- This plan does not impact permit limitations that were established based on site-specific nutrient criteria found in Table N of the WQS.
- Industrial facilities that discharge elevated concentrations of nutrients may require alternate implementation measures to ensure that water quality is protected.

- Facilities that discharge to impaired lake watersheds based on either new or existing nutrient criteria will follow different procedures. See the “Impaired Lakes” section for further information.

This plan does not prohibit establishing alternative methods of analysis, permit limits, or requirements provided that the alternatives are technically sound, consistent with state and federal regulations, and are protective of water quality.

Phase 1 – Data Collection and Analysis
Nutrient data collection is a necessary first step for multiple reasons.

1) Facilities will use the data to determine current treatment capabilities regarding nutrient removal.
2) Permit writers will use the data in Phase 3 to determine if reasonable potential (RP) for a discharge to cause or contribute to an excursion of the nutrient criteria exists.
3) The data will aid the Department in conducting analyses to determine nutrient loading contributions from point sources versus nonpoint sources into lake watersheds.

The Effluent Regulation [10 CSR 20-7.015] requires facilities that typically discharge nutrients with a design flow greater than 100,000 GPD to monitor discharges for TN and TP quarterly. Currently, the Department is proposing an amendment to the regulation that would expand the monitoring requirements in various ways. First, facilities with a design flow greater than 1,000,000 GPD will be required to monitor monthly instead of quarterly. Second, instead of reporting TN, facilities will need to report nitrogen’s constituents as: total Kjeldahl nitrogen, nitrate plus nitrite, and ammonia. Third, the facility will need to monitor influent, for a period of time, in addition to effluent.

The Department will generally not require nutrient monitoring for facilities that discharge less than or equal to 100,000 GPD because it does not anticipate these discharges will contribute a significant portion to the total nutrient load in lake watersheds. The total design flow of Missouri’s domestic wastewater facilities is 1,324 million gallons per day. Facilities with a design flow greater than 100,000 GPD discharge 1,288 million gallons per day. While smaller facilities make up 82% of total facilities in number, they contribute only 3% of the total daily flow. Not only do facilities that discharge less than or equal to 100,000 GPD make up a minimal portion of the point source loading, but that contribution is made even more insignificant when considering the total nutrient load from both point and nonpoint sources. The USGS spatially referenced regression on watershed (SPARROW) attributes model provides estimates of sources of TN and TP transported from the Mississippi River Basin to the Gulf of Mexico (Robertson and Saad, 2013). At this basin scale, relative nutrient contribution from wastewater treatment plants is estimated to be only 7% of TN and 13% of TP. The Department will develop nutrient reduction requirements for facilities discharging below 100,000 GPD if localized impacts from specific small facilities are identified.

Permits for facilities that typically discharge nutrients with a design flow greater than 100,000 GPD will require monitoring of the influent and effluent for the following parameters:

- Total Phosphorus
- Total Kjeldahl Nitrogen
- Nitrate plus Nitrite
- Ammonia

Because there are existing numeric criteria for ammonia in the WQS, these facilities likely already have permit monitoring requirements and/or effluent limitations in their permits for ammonia.

Table 5. Sampling Frequency by Design Flow

Design flow in GPD	Sampling frequency
100,001-1,000,000	Quarterly
1,000,001 and greater	Monthly

Phase 2 – Voluntary Plant Optimization and Source Controls

After permittees have completed the data collection process outlined in Phase 1, permittees and the Department will have an understanding of current treatment capabilities of the facility. Permittees can then elect to study and implement plant optimization or source control measures where they anticipate being able to reduce nutrient discharges with minimal capital and/or operational costs. This voluntary phase of plant optimization and/or source controls will provide permittees with time (up to 5 years) to take cost-effective strategies for early nutrient reductions. If permittees elect to not take advantage of this Phase, then the Department will use data collected under Phase 1 to evaluate RP and develop nutrient permit limitations, if needed.

As a part of Missouri’s Nutrient Loss Reduction Strategy, the Department will be conducting a study to determine attainable nutrient reduction values based upon various wastewater treatment technologies. This entails an analysis of point source dischargers and available discharge data to determine nutrient removal rates of different technologies throughout the state. Depending on existing treatment process design, operational adjustments can potentially increase the removal efficiency of TN without significant capital investments on plant upgrades. This approach may be more difficult for TP; however, reducing phosphorus from entering the treatment plant can be an effective strategy. These cost-effective efforts may significantly reduce point source loading in the watershed.

Permits for facilities that typically discharge nutrients with a design flow of greater than 100,000 GPD and voluntarily engage into Phase 2 will include a special condition requiring the development and implementation of a Plant Optimization Plan and a Phosphorus Minimization Plan. Because Phase 2 is voluntary, Missouri affordability statutes do not apply to these permit conditions. The Department will develop and provide the following resources to permittees:

- Operator Training Workshops – Engineering staff and water specialists will offer training opportunities to operators on practical methods of improving treatment capabilities in current operations.
- Online Resources – The Department will provide online resources including fact sheets and links to information that will aid in the development of Plant Optimization Plans and

Phosphorus Minimization Plans. Easy-to-use templates for these plans will also be provided by the Department.
- Staff Assistance – Department staff are always available to assist permittees by phone and email. Permittees may request compliance assistance visits on-line at https://dnr.mo.gov/cav/compliance.htm.

During Phase 2, permittees will maintain the monitoring requirements established in Phase 1. With this data, removal efficiency and phosphorus minimization efforts can be tracked throughout Phase 2. Permittees who are able to show significant improvements in treatment plant operations are more likely to be issued permits with less stringent nutrient requirements as the improvements may show that there is no RP to cause or contribute to an excursion of the nutrient criteria. With some effort, plant optimization may be a more economically viable option than costly upgrades. However, depending on treatment processes, plant optimization efforts may detrimentally impact effluent performance for other important pollutants, such as biochemical oxygen demand and ammonia. In addition, plant optimization strategies for facilities below design capacity could use (on an interim or permanent basis) reserved treatment plant capacity (e.g., basin volumes) originally designed to serve community growth. Therefore, the Department will not establish nutrient reduction baselines for future limits based upon optimized plant loading. Rather, the Department will include technology-based effluent goals in permits that support plant optimization and/or source reduction goals.

Phase 3 – Final Effluent Limitations

During the third phase of the plan, final effluent limitations will be established in permits where RP exists. Chl-a data from Missouri's lakes are strongly correlated with TN and TP. However, studies show through regression models that TN accounts for less Chl-a variation compared to TP (Jones and Knowlton, 2005). This suggests that TP is the limiting nutrient in most of Missouri's lakes; therefore, phosphorus reductions made at wastewater facilities will strongly contribute to water quality improvements in lakes with elevated levels of Chl-a and TP. As a Missouri-specific demonstration, permits for facilities discharging to the Table Rock Lake and Lake Taneycomo watersheds have contained technology-based phosphorus effluent limitations for decades per Missouri's Effluent Regulation [10 CSR 20-7.015(3)]. Because of this requirement, most permittees in these areas have installed a chemical feed to their facilities' treatment processes to facilitate phosphorus removal which in turn has greatly reduced the number of algal blooms on these lakes. Water quality in these watersheds has improved since the requirements were first established, suggesting that phosphorus removal technologies from point sources are responsible for the improvement.

By Phase 1, or the voluntary Phase 2, facilities have collected and reported sufficient data for an RP determination to be made. Determining RP for a discharge to cause or contribute to an excursion of the nutrient criteria can be complicated using numeric nutrient criteria for Chl-a. Furthermore, the typical statistical analysis used by permit writers to determine RP for toxics cannot be used to determine RP for Chl-a because it is not a discharged pollutant that can be sampled from a facility's outfall. Because exceedance of the numeric Chl-a criteria is a response to excess TN and/or TP in the water body, regional correlations between nutrients and algal biomass will be used to set in-lake nutrient targets. Then, watershed modeling will be used to identify and estimate sources (both point and nonpoint sources) of TN and TP loads and quantify the proportion of contributions from these sources into the watershed, which is necessary to make a RP determination for a specific facility.

Facilities that typically discharge nutrients with a design flow of greater than 100,000 GPD will be modeled. If watershed modeling shows that there is RP for a discharge to cause or contribute to an excursion of the Chl-a criteria, TP effluent limits (with a compliance schedule) will be established in the permit requiring the permittee to install phosphorus removal at the facility. This approach will need adjustments in situations where watershed modeling shows TN as the limiting pollutant over TP. Nutrient limits will be set to achieve in-lake nutrient targets based upon source sector contributions and within the point source sector, the relative contribution of each such source. Relative contribution should take into account early nutrient reduction actions by individual dischargers. The Department also intends to provide opportunities for watershed-based, bubble permitting to facilitate cost-effective point source nutrient reductions and compliance as well as fostering collaboration between permittees.

Impaired Lakes

In cases where a facility discharges to a watershed that contains a lake with nutrient impairments, supplemental procedures, in addition to those previously discussed in this plan, will be utilized. The first step is to determine if the facility's discharge is causing or contributing to the nutrient impairment. As discussed in Phase 3, watershed modeling will be used to identify the sources (both point and nonpoint) of TN and TP loads and quantify the proportion of contributions from these sources into the watershed, which is necessary to make the RP determination for specific facilities.

If, through modeling or other means, a determination is made that a particular facility *is not* causing or contributing to the impairment, then effluent limitations are not needed at that time to protect water quality. However, the permit writer may determine that nutrient monitoring is still needed to make future RP determinations.

If it is shown that the facility *is* causing or contributing to the impairment, effluent limitations will be established that are protective of water quality. This can be accomplished in several ways:

- The permit writer can establish TP effluent limitations based on the capabilities of specific treatment technologies with the supporting rationale that potential TP reductions made by the facility are protective of water quality.
- The permit writer can establish effluent limitations based on wasteload allocations identified through watershed and lake modeling based upon point source relative contribution.
- Following TMDL development, wasteload allocations will be established and permit writers will establish effluent limitations from those wasteload allocations.

Other methods of effluent limitation derivation are allowed with appropriate justification by the permit writer.

New and Expanding Sources and Antidegradation Review Requirements

Implementation procedures for new sources differ from those previously listed in this plan. For the purposes of this plan, "new sources" refers to new, altered, or expanding discharges of TP and/or TN. Per Missouri's WQS [10 CSR 20-7.031(3)], for new sources, the Department will document by means of antidegradation review that the use of a water body's available assimilative capacity is justified. Missouri's Antidegradation Implementation Procedures provide a detailed process for conducting antidegradation reviews, which will be applicable to any new or expanding discharges of nutrients into lake watersheds. Permittees must submit an antidegradation review request to the Department prior to establishing, altering, or expanding discharges.

The following procedures for new sources are split between lakes with and without nutrient impairments.

<u>Scenario 1: The new source requests to discharge to a watershed that contains a lake *with* a nutrient impairment</u>. The Department will conduct watershed modeling to determine whether the facility's discharge would cause or contribute to the nutrient impairment. Permitting decisions that fall under this scenario will be based upon a Tier 1 antidegradation review, which are designed to prohibit degradation that may cause or contribute to the impairment of a beneficial use. Increased pollutant loading is allowed as long as the discharge does not cause or contribute to the impairment.

- If the facility's discharge is shown not to cause or contribute to the nutrient impairment, then the permit writer will establish best available technology limits for TP in the permit.
- If the facility's discharge is shown to cause or contribute to the nutrient impairment, then the permittee will be required to utilize a more advanced level of wastewater treatment or find an alternative method of wastewater disposal.

<u>Scenario 2: The new source requests to discharge to a watershed that contains a lake *without* a nutrient impairment</u>. There is little need for the data collection and plant optimization conducted in Phases 1 and 2 for new facilities. Because of this, permits that fall under this scenario will include effluent limitations for TP in their initial permit based upon a Tier 2 antidegradation review.

Potential Flexibilities for Permittees

The Department has multiple tools to aid permittees with permit compliance. As permits are renewed, permittees may find it difficult to meet new effluent limitations and requirements. Depending on the situation, each flexibility listed below offers its own set of results and benefits.

Table 6. Regulatory Flexibilities for Permitting

Permit Flexibility	Quick Facts
Schedules of Compliance 10 CSR 20-7.015(9)(C)	• Allows permittees time to comply with newly established effluent limitations • Establishes yearly (or more frequent) milestones • Established using a cost analysis which takes into account a community's socioeconomic and financial capability status for publicly-owned treatment works • Must comply with 40 CFR 122.47 • May be extended with proper justification • May extend beyond the permit term
WQS Variance 10 CSR 20-7.031(12)	• Variances are paths to improve water quality over the variance term • Provides permittees time to achieve incremental improvements to ultimately work toward compliance with WQS through a Pollutant Minimization Program • Establishes a time-limited WQS, and therefore, must be approved by the Missouri Clean Water Commission and EPA
Watershed-based Permits	• Watershed-based permitting is an approach to develop permits for multiple point sources located within a defined geographic area. • Allows the Department to consider watershed goals and the impact of multiple nutrient sources.
Water Quality Trading Missouri Water Quality Trading Framework	• Trading is a market-based approach for compliance with effluent limitations • Instead of, or in addition to, upgrading facilities, permittees can buy and sell water quality credits to meet effluent limitations • Point to point source trades or nonpoint source to point source trades can be made
Integrated Management Plans Missouri Integrated Planning Framework	• Allows communities to prioritize investments to meet environmental requirements • Plan development is voluntary and the responsibility of the community • Plan development is a method to include utility rate payers in the decision making process • May provide assurance which allows relaxation of timelines for regulatory requirements such as permit requirements, enforcement action, and TMDL development

Incentives for Early Nutrient Reduction

Receiving water quality may benefit from earlier nutrient reductions resulting from wastewater treatment optimization, pilot testing, stress testing, new technology trials, etc. as well as from trading for nutrient reductions or offsets. The Department encourages wastewater utilities to make voluntary reductions of nutrients earlier than required, improving the receiving water quality. In exchange, permittees will receive regulatory flexibilities, such as extended compliance schedules to achieve final effluent nutrient limits or other water quality-based effluent limits. In addition, permittees adopting early nutrient reduction strategies could balance other regulatory obligations through integrated planning. Permittees also may accrue credits for watershed-based trading.

Wastewater utility participation in an early nutrient reduction is voluntary. Any method of achieving early reductions in nutrients is allowable, whether achieved with nutrient removal optimization, a water quality trade, a source reduction plan, watershed nutrient reductions, or capital improvements to implement nutrient removal. If TMDLs or other watershed-based nutrient reduction strategies are developed, baselines for utilities will be established based upon point source sector reduction requirements in the absence of such early actions (i.e., facility-specific early action performance will not be set as the future regulatory requirement). This will eliminate regulatory disincentives for taking early nutrient reduction actions.

References

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Appendices

A – Missouri Department of Conservation Fish Stocking Information Letter

B – Methodology for the Development of the 2020 Section 303(d) List in Missouri

MISSOURI DEPARTMENT OF CONSERVATION

Headquarters
2901 West Truman Boulevard, P.O. Box 180, Jefferson City, Missouri 65102-0180
Telephone: 573-751-4115 ▲ www.MissouriConservation.org

SARA PARKER PAULEY, Director

June 18, 2018

Mr. Chris Wieberg
Director, Water Protection Program
Missouri Department of Natural Resources
PO Box 176
Jefferson City, Missouri 65102

Dear Mr. Wieberg:

RE: Missouri Department of Conservation fish stocking information – EPA Nutrient Criteria

Thank you for your interest in the Missouri Department of Conservation's (Department) fish stocking records for major reservoirs in Missouri. As Fisheries Division Chief, I have been asked to respond and I am happy to do so.

The Department's mission is to protect and manage the fish, forest and wildlife resources of the state and to facilitate and provide opportunity for all citizens to use, enjoy, and learn about these resources. This mission is not only to benefit current Missourians, but future generations as well.

The Department effectively manages fish populations in Missouri's major reservoirs for a sport fish combination of black bass spp., bluegill, crappie and catfishes. Those populations are self-sustaining and managed through effective regulation and enforcement. Supplemental stocking for these primary species is not needed. Additionally, those reservoirs also have strong populations of non-sportfish that are self-sustaining and managed through effective regulation and enforcement. Again, supplemental stocking is not needed to maintain these populations.

Where appropriate, the Department stocks additional fish species to provide a "bonus" or "specialty" sport fishing opportunity. Species included in the bonus or specialty fishing opportunities include (but are not limited to) paddlefish, rainbow trout, brown trout, striped bass, hybrid striped bass, walleye, and muskellunge. I have enclosed a spreadsheet from calendar year 2017 for your convenience.

The Department regularly monitors fish populations of primary sport fishes (black bass, crappie, catfishes) in major reservoirs (typically annually) to ensure we have appropriate regulations to manage these fish populations for today and into the future. We use various sampling techniques including electrofishing, netting, creel surveys and angler surveys to collect information related to fish populations and angler satisfaction over time.

If you have any questions or if I can provide any additional information, please contact me at (573) 522-4115, Ext. 3174 or by email at brian.canaday@mdc.mo.gov.

Sincerely,

BRIAN D. CANADAY
FISHERIES DIVISION CHIEF

Enclosure

c: Director Sara Parker Pauley
Deputy Director Mike Hubbard
Deputy Director Aaron Jeffries
Dru Buntin, Missouri Department of Natural Resources
John Hoke, Missouri Department of Natural Resources

Table 3. Major reservoirs stocked during 2017 under the Federal Aid Project F-52-D-13 (January 1, 2017 - December 31, 2017).

Location	County	Type of Stocking	Species; Size Stocked	Number Stocked	Source
Bull Shoals Lake - Bull Shoals Lake	Taney	MPS	striped bass; => 4"	16,109	MDC
Bull Shoals Lake - Bull Shoals Lake	Taney	MPS	walleye; < 4"	170,397	MDC
Bull Shoals Lake - Bull Shoals Lake	Taney	MPS	walleye; fry	250,000	MDC surplus
Lake of the Ozarks - Lake of the Ozarks	(none)	MPS	paddlefish; => 10"	3,600	MDC
Lake of the Ozarks - Lake of the Ozarks	(none)	MPS	striped bass; => 4"	7,508	MDC surplus
Lake of the Ozarks - Lake of the Ozarks	(none)	MPS	walleye; < 4"	214,860	MDC
Lake of the Ozarks - Lake of the Ozarks	(none)	MPS	walleye; fry	47,304	MDC surplus
Lake Taneycomo - Lake Taneycomo	Taney	MPS	brown trout; => 10"	10,001	MDC
Lake Taneycomo - Lake Taneycomo	Taney	MPS	brown trout; => 10"	10,017	MDC surplus
Lake Taneycomo - Lake Taneycomo	Taney	MPPO	rainbow trout; => 10"	381,972	MDC
Pomme de Terre Lake - Pomme de Terre Lake	Hickory	MPS	muskellunge; 10-12"	5,210	MDC
Pomme de Terre Lake - Pomme de Terre Lake	Hickory	MPS	walleye; < 4"	55,863	MDC surplus
Smithville Lake - Smithville Lake	Clay	MPS	walleye; < 4"	262,466	MDC
Stockton Lake - Stockton Lake	Cedar	MPS	walleye; < 4"	300,127	MDC
Table Rock Lake - Table Rock Lake	Taney	MPS	paddlefish; => 10"	2,451	MDC
Truman (Harry S) Lake - Truman (Harry S) Lake	Benton	MPS	paddlefish; => 10"	4,450	MDC
Truman (Harry S) Lake - Truman (Harry S) Lake	Benton	MPS	walleye; < 4"	188,022	MDC surplus

Appendix B – Methodology for the Development of the 2020 Section 303(d) List in Missouri

Methodology for the Development of the 2020 Section 303(d) List in Missouri

Approved by the Clean Water Commission on
July 16, 2018

Missouri Department of Natural Resources
Division of Environmental Quality
Water Protection Program

MISSOURI DEPARTMENT OF NATURAL RESOURCES

Table of Contents

I. Citation and Requirements

A. Citation of Section of Clean Water Act

The Missouri Department of Natural Resources (MDNR) is responsible for the implementation and administration of the Federal Clean Water Act in Missouri. Pursuant to Section 40 CFR 130.7, States, Territories or authorized Tribes must submit biennially to the United States Environmental Protection Agency (EPA) a list of water quality limited (impaired) segments, pollutants causing impairment, and the priority ranking of waters targeted for Total Maximum Daily Load (TMDL) development. Federal regulation at 40 CFR 130.7 also requires States, Territories, and authorized Tribes to submit to EPA a written methodology document describing the State's approach in considering, and evaluating existing readily available data used to develop their 303(d) list of impaired water bodies. The listing methodology must be submitted to the EPA each year the Section 303(d) list is due. While EPA does not approve or disapprove the listing methodology, the agency considers the methodology during its review of the states 303(d) impaired waters list and the determination to list or not to list waters.

Following the Missouri Clean Water Commission approval, Section 303(d) is submitted to EPA. This fulfills Missouri's biennial submission requirements of an integrated report required under Sections 303(d), 305(b) and 314 of the Clean Water Act. In years when no integrated report is submitted, the department submits a copy of its statewide water quality assessment database to EPA.

B. U.S. EPA Guidance

In 2001 the Office of General Counsel and the Office of Wetlands, Oceans, and Watersheds developed a recommended framework to assist EPA regions in the preparation of their approval letters for the States' 2002 Section 303(d) list submissions. This was to provide consistency in making approval decisions along with guidance for integrating the development and submission of the 2002 Section 305(b) water quality reports and Section 303(d) list of impaired waters[1].

The following sections provide an overview of EPA Integrated Report guidance documents from calendar year 2002 through 2015.

The 2002 Integrated Water Quality Monitoring and Assessment Report Guidance was the first document EPA provided to the States, Territories, and authorized Tribes with directions on how to integrate the development and submission of the 2002 305(b) water quality reports and Section 303(d) list of impaired waters.

The guidance recommended that States, Territories and authorized Tribes submit a combined integrated report that would satisfy the Clean Water Act requirements for both Section 305(b) water quality reports and Section 303(d) list. The 2002 Integrated Report was to include:

[1] Additional information can be obtained from EPA's website: http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/guidance.cfm).

- Delineation of water quality assessment units based on the National Hydrography Dataset (NHD);
- Status of and progress toward achieving comprehensive assessments of all waters;
- Water quality standard attainment status for every assessment unit;
- Basis for the water quality standard attainment determinations for every assessment unit;
- Additional monitoring that may be needed to determine water quality standard attainment status and, if necessary, to support development of total maximum daily loads (TMDLs) for each pollutant/assessment unit combination;
- Schedules for additional monitoring planned for assessment units;
- Pollutant/assessment unit combinations still requiring TMDLs; and
- TMDL development schedules reflecting the priority ranking of each pollutant/ assessment unit combination.

The 2002 EPA guidance described the requirements under Section 303(d) of the Clean Water Act where states were required to describe the methodology used to develop their 303(d) list. EPA's guidance recommended the states provide: (1) a description of the methodology used to develop Section 303(d) list; (2) a description of the data and information used to identify impaired and threatened waters; (3) a rationale for not using any readily available data and information; and (4) information on how interstate or international disagreements concerning the list are resolved. Lastly (5), it is recommended that "prior to submission of its Integrated Report, each state should provide the public the opportunity to review and comment on the methodology." In accordance with EPA guidance, the department reviews and updates the Listing Methodology Document (LMD) every two years. The LMD is made available to the public for review and comment at the same time the state's 303(d) impaired waters list is published for public comment. Following the public comment period, the department responds to public comments and provides EPA with a document summarizing all comments received.

In July 2003, EPA issued new guidance entitled "Guidance for 2004 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d) and 305(b) of the Clean Water Act." This guidance gave further recommendations about listing of 303(d) and other waters.

In July 2005, EPA published an amended version entitled "Guidance for 2006 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d), 305(b) and 314 of the Clean Water Act" (see Appendix A for Excerpt).

In October 2006, EPA issued a memorandum entitled "Information Concerning 2008 Clean Water Act Sections 303(d), 305(b) and 314 Integrated Reporting and Listing Decisions." This memorandum serves as EPA's guidance for the 2008 reporting cycle and beyond. This guidance recommended the use of a five-part categorization scheme and that each state provides a comprehensive description of the water quality standards attainment status of all segments within a state (reference Table 1 below). The guidance also defined a "segment" as being used synonymous with the term "assessment unit" used in previous Integrated Report Guidance. Overall, the selected segmentation approach should be consistent with the state's water quality standards and be capable of providing a spatial scale that is adequate to characterize the water quality standards attainment status for the segment.

It was in the 2006 guidance that EPA recommended all waters of the state be placed in one of five categories described below.

Table 1. Placement of Waters within the Five Categories in the 2006[2] EPA Assessment, Listing and Reporting Guidance

Category 1	All designated uses are fully maintained. Data or other information supporting full use attainment for all designated uses must be consistent with the state's Listing Methodology Document (LMD). The department will place a water in Category 1 if the following conditions are met: • The water has physical and chemical data (at a minimum, water temperature, pH, dissolved oxygen, ammonia, total cobalt, and total copper for streams, and total nitrogen, total phosphorus and secchi depth for lakes) and biological water quality data (at a minimum, *E. coli* or fecal coliform bacteria) that indicates attainment with water quality standards. • The level of mercury in fish fillets or plugs used for human consumption is 0.3 mg/kg (wet weight) or less. Only samples of higher trophic level species (largemouth, smallmouth and spotted bass, sauger, walleye, northern pike, trout (rainbow and trout), striped bass, white bass, flathead catfish and blue catfish) will be used. • The water is not rated as "threatened."
Category 2	One or more designated uses are fully attained but at least one designated use has inadequate data or information to make a use attainment decision consistent with the state's LMD. The department will place a water in Category 2 if at least one of the following conditions are met: • There is inadequate data for water temperature, pH, dissolved oxygen, ammonia, total cobalt or total copper in streams to assess attainment with water quality standards or inadequate data for total nitrogen, total phosphorus or secchi depth in lakes. • There is inadequate *E. coli* or fecal coliform bacteria data to assess attainment of the whole body contact recreational use. • There are insufficient fish fillet, tissue, or plug data available for mercury to assess attainment of the fish consumption use. Category 2 waters will be placed in one of two sub-categories. Category 2A: Waters will be placed in this category if available data, using best professional judgement, suggests compliance with numerical water quality criteria of Tables A or B in Missouri's Water Quality Standards (10 CSR 20-7.031) or other quantitative thresholds for determining use attainment.

[2] http://www.epa.gov/sites/production/files/2015-10/documents/2006irg-report.pdf

	Category 2B: Waters will be placed in this category if the available data, using best professional judgment, suggests noncompliance with numeric water quality criteria of Tables A or B in Missouri's Water Quality Standards, or other quantitative thresholds for determining use attainment, and these data are insufficient to support a statistical test or to qualify as representative data. Category 2B waters will be given high priority for additional water quality monitoring.
<u>Category 3</u>	Water quality data are not adequate to assess any of the designated beneficial uses consistent with the LMD. The department will place a water in Category 3 if data are insufficient to support a statistical test or to qualify as representative data to assess any of the designated uses. Category 3 waters will be placed in one of two sub-categories. Category 3A. Waters will be placed in this category if available data, using best professional judgment, suggests compliance with numerical water quality criteria of Tables A or B in Missouri's Water Quality Standards (10 CSR 20-7.031) or other quantitative thresholds for determining use attainment. Category 3A waters will be tagged for additional water quality monitoring, but will be given lower priority than Category 3B waters. Category 3B. Waters will be placed in this category if the available data, using best professional judgment, suggest noncompliance with numerical water quality criteria of Tables A or B in Missouri's Water Quality Standards or other quantitative thresholds for determining use attainment. Category 3B waters will be given high priority for additional water quality monitoring.
<u>Category 4</u>	State water quality standards or other criteria, as per the requirements of Appendix B & C of this document, are not attained, but a Total Maximum Daily Load (TMDL) study is not required. Category 4 waters will be placed in one of three sub-categories. Category 4A. EPA has approved a TMDL study that addresses the impairment. The department will place a water in Category 4A if both the following conditions are met: • Any portion of the water is rated as being in non-attainment with state water quality standards or other criteria as explained in Appendix B & C of this document due to one or more discrete pollutants or discrete properties of the water[3], and

[3] A discrete pollutant or a discrete property of water is defined here as a specific chemical or other attribute of the water (such as temperature, dissolved oxygen or pH) that causes beneficial use impairment and that can be measured quantitatively.

	• EPA has approved a TMDL for all pollutants that are causing non-attainment. Category 4B. Water pollution controls required by a local, state or federal authority, are expected to correct the impairment in a reasonable period of time. The department will place a water in Category 4B if **both** of the following conditions are met: • Any portion of the water is rated as being in non-attainment with state water quality standards or other criteria as explained in Appendix B & C of this document due to one or more discrete pollutants or discrete properties of water[3], and • A water quality based permit that addresses the pollutant(s) causing the designated use, impairment has been issued, and compliance with the permit limits will eliminate the impairment; or other pollution control requirements have been made that are expected to adequately address the pollutant(s) causing the impairment. This may include implemented voluntary watershed control plans as noted in EPA's guidance document. Category 4C. Any portion of the water is rated as being in non-attainment with state water quality standards or other criteria as explained in Appendix B & C of this document, and a discrete pollutant(s) or other discrete property of the water[3] does not cause the impairment. Discrete pollutants may include specific chemical elements (e.g., lead, zinc), chemical compounds (e.g., ammonia, dieldrin, atrazine) or one of the following quantifiable physical, biological or bacteriological conditions: water temperature, percent of gas saturation, amount of dissolved oxygen, pH, deposited sediment, toxicity or counts of fecal coliform or *E. coli* bacteria.
<u>Category 5</u>	At least one discrete pollutant has caused non-attainment with state water quality standards or other criteria as explained in Appendix B & C of this document, and the water does not meet the qualifications for listing as either Categories 4A or 4B. Category 5 waters are those that are candidates for the state's 303(d) List[4]. If a designated use is not supported and the segment is impaired or threatened, the fact that a specific pollutant is not known does not provide a basis for excluding a segment from Category 5. Category 5. These segments must be listed as Category 5 unless the state can demonstrate that no discrete pollutant(s) causes or contributes to the impairment. Pollutants causing the impairment will be identified

[4] The proposed state 303(d) List is determined by the Missouri Clean Water Commission and the final list is determined by the U.S. Environmental Protection Agency.

	through the 303(d) assessment and listing process before a TMDL study is written. The TMDL should be written within the time frame preferred in EPA guidance for TMDL development, when it fits within the state's TMDL prioritization scheme. Category 5-alt. A water body assigned to 5-alt is an impaired water without a completed TMDL but assigned a low priority for TMDL development because an alternative restoration approach is being pursued. This also provides transparency to the public that a state is pursuing restoration activities in those waters to achieve water quality standards. The addition of this sub-category will facilitate tracking alternative restoration approaches in 303(d) listed waters in priority areas.
Threatened Waters	When a water is currently attaining all designated uses, but the data shows an inverse (time) trend in quality for one or more discrete water quality pollutants indicating the water will not continue to meet these uses before the next listing cycle. Such water will be considered "threatened." A threatened water will be treated as an impaired water and placed in the appropriate Category (4A, 4B, or 5).

In subsequent years, EPA has provided additional guidance, but only limited new supplemental information has been provided since the 2008 cycle.

In August 2015, the EPA provided draft guidance that would include a Category 5-alternative (5-alt) (reference Table 1 above). Additional information can be found at EPA's website: http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/guidance.cfm.

II. The Methodology Document

A. Procedures and Methods Used to Collect Water Quality Data

- Department Monitoring

The major purposes of the department's water quality monitoring program are to:

- characterize background or reference water quality conditions;
- better understand daily, flow event and seasonal water quality variations and their underlying processes;
- characterize aquatic biological communities;
- assess trends in water quality;
- characterize local and regional effects of point and nonpoint sources pollutants on water quality;
- check for compliance with water quality standards and/or wastewater permit limits;
- support development of strategies, including Total Maximum Daily Loads, to return impaired waters to compliance with Water Quality Standards. All of these objectives are statewide in scope.

- Coordination with Other Monitoring Efforts in Missouri

To maximize efficiency, the department routinely coordinates its monitoring activities with other agencies to avoid overlap, and to give and receive feedback on monitoring design. Data from other sources are used for meeting the same objectives as department-sponsored monitoring. The data must fit the criteria described in the data quality considerations section of this document. The agencies most often involved are the U.S. Geological Survey, the U.S. Army Corps of Engineers, EPA, the Missouri Department of Conservation (MDC), and the Missouri Department of Health and Senior Services. The Department of Natural Resources also tracks the monitoring efforts of the National Park Service; the U.S. Forest Service; several of the state's larger cities; the states of Oklahoma, Arkansas, Kansas, Iowa, and Illinois; and graduate level research conducted at universities within Missouri. For those wastewater discharges where the department has required instream water quality monitoring, the department may also use monitoring data acquired by wastewater dischargers as a condition of discharge permits issued by the department. In 1995, the department also began using data collected by volunteers that have passed Volunteer Water Quality Monitoring Program Quality Assurance/Quality Control tests.

- Existing Monitoring Networks and Programs

The following is a list and a brief description of the kinds of water quality monitoring activities presently occurring in Missouri.

1. Fixed Station Network

a) Objective: To better characterize background or reference water quality conditions, to better understand daily, flow events, and seasonal water quality variations and their underlying processes, to assess trends and to check for compliance with water quality standards.

b) Design Methodology: Sites are chosen based on one of the following criteria:

- Site is believed to have water quality representative of many neighboring streams of similar size due to similarity in watershed geology, hydrology and land use, and the absence of any impact from a significant point or discrete nonpoint water pollution source.
- Site is downstream of a significant point source or discrete nonpoint source area.

c) Number of Sites, Sampling Methods, Sampling Frequency, and Parameters:

- MDNR/U.S. Geological Survey cooperative network: approximately 70 sites statewide, horizontally and vertically integrated grab samples, four to twelve times per year. Samples are analyzed for major ions (e.g. calcium, magnesium, sulfate, and chloride), nutrients (e.g. phosphorus and nitrogen), temperature, pH, dissolved oxygen, specific conductance, bacteria (e.g. *Escherichia coli (E. coli)* and fecal coliform) and flow on all visits, two to four times annually for suspended solids and heavy metals, and for pesticides six times annually at four sites.
- MDNR/University of Missouri-Columbia's lake monitoring network. This program has monitored about 249 lakes since 1989. About 75 lakes are monitored each year. Each lake is usually sampled four times during the summer and about 12 are monitored spring through fall for nutrients, chlorophyll, turbidity and suspended solids.
- Department routine monitoring of finished public drinking water supplies for bacteria and trace contaminants.
- Routine bacterial monitoring for *E. coli* of swimming beaches at Missouri's state parks during the recreational season by the department's Missouri State Parks.
- Monitoring of sediment quality by the department at approximately 10-12 discretionary sites annually. Sites are monitored for several heavy metals (e.g. arsenic, cadmium, copper, lead, mercury, nickel, zinc, etc.) and/or organic contaminants (e.g. polycyclic aromatic hydrocarbons, etc.).

2. Special Water Quality Studies

a) Objective: Special water quality studies are used to characterize water quality effects from a specific pollutant source area.

b) Design Methodology: These studies are designed to verify and measure the contaminants of concern based on previous water quality studies, effluent sampling and/or Missouri State Operating Permit applications. These studies employ multiple sampling stations downstream and upstream (if appropriate). If contaminants of concern have significant seasonal or daily variation, the sampling design must account for such variation.

c) Number of Sites, Sampling Methods, Sampling Frequency and Parameters: The department conducts or contracts up to 10 to 15 special studies annually, as funding allows. Each study has multiple sampling sites. The number of sites, sampling frequency and parameters all vary greatly depending on the study. Intensive studies would also require multiple samples per site over a relatively short time frame.

3. Toxics Monitoring Program

The fixed station network and many of the department's intensive studies monitor for acute and chronic toxic chemicals[5]. In addition, major municipal and industrial dischargers must monitor for acute and chronic toxicity in their effluents as a condition of their Missouri State Operating Permit.

4. Biological Monitoring Program

a) Objectives: The objectives of the Biological Monitoring programs are to develop numeric criteria describing "reference" aquatic macroinvertebrate and fish communities in Missouri's streams, to implement these criteria within state water quality standards and to maintain a statewide fish and aquatic macroinvertebrate monitoring program.

b) Design Methodology: Development of biocriteria for fish and aquatic marcoinvertebrates[6] involves identification of reference streams in each of Missouri's aquatic ecoregions and 17 ecological drainage units, respectively. It also includes intensive sampling of invertebrate and fish communities to quantify temporal and spatial variation in reference streams within ecoregions and variation among ecoregions, and the sampling of chemically and physically impaired streams to assess the aquatic community.

c) Number of Sites, Sampling Methods, Sampling Frequency and Parameters: The department has conducted biological sampling of aquatic macroinvertebrates for many years. Since 1991, the department's aquatic macroinvertebrate monitoring program has consisted of standardized monitoring of approximately 45 to 55 sites twice annually. In addition, the MDC presently has a statewide fish and aquatic macroinvertebrate monitoring program, the Resource Assessment and Monitoring (RAM) Program, designed monitor and assess the health of Missouri's stream resources on a rotating basis. This program samples a minimum of 450 random and 30 reference sites every five years.

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[5] As defined in 10 CSR 20-7.031(1)
[6] For additional information visit: http://dnr.mo.gov/env/esp/wqm/biologicalassessments.htm

5. Fish Tissue Monitoring Program

a) Objective: Fish tissue monitoring addresses two objectives: (1) the assessment of ecological health or the health of aquatic biota (usually accomplished by monitoring whole fish samples); and (2) the assessment of human health risk based on the level of contamination of fish tissue plugs, or fillets.

b) Design Methodology: Fish tissue monitoring sites are chosen based on one of the following criteria:
- Site is believed to have water and sediment quality representative of many neighboring streams or lakes of similar size due to similarity in geology, hydrology and land use, and the absence of any known impact from a significant point source or discrete nonpoint water pollution source.
- Site is downstream of a significant point source or discrete nonpoint source area.
- Site has shown fish tissue contamination in the past.

c) Number of Sites, Sampling Methods, Sampling Frequency and Parameters:

The department plans to maintain a fish tissue monitoring program to collect whole fish composite samples[7] at approximately 13 fixed sites. In previous years, this was a cooperative effort between EPA and the department through EPAs Regional Ambient Fish Tissue (RAFT) Monitoring Program. Each site will be sampled once every two years. The preferred species for these sites are either Common Carp (*Cyprinus carpio*) or one of the Redhorse (a.k.a. sucker) species (*Moxostoma* sp.).

The department, EPA, and MDC also sample 40 to 50 discretionary sites annually for two fish fillet composite samples or fish tissue plug samples (mercury only) from fish of similar size and species. One sample is of a top carnivore such as Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*Micropterus dolomieu*), Walleye (*Sander vitreus*), or Sauger (*Sander canadensis*). The other sample is for a species of a lower trophic level such as catfish, Common Carp or sucker species (Catostomidae). This program occasionally samples fish eggs for certain fish species at selected locations. Both of these monitoring programs analyze for several chlorinated hydrocarbon insecticides, PCBs, lead, cadmium, mercury, and fat content.

6. Volunteer Monitoring Program

Two major volunteer monitoring programs generate water quality data in Missouri. The data generated from these programs are used for statewide 305(b) reporting on general water quality health, used as a screening level tool to determine where additional monitoring is needed, or used to supplement other water quality data for watershed planning purposes.
- Lakes of Missouri Volunteer Program[8]. This cooperative program consists of persons from the department, the University of Missouri-Columbia, and volunteers who monitor

[7] A composite sample is one in which several individual fish are combined to produce one sample.
[8] For additional program information visit: http://www.lmvp.org/

approximately 137 sites on 66 lakes, including Lake Taneycomo, Table Rock Lake and several lakes in the Kansas City area. Lake volunteers are trained to collect samples for total phosphorus, total nitrogen, chlorophyll and inorganic suspended sediments. Data from this program is used by the university as part of a long-term study on the limnology of mid-western reservoirs.

- Volunteer Water Quality Monitoring Program. The Volunteer Water Quality Monitoring Program[9] is an activity of the Missouri Stream Team Program, which is a cooperative project sponsored by the department, the Missouri Department of Conservation, and the Conservation Federation of Missouri. The program involves volunteers who monitor water quality of streams throughout Missouri. There are currently over 5,000 Stream Teams and more than 3,600 trained water quality monitors. Approximately 80,000 citizens are served each year through the program. Since the beginning of the Stream Team program, 494,232 volunteers have donated about 2 million hours valued at more than $38 million to the State of Missouri.

  After the Introductory class, many attend at least one more class of higher level training: Levels 1, 2, 3 and 4. Each level of training is a prerequisite for the next higher level, as is appropriate data submission. Data generated by Levels 2, 3, and 4 and the Cooperative Stream Investigation (CSI) Program volunteers represent increasingly higher quality assurance. For CSI projects, the volunteers have completed a quality assurance/quality control workshop, completed field evaluation, and/or have been trained to collect samples following department protocols. Upon completing Introductory and Level 1 and 2 training, volunteers will have received the basic level training to conduct visual stream surveys, stream discharge measurements, biological monitoring, and collect physical and chemical measurements for pH, conductivity, dissolved oxygen, nitrate, and turbidity.

  Of those completing an Introductory course, about 35 percent proceed to Levels 1 and 2. The CSI Program uses trained volunteers to collect samples and transport them to laboratories approved by the department. Volunteers and department staff work together to develop a monitoring plan. All Level 2, 3, and 4 volunteers, as well as all CSI trained volunteers, are required to attend a validation session every 3 years to ensure equipment, reagents and methods meet program standards.

- <u>Identification of All Existing and Readily Available Water Quality Data Sources</u>

  Data Solicitation Request

  In the calendar year 2 years prior to the current listing cycle, the department sends out a request for all available water quality data (chemical and biological). The data solicitation requests water quality data for approximately a two year timeframe prior to and including the current calendar year (up to October 31st of the current year). The data solicitation request is sent to multiple agencies, neighboring states, and organizations. In addition, and

[9] For additional program information visit: http://dnr.mo.gov/env/wpp/VWQM.htm

as part of the data solicitation process, the department queries available water quality data from national databases such as EPA's Storage and Retrieval (STORET)/Water Quality Exchange (WQX) data warehouse[10], and the USGS Water Quality Portal[11].

The data must be spatially and temporally representative of the actual annual ambient conditions of the water body. Sample locations should be characteristic and representative of the main water mass or distinct hydrologic areas. With the exception of the data collected for those designated uses that require seasonally based data (e.g., whole body contact recreation, biological community data, and critical season dissolved oxygen), data should be distributed over at least three seasons, over two years, and should not be biased toward specific conditions (such as runoff, season, or hydrologic conditions).

Data meeting the following criteria will be accepted.

- Samples must be collected and analyzed under a Quality Assurance/Quality Control (QA/QC) protocol that follows the EPA requirements for quality assurance project plans.
- Samples must be analyzed following protocols that are consistent with the EPA or Standard Method procedures.
- All data submitted must be accompanied by a copy of the organization's QA/QC protocol and standard operating procedures.
- All data must be reported in standard units as recommended in the relevant approved methods.
- All data must be accompanied by precise sample location(s), preferably in either decimal degrees or Universal Transverse Mercator (UTM).
- All data must be received in a Microsoft Excel or compatible format.
- All data must have been collected within the requested period of record.

All readily available and acceptable data are uploaded into the department's Water Quality Assessment Database[12], where the data undergoes quality control checks prior to 303(d) or 305(b) assessment processes.

- <u>Laboratory Analytical Support</u>

Laboratories used:

- Department/U.S. Geological Survey Cooperative Fixed Station Network: U.S. Geological Survey Lab, Denver, Colorado
- Intensive Surveys: Varies, many are done by the department's Environmental Services Program
- Toxicity Testing of Effluents: Many commercial laboratories

[10] http://www.epa.gov/storet/dw_home.html
[11] http://www.waterqualitydata.us/
[12] http://dnr.mo.gov/mocwis_public/wqa/water bodySearch.do

- Biological Criteria for Aquatic Macroinvertebrates: department's Environmental Services Program and Missouri Department of Conservation
- Fish Tissue: EPA Region VII Laboratory, Kansas City, Kansas, and miscellaneous contract laboratories (Missouri Department of Conservation or U.S. Geological Survey's Columbia Environmental Research Center)
- Missouri State Operating Permit: Self-monitoring or commercial laboratories
- Department's Public Drinking Water Monitoring: department's Environmental Services Program and commercial laboratories[13]
- Other water quality studies: Many commercial laboratories

B. Sources of Water Quality Data

The following data sources are used by the department to aid in the compilation of the state's integrated report (previously the 305(b) report). Where quality assurance programs are deemed acceptable, additional sources would also be used to develop the state's Section 303(d) list. These sources presently include, but are not limited to:

1. Fixed station water quality and sediment data collected and analyzed by the department's Environmental Services Program personnel.
2. Fixed station water quality data collected by the U.S. Geological Survey under contractual agreements with the department.
3. Fixed station water quality data collected by the U.S. Geological Survey under contractual agreements to agencies or organizations other than the department.
4. Fixed station water quality, sediment quality, and aquatic biological information collected by the U.S. Geological Survey under their National Stream Quality Accounting Network and the National Water Quality Assessment Monitoring Programs.
5. Fixed station raw water quality data collected by the Kansas City Water Services Department, the St. Louis City Water Company, the Missouri American Water Company (formerly St. Louis County Water Company), Springfield City Utilities, and Springfield's Department of Public Works.
6. Fixed station water quality data collected by the U.S. Army Corps of Engineers. The Kansas City, St. Louis, and Little Rock Corps Districts have monitoring programs for Corps-operated reservoirs in Missouri.
7. Fixed station water quality data collected by the Arkansas Department of Environmental Quality, the Kansas Department of Health and Environment, the Iowa Department of Natural Resources, and the Illinois Environmental Protection Agency.
8. Fixed station water quality monitoring by corporations.
9. Annual fish tissue monitoring programs by EPA/Department RAFT Monitoring Program and MDC.
10. Special water quality surveys conducted by the department. Most of these surveys are

[13] For additional information visit: http://dnr.mo.gov/env/wpp/labs/

focused on the water quality impacts of specific point source wastewater discharges. Some surveys are of well-delimited nonpoint sources such as abandoned mined lands. These surveys often include physical habitat evaluation and monitoring of aquatic macroinvertebrates as well as water chemistry monitoring.

11. Special water quality surveys conducted by U.S. Geological Survey, including but not limited to:
    a) Geology, hydrology and water quality of various hazardous waste sites,
    b) Geology, hydrology and water quality of various abandoned mining areas,
    c) Hydrology and water quality of urban nonpoint source runoff in metropolitan areas of Missouri (e.g. St. Louis, Kansas City, and Springfield), and
    d) Bacterial and nutrient contamination of streams in southern Missouri.
12. Special water quality studies by other agencies such as MDC, the U.S. Public Health Service, and the Missouri Department of Health and Senior Services.
13. Monitoring of fish occurrence and distribution by MDC.
14. Fish Kill and Water Pollution Investigations Reports published by MDC.
15. Selected graduate research projects pertaining to water quality and/or aquatic biology.
16. Water quality, sediment, and aquatic biological data collected by the department, EPA or their contractors at hazardous waste sites in Missouri.
17. Self-monitoring of receiving streams by cities, sewer districts and industries, or contractors on their behalf, for those discharges that require this kind of monitoring. This monitoring includes chemical and sometimes toxicity monitoring of some of the larger wastewater discharges, particularly those that discharge to smaller streams and have the greatest potential to affect instream water quality.
18. Compliance monitoring of receiving waters by the department and EPA. This can include chemical and toxicity monitoring.
19. Bacterial monitoring of streams and lakes by county health departments, community lake associations, and other organizations using acceptable analytical methods.
20. Other monitoring activities done under a quality assurance project plan approved by the department.
21. Fixed station water quality and aquatic macroinvertebrate monitoring by volunteers who have successfully completed the Volunteer Water Quality Monitoring Program Level 2 workshop. Data collected by volunteers who have successfully completed a training Level 2 workshop is considered to be Data Code One. Data generated from Volunteer Training Levels 2, 3 and 4 are considered “screening” level data and can be useful in providing an indication of a water quality problem. For this reason, the data are eligible for use in distinguishing between waters in Categories 2A and 2B or Categories 3A and 3B. Most of this data are not used to place waters in main Categories (1, 2, 3, 4, and 5) because analytical procedures do not use EPA or Standard Methods or other department approved methods. Data from volunteers who have not yet completed a Level 2 training

workshop do not have sufficient quality assurance to be used for assessment. Data generated by volunteers while participating in the department's Cooperative Site Investigation Program (Section II C1) or other volunteer data that otherwise meets the quality assurance outlined in Section II C2 may be used in Section 303(d) assessment.

The following data sources (22-23) **cannot** be used to rate a water as impaired (Categories 4A, 4B, 4C or 5); however, these data sources may be used to direct additional monitoring that would allow a water quality assessment for Section 303(d) listing.

22. Fish Management Basin Plans published by MDC.
23. Fish Consumption Advisories published annually by the Missouri Department of Health and Senior Services. Note: the department may use data from data source listed as Number 9 above, to list individual waters as impaired due to contaminated fish tissue.

As previously stated, the department will review all data of acceptable quality that are submitted to the department prior to the first public notice of the draft 303(d) list. However, the department will reserve the right to review and use data of acceptable quality submitted after this date if the data results in a change to the assessment outcome of the water.

C. Data Quality Considerations

- DNR Quality Assurance/Quality Control Program

The department and EPA Region VII have completed a Quality Management Plan. All environmental data generated directly by the department, or through contracts funded by the department, or EPA require a Quality Assurance Project Plan[14]. The agency or organization responsible for collecting and/or analyzing environmental data must write and adhere to a Quality Assurance Project Plan approved through the department's Quality Management Plan. Any environmental data generated via a monitoring plan with a department approved Quality Assurance Project Plan are considered suitable for use in water quality assessment and the 303(d) listing. This includes data generated by volunteers participating in the department's CSI Program. Under this program, the department's Environmental Services Program will audit select laboratories. Laboratories that pass this audit will be approved for the CSI Program. Individual volunteers who collect field samples and deliver them to an approved laboratory must first successfully complete department training on how to properly collect and handle environmental samples. The types of information that will allow the department to make a judgment on the acceptability of a quality assurance program are: (1) a description of the training, and work experience of the persons involved in the program, (2) a description of the field meters and maintenance and calibration procedures, (3) a description of sample collection and handling procedures, and (4) a description of all analytical methods used in the laboratory for analysis.

[14] For additional information visit: http://www.epa.gov/quality/qapps.html

- Other Quality Assurance/Quality Control Programs

  Data generated in the absence of a department-approved Quality Assurance Project Plan may be used to assess a water body if the department determines that the data are adequate after reviewing and accepting the quality assurance procedures plan used by the data generator. This review would include: (1) names of all persons involved in the monitoring program, their duties, and a description of their training and work related experience, (2) all written procedures, Standard Operating Procedures, or Quality Assurance Project Plans pertaining to this monitoring effort, (3) a description of all field methods used, brand names and model numbers of any equipment, and a description of calibration and maintenance procedures, and (4) a description of laboratory analytical methods. This review may also include an audit by the department's Environmental Services Program.

- Data Qualifiers

  Data qualifiers will be handled in different ways depending upon the qualifier, the analytical detection limit, and the numeric WQS.

  - Less Than Qualifier "<" – For this qualifier the department will use half of the reported less than value. Unless circumstances cause issues with assessment. Examples of this include but are not limited to:
    - Less than values for bacteria. Since we calculate a geometric mean any value less than 1.0 could cause the data to be skewed if using the geometric mean calculation method of multiplying the values then dividing by the nth root.
    - Less than values below the criterion but still close to the criterion, less than values that are above the criterion. In these cases the department will not use the data for assessments.
  - Non-detection Qualifier "ND" – The department treats these same as less than ("<") qualifiers, with the exception that a value is not reported. For these cases the department will use the method detection limit as the reported less than value.
  - Greater Than Qualifier " >" – The department will only consider data with these qualifiers for assessments when it pertains to bacteria. In the cases of bacteria data the reported greater than (" >") value is doubled then used in the assessment calculation. In circumstances where this practice is the sole reason for impairment then the greater than value(s) will be used at the reported value (i.e. not doubled) in the assessment calculation.
  - Estimated Values "E" – These values are usually characterized as being above the laboratory quantification limit but below the laboratory reporting limit and are thus reported as estimated ("E"). Sometimes bacteria values are reported as estimated ("E") at the high end and due to the particular method used for analysis this usually means a dilution of the sample was used because the true bacteria count is higher than the method reporting maximum. The department will not use estimated ("E") values if the value reported is near the criterion. If the value is well above or well below the criterion then it will be used in assessments.

- Data Age

  For assessing present conditions, more recent data are preferable; however, older data may be used to assess present conditions if the data remains representative of present conditions.

  - If the department uses data older than seven years to make a Section 303(d) list decision a written justification for the use of such data will be provided.

  - If a water body has not been listed previously and all data indicating an impairment is older than 7 years, then the water body shall be placed into Category 2B or 3B and prioritized for future sampling.

  - A second consideration is the age of the data relative to significant events that may have an effect on water quality. Data collected prior to the initiation, closure, or significant change in a wastewater discharge, or prior to a large spill event or the reclamation of a mining or hazardous waste site, for example, may not be representative of present conditions. Such data would not be used to assess present conditions even if it was less than seven years old. Such "pre-event" data can be used to determine changes in water quality before and after the event or to show water quality trends.

- Data Type, Amount and Information Content

  EPA recommends establishing a series of data codes, and rating data quality by the kind and amount of data present at a particular location (EPA 1997[15]). The codes are single-digit numbers from one to four, indicating the relative degree of assurance the user has in the value of a particular environmental data set. Data Code One indicates the least assurance or the least number of samples or analytes and Data Code Four the greatest. Based on EPA's guidance, the department uses the following rules to assign code numbers to data.

  - Data Code[16] One: All data not meeting the requirements of the other data codes.

  - Data Code Two: Chemical data collected quarterly to bimonthly for at least three years, or intensive studies that monitor several nearby sites repeatedly over short periods of time, or at least three composite or plug fish tissue samples per water body, or at least five bacterial samples collected during the recreational season of one calendar year.

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[15] *Guidelines for the Preparation of the Comprehensive State Water Quality Assessments (305b) and Electronic Updates*, 1997. (http://water.epa.gov/type/watersheds/monitoring/repguid.cfm)

[16] Data Code One is equivalent to data water quality assurance Level One in 10 CSR 20-7.050 General Methodology for Development of Impaired Waters List, subsection (2)(C), Data Code Two is equivalent to Level 2, etc.

- Data Code Three: Chemical data collected at least monthly for more than three years on a variety of water quality constituents including heavy metals and pesticides; or a minimum of one quantitative biological monitoring study of at least one aquatic assemblage (fish, macroinvertebrates, or algae) at multiple sites, multiple seasons (spring and fall), or multiple samples at a single site when data from that site is supported by biological monitoring at an appropriate control site.

- Data Code Four: Chemical data collected at least monthly for more than three years that provides data on a variety of water quality constituents including heavy metals and pesticides, and including chemical sampling of sediments and fish tissue; or a minimum of one quantitative biological monitoring study of at least two aquatic assemblages (fish, macroinvertebrates, or algae) at multiple sites.

In Missouri, the primary purpose of Data Code One data is to provide a rapid and inexpensive method of screening large numbers of waters for obvious water quality problems and to determine where more intensive monitoring is needed. In the preparation of the state's Integrated Report, data from all four data quality levels are used. Most of the data is of Data Code One quality, and without Data Code One data, the department would not be able to assess a majority of the state's waters.

In general, when selecting water bodies for the Missouri 303(d) List, only Data Code Two or higher are used, unless the problem can be accurately characterized by Data Code One data.[17] The reason is that Data Code Two data provides a higher level of assurance that a Water Quality Standard is not actually being attained and that a TMDL study is necessary. All water bodies placed in Categories 2 or 3 receive high priority for additional monitoring so that data quality is upgraded to at least Data Code Two. Category 2B and 3B waters will be given higher priority than Categories 2A and 3A.

EPA suggests that states use these codes as a way of describing the type of information collected, the frequency of collection, spatial/temporal coverage, and quality. Missouri has followed this guidance for the most part, but where Missouri differs is that we use the data codes to explain the type of information collected, the frequency it is collected, and the spatial/temporal coverage. For data quality the department reviews the data on a project specific basis and looks at the laboratory analysis and collection methods used to generate the data. If the data is of acceptable quality we mark the project and all of its underlying data as QA acceptable. We should only be using QA acceptable data for assessments, unless that data provides additional corroboration of impairment or attainment status.

[17] When a listing, amendment or delisting of a 303(d) water is made with only Data Code One data, a document will be prepared that includes a display of all data and a presentation of all statistical tests or other evaluative techniques that documents the scientific defensibility of the data. This requirement applies to all Data Code One data identified in Appendix B of this document.

- Dissolved Oxygen and Flow

Dissolved oxygen in streams is highly dependent on flow. For the assessment of streams dissolved oxygen measurements must be accompanied by a flow measurement taken on the same day as the dissolved oxygen measurement. The dissolved oxygen measurements must also be collected from the flowing portion of the stream and must not be influenced by flooding or backwater conditions.

- pH Data Considerations

The criterion for pH will be clarified at some point in the Missouri WQS as a chronic criterion. Assessment will be handled in the following ways:

- Continuous Sampling (i.e. time series or sonde data collection)
    - Data collected in a time series fashion will be looked at on a 4 day period. If an entire 4 day period is outside of the 6.5 – 9.0 criterion range that will count as a chronic toxicity event. More than one of these events will constitute an impairment listing of the stream.
- Grab Samples
    - Data collected as grab samples will be treated as is and the binomial probability calculation will be used for assessment. See Appendix D for further information.

D. How Water Quality Data is Evaluated to Determine Whether or Not Waters are Impaired for 303(d) Listing Purposes

I. Physical, Chemical, Biological and Toxicity Data

During each reporting cycle, the department and stakeholders review and revise the guidelines for determining water quality impairment. The guidelines shown in Appendix B & C provide the general rules of data use and assessment and Appendix D provides details about the specific analytical procedure used. In addition, if trend analysis indicates that presently unimpaired waters will become impaired prior to the next listing cycle, these “threatened waters” will be judged as impaired. Where antidegradation provisions in Missouri’s Water Quality Standards apply, those provisions shall be upheld. The numerical criteria included in Appendix B have been adopted into the state water quality standards, 10 CSR 20-7.031, and are used, as described in Appendix B to make use attainment decisions.

II. Weight of Evidence Approach

When evaluating narrative criteria described in the state water quality standards, 10 CSR 20-7.031, the department will use a weight of evidence analysis for assessing numerical translators that have not been adopted into state water quality standards (see Appendix C). Under the weight of evidence approach, all available information is examined and the greatest weight is given to data providing the “best supporting evidence” for an attainment decision. Determination of “best supporting evidence” will be made using best professional judgment, considering factors such as data quality, and site-specific environmental conditions. For those analytes with numeric thresholds, the threshold values given in Appendix C will trigger a weight of evidence analysis to determine the existence or likelihood of a use impairment and the appropriateness of proposing a 303(d) listing based on narrative criteria. This weight of evidence analysis will include the use of other types of environmental data when it is available or collection of additional data to make the most informed use attainment decision. Examples of other relevant environmental data might include physical or chemical data, biological data on fish [Fish Index of Biotic Integrity (fIBI)] or aquatic macroinvertebrate [Macroinvertebrate Stream Condition Index (MSCI)] scores, fish tissue, or toxicity testing of water or sediments.

Biological data will be given greater weight in a weight of evidence analysis for making attainment decisions for aquatic life use and subsequent Section 303(d) listings. Whether or not numeric translators of biological criteria are met is a strong indicator for the attainment of aquatic life use. Moreover, the department retains a high degree of confidence in an attainment decision based on biological data that is representative of water quality condition.

When the weight of evidence analysis suggests, but does not provide strong scientifically valid evidence of impairment, the department will place the water body in question in Categories 2B or 3B. The department will produce a document showing all relevant data and the rationale for the attainment decision. All such documents will be available to the public at the time of the first public notice of the proposed 303(d) list. A final recommendation on the listing of a water body based on narrative criteria will only be made after full consideration of all comments on the proposed list.

III. <u>Biological Data</u>

Methods for assessing biological data typically receive considerable attention during the public comment period of development of the Listing Methodology Document. Currently, a defined set of biocriteria are used to evaluate biological data for assessing compliance with water quality standards. These biological criteria contain numeric thresholds, that when exceeded relative to prescribed assessment methods, serve as a basis for identifying candidate waters for Section 303(d) listing. Biocriteria are based on three types of biological data, including: (1) aquatic macroinvertebrate community data; (2) fish community data; and, (3) a catch-all class referred to as “other biological data.”

In general, for interpretation of macroinvertebrate data where Stream Habitat Assessment Project Procedure (SHAPP) (MDNR 2016b) assessment scores indicate habitat is less than 75 percent of reference or appropriate control stream scores, and in the absence of other data indicating impairment by a discrete pollutant, a water body judged to be impaired will be placed in Category 4C. When interpreting fish community data, a provisional multi-metric habitat index called the QCPH1 index is used to identify stream habitat in poor condition. The QCPH1 index separates adequate habitat from poor habitat using a 0.39 threshold value; whereby, QCPH1 scores < 0.39 indicate stream habitat is of poor quality, and scores greater than 0.39 indicate available stream habitat is adequate.

In the absence of other data indicating impairment by a discrete pollutant, impaired fish communities with poor habitat will be placed in Category 4C. Additional information about QCPH1 is provided in the *Considerations for the Influence of Habitat Quality and Sample Representativeness* section.

The sections below describe the methods used to evaluate the three types of biological data (macroinvertebrate community, fish community, and other biological data), along with background information on the development and scoring of biological criteria, procedures for assessing biological data, methods used to ensure sample representativeness, and additional information used to aid in assessing biological data such as the weight of evidence approach.

Aquatic Macroinvertebrate Community Data

The department conducts aquatic macroinvertebrate assessments to determine macroinvertebrate community health as a function of water quality and habitat. The health of a macroinvertebrate community is directly related to water quality and habitat. Almost all macroinvertebrate evaluation consists of comparing the health of the community of the "target" to healthy macroinvertebrate communities from reference streams of the same general size and usually in the same Ecological Drainage Unit (EDU).

The department's approach to monitoring and evaluating aquatic macroinvertebrates is largely based on *Biological Criteria for Wadeable/Perennial Streams of Missouri* (MDNR 2002). This document provides the framework for numerical biological criteria (biocriteria) relevant to the protection of aquatic life use for wadeable streams in the state. Biocriteria were developed using wadeable reference streams that occur in specific EDUs as mapped by the Missouri Resource Assessment Partnership (reference Figure 1 below). For macroinvertebrates, the numerical biocriterion translator is expressed as a multiple metric index referred to as the MSCI. The MSCI includes four metrics: Taxa Richness (TR); Ephemeroptera, Plecoptera, and Trichoptera Taxa (EPTT); Biotic Index (BI); and the Shannon Diversity Index (SDI). These metrics are considered indicators of stream health, and change predictably in response to the environmental condition of a stream.

Metric values are determined directly from macroinvertebrate sampling. To calculate the MSCI, each metric is normalized to unitless values of 5, 3, or 1, which are then added together for a total possible score of 20. MSCI scores are divided into three levels of stream condition:

- Fully Biologically Supporting (16-20),
- Partially Biologically Supporting (10-14), and
- Non-Biologically Supporting (4-8).

Partially and Non-Biologically Supporting streams may be considered impaired and are candidates for Section 303(d) listing.

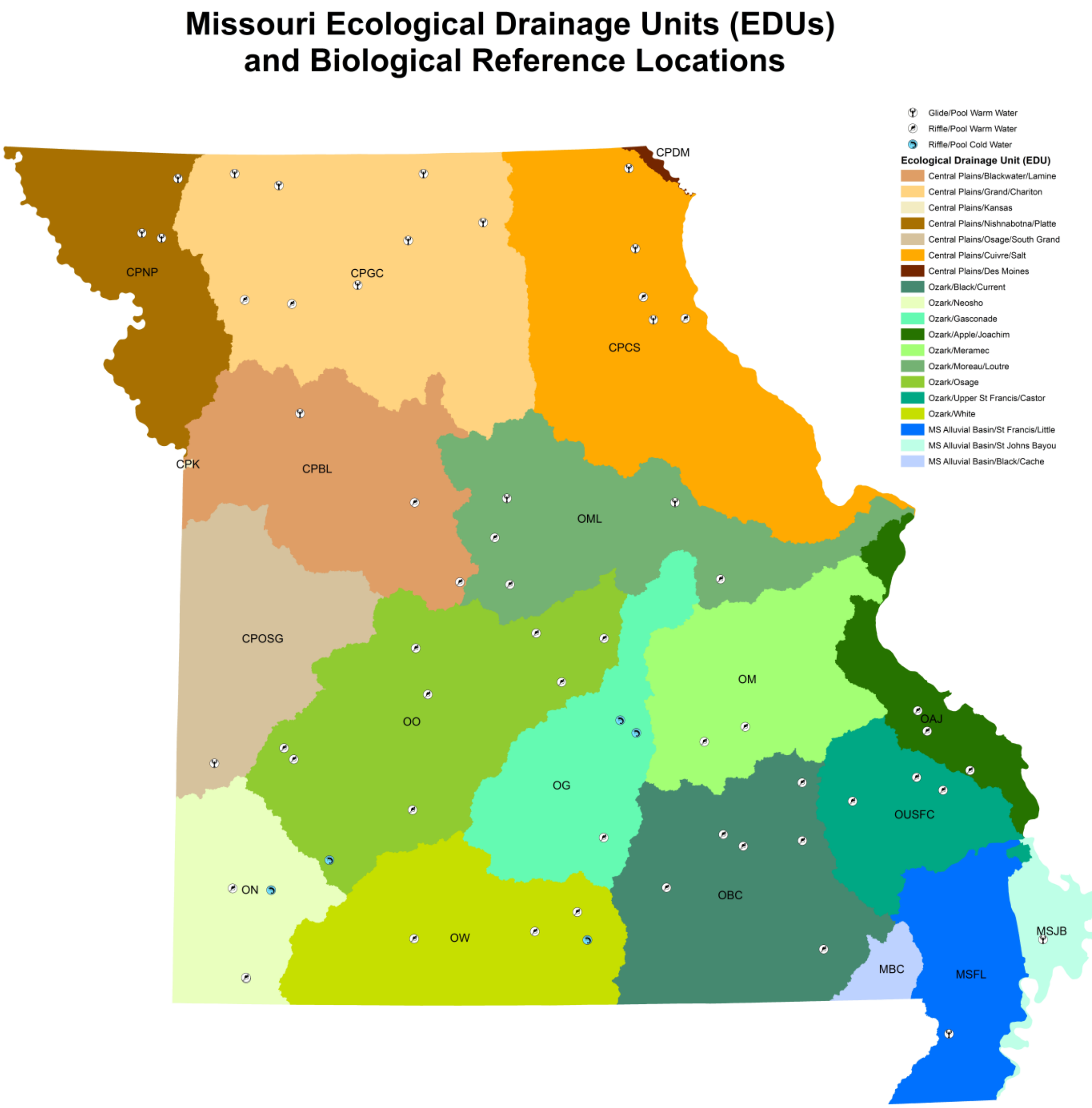

Figure 1: Missouri Ecological Drainage Units (EDUs) and Biological Reference Locations

Unitless metric values (5, 3, or 1) were developed from the lower quartile of the distribution of each metric as calculated from reference streams for each EDU. The lower quartile (25th percentile) of each metric equates to the minimum value still representative of unimpaired conditions. In operational assessments, metric values below the lower quartile of reference conditions are typically judged as impaired (United States Environmental Protection Agency 1996, Ohio Environmental Protection Agency 1990, Barbour *et al.* 1996). Moreover, using the 25th percentile of reference conditions for each metric as a standard for impairment allows natural variability to be filtered out. For metrics with values that decrease with increasing impairment (TR, EPTT, SDI), any value above the lower quartile of the reference distribution receives a score of five. For the BI, whose value increases with increasing impairment, any value below the upper quartile (75th percentile) of the reference distribution receives a score of five. The remainder of each metric's potential quartile range below the lower quartile is bisected, and scored either a three or a one. If the metric value is less than or equal to the quartile value and greater than the bisection value it is scored a three. If the metric value is less than or equal to the bisection value it is scored a one.

MSCI scores meeting data quality considerations may be assessed for the protection of aquatic life using the following procedures.

Determining Full Attainment of Aquatic Life Use:

- For seven or fewer samples, 75% of the MSCI scores must be 16 or greater. Fauna achieving these scores are considered to be very similar to biocriteria reference streams.
- For eight or more samples, results must be statistically similar to representative reference or control streams.

Determining Non-Attainment of Aquatic Life Use:

- For seven or fewer samples, 75% of the MSCI scores must be 14 or lower. Fauna achieving these scores are considered to be substantially different from biocriteria reference streams.
- For eight or more samples, results must be statistically dissimilar to representative reference or control streams.

Data will be judged inconclusive when outcomes do not meet requirements for decisions of full or non-attainment.

As noted, when eight or more samples are available, results must be statistically similar or dissimilar to reference or control conditions in order to make an attainment decision. To accomplish this, a binomial probability with an appropriate level of significance (α=alpha), is calculated based on the null hypothesis that the test stream would have a similar percentage of MSCI scores that are 16 or greater as reference streams. The significance level is set at α=0.1, meaning if the p-value of the hypothesis test is less than α, the hypothesis is considered statistically significant. The significance level of α is in fact the probability of making a wrong decision and committing a Type I error (rejecting a true null hypothesis). When the Type I error rate is less than α=0.1, the null hypothesis is rejected. Inversely, when the Type I error rate is greater than α=0.1, the null hypothesis is accepted. For comparing samples from a test stream to samples collected from reference streams in the same EDU, the percentage of samples from reference streams scoring 16 or greater is used to determine the probability of "success" and "failure" in the binomial probability equation. For example, if 84% of the reference stream MSCI scores in a particular EDU are 16 or greater, then 0.84 would be used as the probability of success and 0.16 would be used as the probability of failure. Note that Appendix D states to "rate a stream as impaired if biological criteria reference stream frequency of fully biologically supporting scores is greater than five percent more than the test stream," thus, a value of 0.79 (0.84 - 0.05) would actually be used as the probability of success in the binomial distribution equation.

Binomial Probability Example:
Reference streams from the Ozark/Gasconade EDU classified as riffle/pool stream types with warm water temperature regimes produce fully biologically supporting streams 85.7% of the time. In the test stream of interest, six out of ten samples resulted in MSCI scores of 16 or more. Calculate the Type I error rate for the probability of getting six or fewer fully biologically supporting scores in ten samples.

The binomial probability formula may be summarized as:

$$p^n + (n!/ X!(n-X)!*p^n q^{n-x}) = 1$$

Where,
Sample Size (n) = 10
Number of Successes (X) = 6
Probability of Success (p) = 0.857 - 0.05 = 0.807
Probability of Failure (q) = 0.193

Excel has the BINOM.DIST function that will perform this calculation.

=BINOM.DIST(number_s,trials,probability_s,cumulative)
=BINOM.DIST(6,10,0.807,TRUE)

Using Excel's Binomial Function	
Probability of Success	0.807
Sample Size	10
# of Successes	6
Type 1 Error Rate	0.109

Since 0.109 is greater than the test significance level (minimum allowable Type I error rate) of α= 0.1, we accept the null hypothesis that the test stream has the same percent of fully biologically supporting scores as the same type of reference streams

from the Ozark/Gasconade EDU. Thus, this test stream would be judged as unimpaired.

If under the same scenario, there were only 5 samples from the test stream with MSCI scores of 16 or greater, the Type I error rate would change to 0.028, and since this value is less than the significance level of α=0.1, the stream would be judged as impaired.

Within each EDU, MSCI scores are categorized by sampling regime (Glide/Pool vs. Riffle/Pool) and temperature regime (warm water vs. cold water). The percentage of fully biologically supporting scores for the Mississippi River Alluvial Basin/Black/Cache EDU is not available due to the lack of reference sites in this region. Percentages of fully biologically supporting samples per EDU is not included here, but can be made available upon request. The percentage of reference streams per EDU that are fully biologically supporting may change periodically as additional macroinvertebrate samples are collected and processed from reference samples within an EDU.

Sample Representativeness
The departments field and laboratory methods used to collect and process macroinvertebrate samples are contained in the document *Semi-Quantitative Macroinvertebrate Stream Bioassessment* (MDNR 2015). Macroinvertebrates are identified to levels following standard operating procedures contained in *Taxonomic Levels for Macroinvertebrate Identifications* (MDNR 2016b). Macroinvertebrate monitoring is accompanied by physical habitat evaluations as described in the document *Stream Habitat Assessment* (MDNR 2016a). For the assessment of macroinvertebrate samples, available information must meet data code levels three and four as described in Section II.C of this LMD. Data coded as levels three and four represent environmental data providing the greatest degree of assurance. Thus, at a minimum, macroinvertebrate assessments include multiple samples from a single site, or samples from multiple sites within a single reach.

It is important to avoid situations where poor or inadequate habitat prohibits macroinvertebrate communities from being assessed as fully biologically supporting. Therefore, when assessing macroinvertebrate samples, the quality of available habitat must be similar to that of reference streams within the appropriate EDU. The department’s policy for addressing this concern has been to exclude MSCI scores from an assessment when accompanying habitat scores are less than 75 percent of the mean habitat scores from reference streams of the appropriate EDU. The following procedures outline the department’s method for assessing macroinvertebrate communities from sites with poor or inadequate habitat.

Assessing Macroinvertebrate Communities from Poor/Inadequate Habitat:

- If less than half the macroinvertebrate samples in an assessed stream segment have habitat scores less than 75 percent of the mean score for reference streams in that EDU, any sample that scores less than 16 and has a habitat score less than 75 percent of the mean reference stream score for that EDU, is excluded from the assessment process.

- If at least half the macroinvertebrate samples in an assessed stream segment have habitat scores less than 75 percent of the mean score for reference streams in that EDU and the assessment results in a judgment that the macroinvertebrate community is impaired, the assessed segment will be placed in Category 4C impairment due to poor aquatic habitat.

    - If one portion of the assessment reach contains two or more samples with habitat scores less than 75 percent of reference streams from that EDU while the remaining portion does not, the portion of the stream with poor habitat scores could be separately assessed as a category 4C stream permitting low MSCI scores.

Macroinvertebrate sampling methods vary by stream type. One method is used in riffle/pool predominant streams, and the other method is for glide/pool predominant streams. For each stream type, macroinvertebrate sampling targets three habitats.

- For riffle/pool streams, the three habitats sampled are flowing water over coarse substrate, non-flowing water over depositional substrate, and rootmat substrate.
- For glide/pool streams, the three habitats sampled are non-flowing water over depositional substrate, large woody debris substrate, and rootmat substrate.

In some instances, one or more of the habitats sampled can be limited or missing from a stream reach, which may affect an MSCI score. Macroinvertebrate samples based on only two habitats may have an MSCI score equal to or greater than 16, but it is also possible that a missing habitat may lead to a decreased MSCI score. Although MDNR stream habitat assessment procedures take into account a number of physical habitat parameters from the sample reach (for example, riparian vegetation width, channel alteration, bank stability, bank vegetation protection, etc.), they do not exclusively measure the quality or quantity of the three predominant habitats from each stream. When evaluating potentially impaired macroinvertebrate communities, the number of habitats sampled, in addition to the stream habitat assessment score, will be considered to ensure MSCI scores less than 16 are properly attributed to poor water quality or poor/inadequate habitat condition.

Biologists responsible for conducting biological assessments will determine the extent to which habitat availability is responsible for a non-supporting (<16) MSCI score. If it is apparent that a non-supporting MSCI score was due to limited habitat, these effects will be stated in the biological assessment report. This limitation will then be considered when deciding which Listing Methodology category is most appropriate for an individual stream. This procedure, as part of an MDNR biological assessment, will aid in determining whether impaired macroinvertebrate samples have MSCI scores based on poor water quality conditions versus habitat limitations.

To ensure assessments are based on representative macroinvertebrate samples, samples collected during or shortly after prolonged drought, shortly after major flood events, or any other conditions that fall outside the range of environmental conditions under which reference streams in the EDU were sampled, will not be used to make an attainment decision for a Section 303(d) listing or any other water quality assessment purposes. Sample "representativeness" is judged by Water Protection Program (WPP) staff after reading the biomonitoring report for that stream, and if needed, consultation with biologists from the department's Environmental Services Program. Regarding smaller deviations from "normal" conditions, roughly 20 percent of reference samples failing to meet a fully biologically supporting MSCI score were collected following weather/climate extremes; as a result, biological criteria for a given EDU are inclusive of samples collected during not only ideal macroinvertebrate-rearing conditions, but also during the weather extremes that Missouri experiences.

Assessing Small Streams

Occasionally, macroinvertebrate monitoring is needed to assess streams smaller than the typical wadeable/perennial reference streams listed in Table I of Missouri's Water Quality Standards. Smaller streams may include Class C streams (streams that may cease flow in dry periods but maintain permanent pools which support aquatic life) or those that are unclassified. Assessing small streams involves comparing test stream and candidate reference stream MSCI scores first, to Wadeable/Perennial Reference Stream (WPRS) criteria, and second to each other.

In MDNR's Biological Criteria Database, there are 16 candidate reference streams labeled as Class P, 23 labeled as Class C, and 24 labeled as Class U. In previous work by MDNR, when the MSCI was calculated according to WPRS criteria, the failure rate for such candidate reference streams was 31% for Class P, 39% for Class C, and 70% for Class U. The data trend showed a higher failure rate for increasingly smaller high quality streams when scored using WPRS biological criteria. This trend demonstrates the need to include the utilization of candidate reference streams in biological stream assessments.

Prior to the 2014 revision of the Missouri Water Quality Standards there was no size classification for streams. The 2014 revision codified size classification for rivers and streams based on five size categories for Warm Water, Cool Water and Cold Water Habitats. The size classifications are defined as Headwater, Creek, Small River, Large River and Great River. Water permanence continues to be classified as Class P (streams that maintain permanent flow even in drought periods); Class C (streams that cease flow in dry periods but maintain permanent pools which support aquatic life); and the newly adopted Class E (streams that do not maintain permanent surface flow or pools, but have surface flow or pools in response to precipitation events).

Table I of Missouri's Water Quality Standards lists 62 wadeable/perennial reference streams that provide the current basis for numeric biological criteria. Wadeable/perennial reference streams are a composite of Creek and Small River size classes. Interpretation of Creek (Size Code 2) and Small River (Size Code 3) is based on the Missouri Resource

Assessment Partnership Shreve Link number found in Table 2. These wadeable/perennial reference streams were selected previous to the 2014 revision of the Missouri Water Quality Standards and were based on the former Table H (Stream Classifications and Use Designations). All, or a portion, of seven wadeable/perennial reference streams are Class C; and all, or a portion, of 57 wadeable/perennial reference streams are Class P.

As part of the 2014 revision of the Missouri Water Quality Standards, classified streams were changed from Table H to a modified version of the 1:100,000 National Hydrography Dataset. This dataset provides a geospatial framework for classified streams and is referred to as the Missouri Use Designation Dataset (MUDD). The streams and rivers now listed in MUDD contain approximately 100,000 miles of newly classified streams, many of which are the Headwater size class. Interpretation of Headwater size (Size Code 1) is based on the Missouri Resource Assessment Partnership Shreve Link number found in Table 2

Table 2.
Missouri Resource Assessment Partnership Shreve Link Number for Stream Size Code

Stream Size	Size Code	Plains Shreve Link Number	Ozark Shreve Link Number
Headwater	1	1-2	1-4
Creek	2	3-30	5-50
Small river	3	31-700	51-450
Large River	4	701-maximum	451- maximum
Great River	5	Missouri & Mississippi	Missouri & Mississippi
Unknown	0		

In natural channels, biological assessments will be based on criteria established from comparable stream size and permanence. The need for alternate criteria is supported by the higher failure rate (70%) for small size streams when scored using wadeable/perennial reference stream biological criteria (MDNR, unpublished data). Since headwater stream biological criteria have not been established, the utilization of candidate headwater reference streams and draft criteria will be necessary to perform biological stream assessments of headwater size streams.

For test streams that are smaller than wadeable perennial reference streams, MDNR also samples five candidate reference streams (small control streams) of same or similar size and Valley Segment Type (VST) in the same EDU twice during the same year the test stream is sampled (additional information about the selection small control streams is provided below). Although in most cases the MDNR samples small candidate reference streams concurrently with test streams, existing data may be used if a robust candidate reference stream data set exists for the EDU.

If the ten small candidate reference stream scores are similar to wadeable perennial reference stream criteria, then they and the test stream are considered to have a Class C or Class P general warm water beneficial use, and the MSCI scoring system in the LMD should be used. If the small candidate reference streams have scores lower than the wadeable perennial reference streams, the assumption is that the small candidate reference streams, and the test stream, represent designated uses related to stream size that are not yet approved by EPA in the state's water quality standards. The current assessment method for test streams that are smaller than reference streams is stated below.

- If the ten candidate reference stream (small control stream) scores are similar to WPRSs and meet LMD criteria for an unimpaired macroinvertebrate community, then the test stream will be assessed using MSCI based procedures in the LMD.

- If the ten candidate reference stream scores are lower than those of WPRSs and do not meet the LMD criteria for an unimpaired macroinvertebrate community, then:

    a) The test stream will be assessed as having an unimpaired macroinvertebrate community if the test stream scores meet the LMD criteria for an unimpaired community;
    b) The test stream data will be judged inconclusive if test stream scores are similar to candidate reference stream scores;
    c) The test stream will be assessed as having a "suspect" macroinvertebrate community if its scores are found to be low but statistically close to candidate reference streams; or,
    d) The test stream will be assessed as having an "impaired" macroinvertebrate community if its scores are found to be statistically lower than the candidate reference streams.

This method of assessing small streams will be used only until such time as the aquatic habitat protection use categories based on watershed size classifications of Headwater, Creek, Small River, Large River and Great River are ~~is~~ promulgated into Missouri Water Quality Standards and appropriate biological metrics are established for stream size and permanence.

The approach for determining a "suspect" or "impaired" macroinvertebrate community will be made using a direct comparison between all streams being evaluated, which may include the use of percent and/or mean calculations as determined on a case by case basis. All work will be documented on the macroinvertebrate assessment worksheet and be made available during the public notice period.

Selecting Small Candidate Reference Streams

Accurately assessing streams that are smaller than reference streams begins with properly selecting small candidate reference streams. Candidate reference streams are smaller than WPRS streams and have been identified as "best available" reference stream segments in the same EDU as the test stream according to watershed, riparian, and in-channel conditions. The selection of candidate reference streams is consistent with framework provided by Hughes *et al*. (1986) with added requirements that candidate reference streams must be from the same EDU and have the same or similar values for VST parameters. If candidate reference streams perform well when compared to WPRS, then test streams of similar size and VST are expected to do so as well. VST parameters important for selection are based on temperature, stream size, flow, geology, and relative gradient, with emphasis placed on the first three parameters.

The stepwise process for candidate reference stream selection is listed below.

1. Determine test stream reaches to be assessed. *Missouri Department of Natural Resources staff in the Water Protection Program's Monitoring and Assessment Unit will use data that indicates potential impairment to determine where additional studies are needed. Department staff with the Environmental Services Program's Aquatic Bioassessment Unit will be used to conduct studies requested by the WPP.*

2. Identify appropriate EDU. *The Ecological Drainage Unit in which the test stream is located will be identified so that applicable biological criteria can be used to score macroinvertebrate data collected by Department biologists.*

3. Determine five variable VST of test stream segments (1st digit = temperature; 2nd digit = size; 3rd digit = flow; 4th digit = geology; and 5th digit = relative gradient). *This five-digit VST code provides a description of the test stream for later use in selecting appropriate candidate reference streams that are similar to the test stream (giving temperature, size, and flow the highest importance).*

4. Filter all stream segments within the same EDU for the relevant five variable VSTs (1st and 2nd digits especially critical for small streams). *The five VST features of the test stream will be determined by checking the "AQUATIC.STRM_SEGMENTS" layer in GIS software (e.g. ArcMap). This layer has an associated Attribute Table that has, among many other features, the five-digit VST code for classified Missouri streams. During the filtering process, the five-digit code (listed as "VST_5VAR in the Attribute Table) of the test stream is chosen in an ArcMap tool called "Select by Attributes." The five-digit code of the test stream is entered into this ArcMap tool, which can then be used to list only streams with the same five VST variables while excluding (i.e. "filtering out") all other streams with different variables.*

5. Filter all potential VST stream segments for stressors against available GIS layers (e.g. point source, landfills, CAFOs, lakes, reservoirs, mining, etc.). *A GIS layer that includes the stream segments selected in Step 4 will be created. The proximity of these selected stream layers will be evaluated relative to stressor layers cataloged in GIS using filtering steps similar to those described above. Stream segments with stressors having documented impacts will be eliminated from further consideration.*

6. Filter all potential VST stream segments against historical reports and databases. *Past accounts of occurrences that may result in a stream failing to meet the "best available, least impaired" criteria will be evaluated. These incidents may include events such as fish kills, combined sewer overflows, or past environmental emergencies (e.g. releases of toxic substances). In contrast, historical reports may also include studies by other biologists that support the use of a candidate reference stream.*

7. Develop candidate stream list with coordinates for field verification.

8. Field verify candidate list for actual use (e.g. animal grazing, in-stream habitat, riparian habitat), migration barriers (e.g. culverts, low water bridge crossings) representativeness, (gravel mining, and other obvious human stressors). *Biologists can make additional fine-scale adjustments to the list of candidate streams by visiting sites in person. Certain features visible on-site may have been missed with GIS and other computer based filtering. Stream flow must be field verified to be similar to test streams.*

9. *Of the sites remaining after field verification and elimination, at least five of the top ranked candidate sites will be subjected to additional evaluation outlined below.*

> *For steps 4-9: These steps occur at the EDU level identified in step 2. These steps look at all streams within the identified EDU including those in the same Aquatic Ecological System (AES) Type as the test stream. Streams in the same AES Type as the test stream (within the identified EDU) will be given preference and be selected to go through the remaining steps (10-13) below.*

10. Calculate land use-land cover *of stream watershed* and compare to EDU. *Streams within the same EDU tend to be more similar to each other than to streams in different EDUs. A reference stream should be representative of the best available conditions in an EDU and should have similar land use-land cover compared to the EDU as a whole. This approach will ensure that waters with similar habitats are compared, provided that the candidate reference is representative of the least impaired and best available condition in the EDU.*

11. Collect chemical, biological, habitat, and possibly sediment field data. *Collection of physical samples is the ultimate manner in which the quality of a stream is judged. Although factors evaluated in the previous steps are good indicators of whether a stream is of reference quality, it is the evaluation of chemical, physical and biological attributes that is the final determinant. If chemical sampling documents an exceedance of water quality standards, the candidate reference stream will be eliminated from consideration.*

12. After multiple sampling events evaluate field data, land use, and historical data in biological assessment report. *Aquatic systems are subject to fluctuation due to weather, stream flow, and other climatic conditions. Land use in the watershed of a candidate reference also can change over time. It is therefore important to collect multiple samples*

over time that are reflective of a variety of conditions to adequately judge a candidate stream's macroinvertebrate community.

13. If field data are satisfactory, retain candidate reference stream label in database. *Reference streams and candidate reference streams are labelled as such in a database maintained by the Department's Aquatic Bioassessment Unit in Jefferson City, Missouri*

Fish Community Data

The department utilizes fish community data to determine if aquatic life use is supported in certain types of Missouri streams. When properly evaluated, fish communities serve as important indicators of stream health. In Missouri, fish communities are surveyed by the MDC. MDC selects an aquatic subregion to sample each year, and therein, surveys randomly selected streams of 2nd to 5th order in size. Fish sampling follows procedures described in the document *Resource Assessment and Monitoring Program: Standard Operational Procedures--Fish Sampling* (Combes 2011). Numeric biocriteria for fish are represented by the fish Index of Biotic Integrity (fIBI). Development of the fIBI is described in the document *Biological Criteria for Stream Fish Communities of Missouri* (Doisy *et al.* 2008).

The fIBI is a multi-metric index made up of nine individual metrics, which include:

- number (#) of native individuals;
- # of native darter species;
- # of native benthic species;
- # of native water column species;
- # of native minnow species;
- # of all native lithophilic species;
- percentage (%) of native insectivore cyprinid individuals;
- % of native sunfish individuals; and,
- % of the three top dominant species.

Values for each metric, as directly calculated from the fish community sample, are converted to unitless scores of 1, 3, or 5 according to criteria in Doisy *et al.* (2008). The fIBI is then calculated by adding these unitless values together for a total possible score of 45. Doisy *et al.* (2008) established an impairment threshold of 36 (where the 25th percentile of reference sites represented a score of 37), with values equal to or greater than 36 representing unimpaired communities, and values less than 36 representing impaired communities. For more information regarding fIBI scoring, please see Doisy *et al.* (2008).

Based on consultation between the department and MDC, the fIBI impairment threshold value of 36 was used as the numeric biocriterion translator for making an attainment decision for aquatic life (Appendix C). Work by Doisy *et al.* (2008) focused on streams 3rd to 5th order in size, and the fIBI was only validated for streams in the Ozark ecoregion, not for streams in the Central Plains and Mississippi Alluvial Basin. Therefore, when assessing streams with the fIBI, the index may only be applied to streams 3rd to 5th order in size from the Ozark ecoregion. Assessment procedures are outlined below.

Full Attainment

- For seven or fewer samples and following MDC RAM fish community protocols, 75% of fIBI scores must be 36 or greater. Fauna achieving these scores are considered to be very similar to Ozark reference streams.

- For eight or more samples, the percent of samples scoring 36 or greater must be statistically similar to representative reference or control streams. To determine statistical similarity, a binomial probability Type I error rate (0.1) is calculated based on the null hypothesis that the test stream would have the same percentage (75%) of fIBI scores greater than 36 as reference streams. If the Type I error rate is more than the significance level $\alpha=0.1$, the fish community would be rated as unimpaired.

Non-Attainment

- For seven or fewer samples and following MDC RAM fish community protocols, 75% of the fIBI scores must be lower than 36. Fauna achieving these scores are considered to be substantially different than regional reference streams.

- For eight or more samples, the percent of samples scoring 36 or less must be statistically dissimilar to representative reference or control streams. To determine statistical dissimilarity, a binomial probability Type I error rate is calculated based on the null hypothesis that the test stream would have the same percentage (75%) of fIBI scores greater than 36 as reference streams. If the Type I error rate is less than 0.1, the null hypothesis is rejected and the fish community would be rated as impaired.

Data will be judged inconclusive when outcomes do not meet requirements for decisions of full or non-attainment.

With the exception of two subtle differences, use of the binomial probability for fish community samples will follow the example provided for macroinvertebrate samples in the previous section. First, instead of test stream samples being compared to reference streams of the same EDU, they will be compared to reference streams from the Ozark ecoregion. Secondly, the probability of success used in the binomial distribution equation will always be set to 0.70 since Appendix D states to "rate a stream as impaired if biological criteria reference stream frequency of fully biologically supporting scores is greater than five percent more than the test stream."

Although 1st and 2nd order stream data will not be used to judge a stream as impaired for Section 303(d) purposes, the department may use the above assessment procedures to judge 1st and 2nd order streams as unimpaired. Moreover, should samples contain fIBI scores less than 29, the department may judge the stream as "suspected of impairment" using the above procedures.

Considerations for the Influence of Habitat Quality and Sample Representativeness
Low fIBI scores that are substantially different than reference streams could be the result of water quality problems, habitat problems, or both. When low fIBI scores are established, it is necessary to review additional information to differentiate between an impairment caused by water quality and one that is caused by habitat. The collection of a fish community sample is also accompanied by a survey of physical habitat from the sampled reach. MDC sampling protocol for stream habitat follows procedures provided by Peck *et al.* (2006). With MDC guidance, the department utilizes this habitat data and other available information to assure that an assessment of aquatic life attainment based on fish data is only the result of water quality, and that an impairment resulting from habitat is categorized as such. This section describes the procedures used to assure low fIBI scores are the result of water quality problems and not habitat degradation. The information below outlines the department's provisional method to identify unrepresentative samples and low fIBI scores with questionable habitat condition, and ensure corresponding fish IBI scores are not used for Section 303(d) listing.

a) Following recommendations from the biocriteria workgroup, the department will consult MDC about the habitat condition of particular streams when assessing low fIBI scores.

b) Samples may be considered for Section 303(d) listing ONLY if they were collected in the Ozark ecoregion, and the samples were collected during normal representative conditions, based upon best professional judgment from MDC staff,. Samples collected from the Central Plains and Mississippi Alluvial Basin are excluded from Section 303(d) listing.

c) Only samples from streams 3rd to 5th order in size may be considered for Section 303(d) listing. Samples from 1st or 2nd order stream sizes are excluded from Section 303(d) consideration; however, they may be placed into Categories 2B and 3B if impairment is suspected, or into Categories 1, 2A, or 3A if sample scores indicate a stream is unimpaired. Samples from lower stream orders are surveyed under a different RAM Program protocol than 3rd to 5th order streams.

d) Samples that are ineligible for Section 303(d) listing include those collected from losing streams, as defined by the Department of Geology and Land Survey, or collected in close proximity to losing streams. Additionally, ineligible samples may include those collected on streams that were considered to have natural flow issues (such as streams reduced predominately to subsurface flow) preventing good fish IBI scores from being obtained, as determined through best professional judgment of MDC staff.

e) Fish IBI scores must be accompanied by habitat samples with a QCPH1 habitat index score. MDC was asked to analyze meaningful habitat metrics and identify samples where habitat metrics seemed to indicate potential habitat concerns. As a result, a provisional index named QCPH1 was developed. QCPH1 values less than 0.39 indicate poor habitat, and values greater than 0.39 suggest adequate habitat is available. The QCPH1 comprises six sub-metrics indicative of substrate quality, channel disturbance, channel volume, channel spatial complexity, fish cover, and tractive force and velocity.

The QCPH1 index is calculated as follows:

QCPH1= ((Substrate Quality*Channel Disturbance*Channel Volume* Channel Spatial Complexity * Fish Cover * Tractive Force & Velocity)$^{1/6}$)

Where sub-metrics are determined by:

Substrate Quality = [(embeddedness + small particles)/2] * [(filamentous algae + aquatic macrophyte)/2] * bedrock and hardpan

Channel Disturbance = concrete * riprap * inlet/outlet pipes * relative bed stability * residual pool observed to expected ratio

Channel Volume = [(dry substrate+width depth product + residual pool + wetted width)/4]

Channel Spatial Complexity = (coefficient of variation of mean depth + coefficient of variation of mean wetted width + fish cover variety)/3

Fish Cover = [(all natural fish cover + ((brush and overhanging vegetation + boulders + undercut bank + large woody debris)/4) + large types of fish cover)/3]

Tractive Force & Velocity = [(mean slope + depth * slope)/2]

Unimpaired fish IBI samples (fIBI ≥36) with QCPH1 index scores below the 0.39 threshold value, or samples without a QCPH1 score altogether, are eliminated from consideration for Category 5 and instead placed into Categories 2B or 3B should an impairment be suspected. Impaired fish communities (fIBI <36) with QCPH1 scores <0.39 can be placed into Category 4C (non-discrete pollutant/habitat impairment). Impaired fish communities (fIBI <36) with adequate habitat scores (QCPH1 >0.39) can be placed into Category 5. Appropriate streams with unimpaired fish communities and adequate habitat (QCPH1 >0.39) may be used to judge a stream as unimpaired.

Similar to macroinvertebrates, assessment of fish community information must be based on data coded level three or four as described in Section II.C of this document. Data coded as levels three and four represent environmental data with the greatest degree of assurance, and thus, assessments will include multiple samples from a single site, or samples from multiple sites within a single reach.

Following the department's provisional methodology, fish community samples available for assessment (using procedures in Appendix C & D include only those from 3rd to 5th order Ozark Plateau streams, collected under normal, representative conditions, where habitat seemed to be good, and where there were no issues with inadequate flow or water volume.

IV. Other Biological Data

On a case by case basis, the department may use biological data other than MSCI or fIBI scores for assessing attainment of aquatic life. Other biological data may include information on single indicator aquatic species that are ecologically or recreationally important, or individual measures of community health that respond predictably to environmental stress. Measures of community health could be represented by aspects of structure, composition, individual health, and processes of the aquatic biota. Examples could include measures of density or diversity of aquatic organisms, replacement of pollution intolerant taxa, or even the presence of biochemical markers.

Acute or Chronic Toxicity Tests

If toxicity tests are to be used as part of the weight of evidence then accompanying media (water or sediment) analysis must accompany the toxicity test results. (e.g. Metals concentrations in the sediment sample used for an acute toxicity test must accompany the toxicity test results if metals are a concern; or if PAHs are a concern then TOC must accompany toxicity test results). The organism, its developmental stage used for the toxicity test, and the duration of the test must also accompany the results.

Other biological data should be collected under a well vetted study that is documented in a scientific report, a weight of evidence approach should be established, and the report should be referenced in the 303(d) listing worksheet. If other biological data is a critical component of the community and has been adversely affected by the presence of a pollutant or stressor, then such data would indicate a water body is impaired. The department's use of other biological data is consistent with EPA's policy on independent applicability for making attainment decisions, which is intended to protect against dismissing valuable information when diagnosing an impairment of aquatic life.

The use of other biological data in water body assessments occurs infrequently, but when available, it is usually assessed in combination with other information collected within the water body of interest. The department will avoid using other biological data as the sole justification for a Section 303(d) listing; however, other biological data will be used as part of a weight of evidence analysis for making the most informed assessment decision.

V. Toxic Chemicals

Water

For the interpretation of toxicity test data, standard acute or chronic bioassay procedures using freshwater aquatic fauna such as, but not limited to, *Ceriodaphnia dubia*, Fathead Minnows (*Pimephales promelas*), *Hyalella azteca*, or Rainbow Trout (*Oncorhynchus mykiss)*[18] will provide adequate evidence of toxicity for 303(d) listing purposes. Microtox®toxicity tests may be used to list a water as affected by "toxicity" only if there are data of another kind (freshwater toxicity tests, sediment chemistry, water chemistry, or biological sampling) that indicate water quality impairment.

For any given water, available data may occur throughout the system and/or be concentrated in certain areas. When the location of pollution sources are known, the department reserves the right to assess data representative of impacted conditions separately from data representative of unimpacted conditions. Pollution sources include those that may occur at discrete points along a water body, or those that are more diffuse.

Chronic Toxicity Events

Parameters in WQS that are labeled as chronic criterion can be assessed in two ways:

1. Continuous Data Sondes
   a. For data that has been collected consecutively over time, (eg. A data sonde collecting pH every 15 minutes or a two week time period) the data will be used as is after QA/QC procedures.
2. Grab Samples
   a. For samples that have not been collected consecutively, (eg. Grab sample collected once a week) the hydrologic flow conditions of the stream or the closest USGS gage will be used to verify the sample was collected during stable flow conditions. If the flow conditions were unstable then the sample will not be assessed against the chronic criterion. If the flow conditions were stable then the sample will be assessed against the chronic criterion. There are three categories of stable flow conditions: High, Medium, and Low.
      i. High Stable Flow – is greater than the 50th percentile exceedance flow and less than 10% change in flow over a 48 hour period.
      ii. Medium Stable Flow – is between the 90th percentile exceedance flow and the 50th percentile exceedance flow and less than 15% change in flow over a 48 hour period.
      iii. Low Stable Flow – is less than the 90th percentile exceedance flow or less than one cubic foot per second and less than 20% change in flow over a 48 hour period.

Sediment

For toxic chemicals occurring in benthic sediments, data interpretation will include calculation of a geometric mean for specific toxins from an adequate number of samples, and comparing that value to a corresponding Probable Effect Concentration (PEC) given by MacDonald *et al.* (2000). The PEC is the level of a pollutant above which harmful effects

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18 Reference 10 CSR 20-7.015(9)(L) for additional information

on the aquatic community are likely to be observed. MacDonald (2000) gave an estimate of accuracy for the ability of individual PECs to predict toxicity. For all metals except arsenic, pollutant geometric means will be compared to 150% of the recommended PEC values. These comparisons should meet confidence requirements applied elsewhere in this document When multiple metal contaminants occur in sediment, toxicity may occur even though the level of each individual pollutant does not reach toxic levels. The method of estimating the synergistic effects of multiple metals in sediments is described below.

The sediment PECs given by MacDonald *et. al.* (2000) are based on some additional data assumptions. Those assumptions include a 1% Total Organic Carbon (TOC) content and that the sample has been sieved to less than 2mm.

The department uses 150% of the PEC values to account for some variability in our assessment of sediment toxicity. Also see the ***Equilibrium Partitioning Sediment Benchmark*** section on page 39 for information on TOC and sulfide considerations for metals toxicity in sediment.

For the sample sieving assumption, the department will use non-sieved (bulk) sediment concentrations for screening level data (Data Code One). Current impairments that have used bulk sediment data as evidence for impairment will remain on the list of impaired streams until sieved data can be collected to show either that it should remain on the list or that the sieved concentrations are below the 150% PEC values. Data that has been sieved to less than 2mm or smaller will be used for comparison to the 150% PEC values.

The Meaning of the Sediment Quotient and How to Calculate It

Although sediment criteria in the form of a PEC are given for several individual contaminants, it is recognized that when multiple contaminants occur in sediment, toxicity may occur even though the level of each individual pollutant does not reach toxic levels. The method of estimating the synergistic effects of multiple pollutants in sediments given in MacDonald *et al.* (2000) includes the calculation of a PECQ. PECQs greater than 0.75 will be judged as toxic.

This calculation is made by dividing the pollutant concentration in the sample by the PEC value for that pollutant. For single samples, the quotients are summed, and then normalized by dividing that sum by the number of pollutants in the formula. When multiple samples are available, the geometric mean (as calculated for specific pollutants) will be placed in the numerator position for each pollutant included in the equation.

Example: A sediment sample contains the following results in mg/kg:

Arsenic 2.5, Cadmium 4.5, Copper 17, Lead 100, and Zinc 260.

The PEC values for these five pollutants in respective order are:

33, 4.98, 149, 128, and 459 mg/kg.

PECQ =

$$[(2.5/33) + (4.5/4.98) + (17/149) + (100/128) + (260/459)]/5 = 0.488$$

Using PECQ to Judge Metals Toxicity

Based on research by MacDonald *et al.* (2000) 83% of sediment samples with a PECQ less than 0.5 were non-toxic while 85% of sediment samples with a PECQ greater than 0.5 were toxic. Therefore, to accurately assess the synergistic effects of sediment contaminants on aquatic life, the department will judge PECQ greater than 0.75 as toxic**.**

Using Total PAHs to Judge Toxicity

Polycyclic Aromatic Hydrocarbons (PAHs) are organic compounds containing carbon and hydrogen forming aromatic rings (cyclic molecular shapes). The presence of PAHs in the environment when not expected (natural sources can be coal and oil deposits) result from the use and breakdown hydrocarbon compounds. There are three different sources of hydrocarbon compounds: plants (Phytogenic), petroleum (Petrogenic), and the combustion of petroleum, wood, coal etc. (Pyrogenic). Most common sources of PAHs in stream are sealants (coal tar) and other treatments of roads, driveways, and parking lots.

Mount *et al.* (2003) indicates that individual PAH sediment guidelines (PECs) are based on the samples also having an elevated presence of additional PAHs, potentially overestimating the actual toxicity of an individual PAH PEC value. The use of a Total PAH guideline (PEC) reduces variability and provides a better representation of toxicity than the use of individual PAH PECs.

Based on research by MacDonald *et.al* (2000) 81.5% of sediment samples with a Total PAH value less than 22.8 mg/kg (ppm) were non-toxic while 100% of sediment samples with a Total PAH value greater than 22.8 mg/kg (ppm) were toxic. Therefore, to accurately assess the toxicity to aquatic life of total PAHs in sediment, the department will judge Total PAH values greater than 150% of the PEC value (34.2 mg/kg) as toxic. For PAHs the sum of the geometric means for all PAH compounds will be compared to 150% of the recommended PEC value for total PAHs.

What compounds are considered in calculating Total PAHs and how will they be compared to the 150% PEC value?

To calculate Total PAHs for a sample, Mount *et.al*. (2003) recommends following United States Environmental Protection Agency, Environmental Monitoring Assessment Program's definition of Total PAHs. This definition includes 34 PAH compounds; 18 parent PAHs and 16 alkylated PAHs. (See Table 3 below for a list of these compounds.) Mount *et.al.* (2003) shows that using less than the 34 PAH compounds can underestimate the toxicity of PAHs in sediment. Total Organic Carbon (TOC) has the potential to affect the bioavailability of PAHs. Organic carbon can provide a binding phase for PAHs, but the extent of that binding capacity is unknown. Through the Weight of Evidence approach (see section D II) the department will consider the effects of TOC on a case by case basis.

Commonly only 14 to 18 of the 34 PAH compounds are requested for analysis. Therefore the process to judge toxicity due to total PAHs is as follows:

- If samples are analyzed for fewer than the 34 PAH compounds then
  - If the sum (sum of the geometric means for more than one sample) of those compounds is greater than the 150% PEC then the sample(s) will be judged as toxic.
  - If the sum (sum of the geometric means for more than one sample) of those compounds is greater than the 100% PEC but less than 150% of the PEC then the sample(s) will be judged as inconclusive.
  - If the sum (sum of the geometric means for more than one sample) of those compounds is less than the 100% PEC then the values will be judged as non-toxic.
- If samples are analyzed for the 34 PAH compounds then
  - If the sum (sum of the geometric means for more than one sample) of those compounds is greater than the 150% PEC then the sample(s) will be judged as toxic.
  - If the sum (sum of the geometric means for more than one sample) of those compounds is less than the 150% PEC then the values will be judged as non-toxic.

Table 3. List of 34 polycyclic aromatic hydrocarbon (PAH) compounds that are considered for the calculation of total PAHs.

Parent PAHs	Alkylated PAHs
Acenaphthene	C1-Benzanthracene/chrysenes
Acenphthylene	C1-Fluorenes
Anthracene*	C1-Naphthalenes
Benz(a)anthracene*	C1-Phenanthrene/anthracenes
Benzo(a)pyrene*	C1-Pyrene/fluoranthenes
Benzo(b)fluoranthene	C2-Benzanthracene/chrysenes
Benzo(e)pyrene	C2-Fluorenes
Benzo(g,h,i)perylene	C2-Naphthalenes
Benzo(k)fluoranthene	C2-Phenanthrene/anthracenes

Chrysene*	C3-Benzanthracene/chrysenes
Dibenz(a,h)anthracene	C3-Fluorenes
Fluoranthene*	C3-Naphthalenes
Fluorene*	C3-Phenanthrene/anthracenes
Indeno(1,2,3-cd)pyrene	C4-Benzanthracene/chrysenes
Naphthalene*	C4-Naphthalenes
Perylene	C4-Phenanthracene/anthracenes
Phenanthrene*	
Pyrene*	
**Listed in Table 3 of MacDonald et.al (2000)*	

Equilibrium Partitioning Sediment Benchmark (ESB) Data

Another type of analysis of the toxicity of metals in sediment is based on the EPA (2006) paper that discusses ESBs and their use. The department will not be collecting this type of data but will consider the data under the weight of evidence approach. To be considered the data must be accompanied by the name of the laboratory that completed the analysis and a copy of their laboratory procedures and QC documentation. Sieved sediment samples will be judged as toxic for metals in sediment if the sum of the simultaneously extracted metals minus acid volatile sulfides then divided by the fractional organic carbon [(ΣSEM-AVS)/FOC] is greater than 3000. If additional sieved sediment samples also show toxicity for a particular metal(s) then that particular metal(s) will be identified as the cause for toxicity.

Pictorial Representations (flow charts) for how these different sediment toxicity procedures could be used in the weight of evidence procedure are displayed in Appendix E.

VI. Duration of Assessment Period

Except where the assessment period is specifically noted in Appendix B, the time period during which data will be used in making the assessments will be determined by data age and data code considerations, as well as representativeness considerations such as those described in footnote 14.

VII. Assessment of Tier Three Waters

Waters given Tier Three protection by the anti-degradation rule at 10 CSR 20-7.031(2) shall be considered impaired if data indicate water quality has been reduced in comparison to its historical quality. Historical quality is determined from past data that best describes a water body's water quality following promulgation of the anti-degradation rule and at the time the water was given Tier Three protection.

Historical data gathered at the time waters were given Tier Three protection will be used if available. Because historical data may be limited, the historical quality of the waters may be determined by comparing data from the assessed segment with data from a "representative" segment. A representative segment is a body or stretch of water that best reflects the conditions that probably existed at the time the anti-degradation rule first applied to the waters being assessed. Examples of possible representative data include 1) data from stream segments upstream of assessed segments that receive discharges, and 2) data from other water bodies in the same ecoregion having similar watershed and landscape characters. These representative stream segments also would be characterized by receiving discharges similar to the quality and quantity of historic discharges of the assessed segment. The assessment may also use data from the assessed segment gathered between the time of the initiation of Tier Three protection and the last known time in which upstream discharges, runoff, and watershed conditions remained the same, provided that the data do not show any significant trends of declining water quality during that period.

The data used in the comparisons will be tested for normality and an appropriate statistical test will be applied. The null hypothesis for statistical analysis will be that water quality at the test segment and representative segment is the same. This will be a one-tailed test (the test will consider only the possibility that the assessed segment has poorer water quality) with the alpha level of 0.1, meaning that the test must show greater than a 90 percent probability that the assessed segment has poorer water quality than the representative segment before the assessed segment can be listed as impaired.

VIII. Other Types of Information

1. Observation and evaluation of waters for noncompliance with state narrative water quality criteria. Missouri's narrative water quality criteria, as described in 10 CSR 20-7.031 Section (3), may be used to evaluate waters when a quantitative (narrative) value can be applied to the pollutant. These narrative criteria apply to both classified and unclassified waters and prohibit the following in waters of the state:
    a. Waters shall be free from substances in sufficient amounts to cause the formation of putrescent, unsightly, or harmful bottom deposits or prevent full maintenance of beneficial uses;
    b. Waters shall be free from oil, scum, and floating debris in sufficient amounts to be unsightly or prevent full maintenance of beneficial uses;
    c. Waters shall be free from substances in sufficient amounts to cause unsightly color or turbidity, offensive odor, or prevent full maintenance of beneficial uses;
    d. Waters shall be free from substances or conditions in sufficient amounts to result in toxicity to human, animal, or aquatic life;

e. There shall be no significant human health hazard from incidental contact with the water;

f. There shall be no acute toxicity to livestock or wildlife watering;

g. Waters shall be free from physical, chemical, or hydrologic changes that would impair the natural biological community;

h. Waters shall be free from used tires, car bodies, appliances, demolition debris, used vehicles or equipment, and solid waste as defined in Missouri's Solid Waste Law, section 260.200, RSMo, except as the use of such materials is specifically permitted pursuant to sections 260.200–260.247, RSMo;

2. Habitat assessment protocols for wadeable streams have been established and are conducted in conjunction with sampling aquatic macroinvertebrates and fish. Methods for evaluating aquatic macroinvertebrate and fish community data include assessment procedures that account for the presence or absence of representative habitat quality. The department will not use habitat data alone for assessment purposes.

E. Other 303(d) Listing Considerations

- Adding to the Existing List or Expanding the Scope of Impairment to a Previously Listed Water.

  The listed portion of impaired water bodies may be increased based on recent monitoring data following the guidelines in this document. One or more new pollutants may be added to the listing for a water body already on the list based on recent monitoring data following these same guidelines. Waters not previously listed may be added to the list following the guidelines in this document.

- Deleting from the Existing List or Decreasing the Scope of Impairment to a Previously Listed Water

  The listed portion of an impaired water body may be decreased based on recent monitoring data following the guidelines in this document. One or more pollutants may be deleted from the listing for a water body already on the list based on recent monitoring data following guidelines in Appendix D. Waters may be completely removed from the list for several reasons[19]; the most common being (1) water has returned to compliance with water quality standards, or (2) the water has an approved TMDL study or Permit in Lieu of a TMDL.

- Listing Length of Impaired Segments

  The length of a 303(d) listing is currently based on the WBID length from the Missouri WQS. The department is using the WBID as the assessment unit to report to USEPA.

[19] See, "Guidance for 2006 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d), 305(b) and 314 of the Clean Water Act". USEPA, Office of Water, Washington DC.

When the department gains the database capability to further refine assessment units into segments smaller than WBIDs while maintain a transparent link to the WBID and Missouri's WQS, then the department will do so and will provide justification for splitting the WBID up into smaller assessment units in the assessment worksheets and can be discussed during the public notice process.

F. Prioritization of Waters for TMDL Development

Section 303(d) of the Clean Water Act and federal regulation 40 CFR 130.7(b)(4) requires states to submit a priority ranking of waters requiring TMDLs. The department will prioritize development of TMDLs based on several variables including:

- social impact/public interest and risk to public health
- complexity and cost (including consideration of budget constraints), availability of data of sufficient quality and quantity for TMDL modeling
- court orders, consent decrees, or other formal agreements
- source of impairments
- existence of appropriate numeric quality criteria
- implementation potential and amenability of the problem to treatment, and
- Integrated Planning efforts by municipalities and other entities

The department's TMDL schedule will represent its prioritization. The TMDL Program develops the TMDL schedule and maintains it at the following website: http://www.dnr.mo.gov/env/wpp/tmdl/.

G. Resolution of Interstate/International Disagreements

The department will review the draft 303(d) Lists of all other states with which it shares a border (Missouri River, Mississippi River, Des Moines River and the St. Francis River) or other interstate waters. Where the listing for the same water body in another state is different than the one in Missouri, the department will request the data and the listing justification. These data will be reviewed following the evaluation guidelines in this document. The Missouri Section 303(d) list may be changed pending the evaluation of this additional data.

H. Statistical Considerations

The most recent EPA guidance on the use of statistics in the 303(d) listing methodology document is given in Appendix A. Within this guidance there are three major recommendations regarding statistics:

- Provide a description of analytical tools the state uses under various circumstances
- When conducting hypothesis testing, explain the various circumstances under which the burden of proof is placed on proving the water is impaired and when it is placed on proving the water is unimpaired, and
- Explain the level of statistical significance (α) used under various circumstances.

- Description of Analytical Tools

  Appendix D, describes the analytical tools the department will use to determine whether a water body is impaired and whether or when a listed water body is no longer impaired.

- Rationale for the Burden-of-Proof

  Hypothesis testing is a common statistical practice. The procedure involves first stating a hypothesis you want to test, such as "the most frequently seen color on clothing at a St. Louis Cardinals game is red" and then the opposite or null hypothesis "red is not the most frequently seen color on clothing at a Cardinals game." Then a statistical test is applied to the data (a sample of the predominant color of clothing worn by 200 fans at a Cardinals game on July 12) and based on an analysis of that data, one of the two hypotheses is chosen as correct.

  In hypothesis testing, the burden-of-proof is always on the alternate hypothesis. In other words, there must be very convincing data to make us conclude that the null hypothesis is not true and that we must accept the alternate hypothesis. How convincing the data must be is stated as the "significance level" of the test. A significance level of α=0.10 means that there must be at least a 90 percent probability that the alternate hypothesis is true before we can accept it and reject the null hypothesis.

  For analysis of a specific kind of data, either the test significance level or the statement of null and alternative hypotheses, or both, can be varied to achieve the desired degree of statistical rigor. The department has chosen to maintain a consistent set of null and alternate hypotheses for all our statistical procedures. The null hypothesis will be that the water body in question is unimpaired and the alternate hypothesis will be that it is impaired. Varying the level of statistical rigor will be accomplished by varying the test significance level. For determining impairment (Appendix D) test significance levels are set at either α=0.1 or α=0.4, meaning the data must show at minimum 90% or 60% probability, respectively that the water body is impaired. However, if the department retained these same test significance levels in determining when an impaired water body had been restored to an unimpaired status (Appendix D) some undesirable results can occur.

  For example, using a 0.1 significance level for determining both impairment and non-impairment, if the sample data indicate the stream had a 92 percent probability of being impaired, it would be rated as impaired. If subsequent data were collected and added to the database, and the data now showed the water had an 88 percent chance of being impaired, it would be rated as unimpaired. Judging as unimpaired a water body with only a 12 percent probability of being unimpaired is clearly a poor decision. To correct this problem, the department will use a test significance level of 0.4 for some analytes and 0.6 for others. This will increase our confidence in determining compliance with criteria to 40 percent and 60 percent, respectively under the worst case conditions, and for most databases will provide an even higher level of confidence.

- Level of Significance Used in Tests

  The choice of significance levels is largely related to two concerns. The first concern is with matching error rates with the severity of the consequences of making a decision error. The second addresses the need to balance, to the degree practicable, Type I and Type II error rates. For relatively small number of samples, the disparity between Type I and Type II errors can be large. The tables 4 and 5 below shows error rates calculated using the binomial distribution for two very similar situations. Type I error rates are based on a stream with a 10 percent exceedance rate of a standard, and Type II error rates are based on a stream with a 15 percent exceedance rate of a standard. Note that when sample size remains the same, Type II error rates increase as Type I error rates decrease (Table 4). Also note that for a given Type I error rate, the Type II error rate declines as sample size increases (Table 5).

Table 4.
Effects of Type I error rates on Type II error rates. Type I error rates are based on a stream with a 10 percent exceedance rate of a standard and Type II error rates for a stream with a 15 percent exceedance rate of a standard.

Total No. of Samples	No. Samples Meeting Std.	Type I Error Rate	Type II Error Rate
18	17	0.850	0.479
18	16	0.550	0.719
18	15	0.266	0.897
18	14	0.098	0.958
18	13	0.028	0.988

Table 5.
Effects of Type I error rates and sample size on Type II error rates. Type I error rates are based on a stream with a 10 percent exceedance rate of a standard and Type II error rates for a stream with a 15 percent exceedance rate of a standard.

Total No. of Samples	No. Samples Meeting Std.	Type I Error Rate	Type II Error Rate
6	5	0.469	0.953
11	9	0.303	0.930
18	15	0.266	0.897
25	21	0.236	0.836

- Use of the Binomial Probability Distribution for Interpretation of the 10 Percent Rule

  There are two options for assessing data for compliance with the 10 percent rule. One is to simply calculate the percent of time the criterion value is not met, and to judge the water to be impaired if this value is greater than 10 percent. The second method is to use some evaluative procedure that can review the data and provide a probability statement regarding compliance with the 10 percent rule. Since the latter option allows assessment decisions relative to specific test significance levels and the first option does not, the latter option is preferred. The procedure chosen is the binomial probability distribution and calculation of the Type I error rate.

- Other Statistical Considerations

Prior to calculation of confidence limits, the normality of the data set will be evaluated. If normality is improved by a data transformation, the confidence limits will be calculated on the transformed data.

Time of sample collection may be biased and interfere with an accurate measurement of frequency of exceedance of a criterion. Data sets composed mainly or entirely of storm water data or data collected only during a season when water quality problems are expected could result in a biased estimate of the true exceedance frequency. In these cases, the department may use methods to estimate the true annual frequency and display these calculations whenever they result in a change in the impairment status of a water body.

For waters judged to be impaired based on biological data where data evaluation procedures are not specifically noted in Table 1, the statistical procedure used, test assumptions, and results will be reported.

- Examples of Statistical Procedures

Two Sample "t" Test for Color

Null Hypothesis: Amount of color is no greater in a test stream than in a control stream. As stated, this is a one-sided test, meaning that we are only interested in determining whether or not the color level in the test stream is greater than in a control stream. If the null hypothesis had been "amount of color is different in the test and control streams," we would have been interested in determining if the amount of color was either less than or greater than the control stream, a two-sided test.

Significance Level: α=0.10

Data Set: Platinum-Cobalt color units data for the test stream and a control stream samples collected at each stream on same date.

Test Stream	70	45	35	45	60	60	80
Control Stream	50	40	20	40	30	40	75
Difference (T-C)	20	5	15	5	30	20	5

Statistics for the Difference: Mean = 14.28, standard deviation = 9.76, n = 7
Calculated "t" value = (square root of n)(mean)/standard deviation = 3.86

Tabular "t" value is taken from a table of the "t" distribution for 2 alpha (0.20) and n-1 degrees of freedom. Tabular "t" = 1.44.

Since calculated "t" value is greater than tabular t value, reject the null hypothesis and conclude that the test stream is impaired by color.

Statistical Procedure for Mercury in Fish Tissue

Data Set: data in µg/Kg 130, 230, 450. Mean = 270, Standard Deviation = 163.7
The 60% Lower Confidence Limit Interval = the sample mean minus the quantity:
((0.253)(163.7)/square root 3) = 23.9. Thus the 60% LCL Confidence Interval is 246.1 µg/Kg.

The criterion value is 300 µg/Kg. Therefore, since the 60% LCL Confidence Interval is less than the criterion value, the water is judged to be unimpaired by mercury in fish tissue, and the water body is placed in either Category 2B or 3B.

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Appendix A

Excerpt from *Guidance for 2006 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d), 305(b) and 314 of the Clean Water Act.* July 29, 2005. USEPA pp. 39-41.

The document can be read in its entirety from the US. EPA web site:
http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/2006irg-report.pdf

G. How should statistical approaches be used in attainment determinations?

The state's methodology should provide a rationale for any statistical interpretation of data for the purpose of making an assessment determination.

- *Description of statistical methods to be employed in various circumstances*

The methodology should provide a clear explanation of which analytic tools the state uses and under which circumstances. EPA recommends that the methodology explain issues such as the selection of key sample statistics (arithmetic mean concentration, median concentration, or a percentile), null and alternative hypotheses, confidence intervals, and Type I and Type II error thresholds. The choice of a statistic tool should be based on the known or expected distribution of the concentration of the pollutant in the segment (e.g., normal or log normal) in both time and space.

Past EPA guidance (1997 305(b) and 2000 CALM) recommended making non-attainment decisions, for "conventional pollutants[20]" — TSS, pH, BOD, fecal coliform bacteria, and oil and grease — when more than "10% of measurements exceed the water quality criterion." (However, EPA guidance has not encouraged use of the "10% rule" with other pollutants, including toxics.) Use of this rule when addressing conventional pollutants, is appropriate if its application is consistent with the manner in which applicable WQC are expressed. An example of a WQC for which an assessment based on the ten percent rule would be appropriate is the EPA acute WQC for fecal coliform bacteria, applicable to protection of water contact recreational use. This 1976-issued WQC was expressed as, "...no more than ten percent of the samples exceeding 400 CFU per 100 ml, during a 30-day period." Here, the assessment methodology is clearly reflective of the WQC.

On the other hand, use of the ten percent rule for interpreting water quality data is usually not consistent with WQC expressed either as: 1) instantaneous maxima not to be surpassed at any time, or 2) average concentrations over specified times. In the case of "instantaneous maxima (or minima) never to occur" criteria use of the ten percent rule typically leads to the belief that segment conditions are equal or better than specified by the WQC, when they in fact are considerably worse. (That is,

[20] There are a variety of definitions for the term "conventional pollutants." Wherever this term is referred to in this guidance, it means "a pollutant other than a toxic pollutant."

pollutant concentrations are above the criterion-concentration a far greater proportion of the time than specified by the WQC.) Conversely, use of this decision rule in concert with WQC expressed as average concentrations over specific times can lead to concluding that segment conditions are worse than WQC, when in fact they are not.

If the state applies different decision rules for different types of pollutants (e.g., toxic, conventional, and non-conventional pollutants) and types of standards (e.g., acute vs. chronic criteria for aquatic life or human health), the state should provide a reasonable rationale supporting the choice of a particular statistical approach to each of its different sets of pollutants and types of standards.

1. *Elucidation of policy choices embedded in selection of particular statistical approaches and use of certain assumptions EPA strongly encourages states to highlight policy decisions implicit in the statistical analysis that they have chosen to employ in various circumstances. For example, if hypothesis testing is used, the state should make its decision-making rules transparent by explaining why it chose either "meeting WQS" or "not meeting WQS" as the null hypothesis (rebuttable presumption) as a general rule for all waters, a category of waters, or an individual segment. Starting with the assumption that a water is "healthy" when employing hypothesis testing means that a segment will be identified as impaired, and placed in Category 4 or 5, only if substantial amounts of credible evidence exist to refute that presumption. By contrast, making the null hypothesis "WQS not being met" shifts the burden of proof to those who believe the segment is, in fact, meeting WQS.*

Which "null hypothesis" a state selects could likely create contrasting incentives regarding support for additional ambient monitoring among different stakeholders. If the null hypothesis is "meeting standards," there were no previous data on the segment, and no additional existing and readily available data and information are collected, then the "null hypothesis" cannot be rejected, and the segment would not be placed in Category 4 or 5. In this situation, those concerned about possible adverse consequences of having a segment declared "impaired" might have little interest in collection of additional ambient data. Meanwhile, users of the segment would likely want to have the segment monitored, so they can be ensured that it is indeed capable of supporting the uses of concern. On the other hand, if the null hypothesis is changed to "segment not meeting WQS," then those that would prefer that a particular segment not be labeled "impaired" would probably want more data collected, in hopes of proving that the null hypothesis is not true.

Another key policy issue in hypothesis testing is what significance level to use in deciding whether to reject the null hypothesis. Picking a high level of significance for rejecting the null hypothesis means that great emphasis is being placed on avoiding a Type I error (rejecting the null hypothesis, when in fact, the null hypothesis is true). This means that if a 0.10 significance level is chosen, the state wants to keep the chance of making a Type I error at or below ten percent. Hence, if the chosen null hypothesis is "segment meeting

WQS," the state is trying to keep the chance of saying a segment is impaired – when in reality it is not – under ten percent.

An additional policy issue is the Type II errors (not rejecting the null hypothesis, when it should have been). The probability of Type II errors depends on several factors. One key factor is the number of samples available. With a fixed number of samples, as the probability of Type I error decreases, the probability of a Type II error increases. States would ideally collect enough samples so the chances of making Type I and Type II errors are simultaneously small. Unfortunately, resources needed to collect such numbers of samples are quite often not available.

The final example of a policy issue that a state should describe is the rationale for concentrating limited resources to support data collection and statistical analysis in segments where there are documented water quality problems or where the combination of nonpoint source loadings and point source discharges would indicate a strong potential for a water quality problem to exist.

EPA recommends that, when picking the decision rules and statistical methods to be utilized when interpreting data and information, states attempt to minimize the chances of making either of the two following errors:

- *Concluding the segment is impaired, when in fact it is not, and*
- *Deciding not to declare a segment impaired, when it is in fact impaired.*

States should specify in their methodology what significance level they have chosen to use, in various circumstances. The methodology would best describe in "plain English" the likelihood of deciding to list a segment that in reality is not impaired (Type I error if the null hypothesis is "segment not impaired"). Also, EPA encourages states to estimate, in their assessment databases, the probability of making a Type II error (not putting on the 303(d) list a segment that in fact fails to meet WQS), when: 1) commonly-available numbers of grab samples are available, and 2) the degree of variance in pollutant concentrations are at commonly encountered levels. For example, if an assessment is being performed with a WQC expressed as a 30-day average concentration of a certain pollutant, it would be useful to estimate the probability of a Type II error when the number of available samples over a 30 day period is equal to the average number of samples for that pollutant in segments state-wide, or in a given group of segments, assuming a degree of variance in levels of the pollutant often observed over typical 30 day periods.

Appendix B

METHODS FOR ASSESSING COMPLIANCE WITH WATER QUALITY STANDARDS USED FOR 303(d) LISTING PURPOSES: NUMERIC CRITERIA THAT ARE INCLUDED IN STATE WATER QUALITY STANDARDS (10 CSR 20-7.031)

DESIGNATED USES	DATA TYPE	DATA QUALITY CODE	COMPLIANCE WITH WATER QUALITY STANDARDS[i]	Notes
Overall use protection (all designated uses)	No data. Evaluated based on similar land use/ geology as stream with water quality data.	Not applicable	Given same rating as monitored stream with same land use and geology.	**Data Type Note:** This data type is used only for wide-scale assessments of aquatic biota and aquatic habitat for 305(b) Report purposes. This data type is not used in the development of the 303(d) List.
Any designated uses	No data available or where only effluent data is available. Results of dilution calculations or water quality modeling	Not applicable	Where models or other dilution calculations indicate noncompliance with allowable pollutant levels and frequencies noted in this table, waters may be added to Category 3B and considered high priority for water quality monitoring.	
Protection of Aquatic Life	Dissolved oxygen, water temperature, pH, total dissolved gases, oil and grease.	1-4	<u>Full</u>: No more than 10% of all samples exceed criterion. <u>Non-Attainment</u>: Requirements for full attainment not met. <u>Requirements:</u> A minimum sample size of 10 samples during the assessment period (see Section VI above).	**Compliance with Water Quality Standards Note:** Some sampling periods are wholly or predominantly during the critical period of the year when criteria violations occur. Where the monitoring program presents good evidence of a demarcation between seasons where criteria exceedances occur and seasons when they do not, the 10% exceedance rate will be based on an annual estimate of the frequency of exceedance. Continuous (e.g. sonde) data with a quality rating of excellent or good will be used for assessments. Chronic pH will be used in the 2018 LMD only if these criteria appear in the Code of State Regulations, and approved by the U.S. Environmental Protection Agency.

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DESIGNATED USES	DATA TYPE	DATA QUALITY CODE	COMPLIANCE WITH WATER QUALITY STANDARDS[i]	Notes
Losing Streams	*E. coli* bacteria	1-4	Full: No more than 10% of all samples exceed criterion. Non-Attainment: Requirements for full attainment not met. The criterion for *E. coli* is 126 counts/100ml. 10 CSR 20-7.031 (4)(C)	
Protection of Aquatic Life	Toxic chemicals	1-4	Full: No more than one acute toxic event in three years that results in a documented die-off of aquatic life such as fish, mussels, and crayfish (does not include die-offs due to natural origin). No more than one exceedance of acute or chronic criterion in the last three years for which data is available. Non-Attainment: Requirements for full attainment not met.	**Compliance with Water Quality Standards Note:** For hardness based metals with eight or fewer samples, the hardness value associated with the sample will be used to calculate the acute or chronic thresholds. For hardness based metals with more than eight samples, the hardness definition provided in state water quality standards will be used to calculate the acute and chronic thresholds.
Protection of Aquatic Life	Nutrients in Lakes (total phosphorus, total nitrogen, plus chlorophyll)	1-4	Full: Nutrient levels do not exceed water quality standards following procedures stated in Appendix D. Non-Attainment: Requirements for full attainment not met.	**Compliance with Water Quality Standards Note:** Nutrient criteria will be used in the 2020 LMD only if these criteria appear in the Code of State Regulations, and approved by the U.S. Environmental Protection Agency.
Human Health - Fish Consumption	Chemicals (water)	1-4	Full: Water quality does not exceed water quality standards following procedures stated in Appendix D. Non-Attainment: Requirements for full attainment not met.	

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DESIGNATED USES	DATA TYPE	DATA QUALITY CODE	COMPLIANCE WITH WATER QUALITY STANDARDS[i]	Notes
Drinking Water Supply -Raw Water.	Chemical (toxics)	1-4	Full: Water Quality Standards not exceeded following procedures stated in Appendix D. Non-Attainment: Requirements for full attainment not met.	**Designated Use Note:** Raw water is water from a stream, lake or groundwater prior to treatment in a drinking water treatment plant.
Drinking Water Supply- Raw Water	Chemical (sulfate, chloride, fluoride)	1-4	Full: Water quality standards not exceeded following procedures stated in Appendix D. Non-Attainment: Requirements for full attainment not met.	
Drinking Water Supply-Finished Water	Chemical (toxics)	1-4	Full: No Maximum Contaminant Level (MCL) violations based on Safe Drinking Water Act data evaluation procedures. Non-Attainment: Requirements for full attainment not met.	**Compliance with Water Quality Standards Note:** Finished water data will not be used for analytes where water quality problems may be caused by the drinking water treatment process such as the formation of Trihalomethanes (THMs) or problems that may be caused by the distribution system (bacteria, lead, copper).
Whole-Body-Contact Recreation and Secondary Contact Recreation	Fecal coliform or *E. coli* count	2-4	Where there are at least five samples per year taken during the recreational season: Full: Water quality standards not exceeded as a geometric mean, in any of the last three years for which data is available, for samples collected during seasons for which bacteria criteria apply. Non-Attainment: Requirements for full attainment not met.	**Compliance with Water Quality Standards Note:** A geometric mean of 206 cfu/100 ml for *E. coli* will be used as a criterion value for Category B Recreational Waters. Because Missouri's Fecal Coliform Standard ended December 31, 2008, any waters appearing on the 2008 303(d) List as a result of the Fecal Coliform Standard will be retained on the list with the pollutant listed as "bacteria" until sufficient *E. coli* sampling has determined the status of the water.
Irrigation, Livestock and	Chemical	1-4	Full: Water quality standards not exceeded following procedures stated in Appendix D.	

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DESIGNATED USES	DATA TYPE	DATA QUALITY CODE	COMPLIANCE WITH WATER QUALITY STANDARDS[i]	Notes
Wildlife Water			Non-Attainment: Requirements for full attainment not met.	

[i] See section on Statistical Considerations, Appendix C & D.

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METHODS FOR ASSESSING COMPLIANCE WITH WATER QUALITY STANDARDS USED FOR 303(d) LISTING PURPOSES: NARRATIVE CRITERIA BASED ON NUMERIC THRESHOLDS NOT CONTAINED IN STATE WATER QUALITY STANDARDS (10 CSR 20-7.031)

BENEFICIAL USES	DATA TYPE	DATA QUALITY CODE	COMPLIANCE WITH WATER QUALITY STANDARDS[ii]	Notes
Overall use protection (all beneficial uses)	Narrative criteria for which quantifiable measurements can be made.	1-4	Full: Stream condition typical of reference or appropriate control streams in this region of the state. Non-Attainment: The weight of evidence, based on the narrative criteria in 10 CSR 20-7.031(3), demonstrates the observed condition exceeds a numeric threshold necessary for the attainment of a beneficial use. For example: Color: Color as measured by the Platinum-Cobalt visual method (SM 2120 B) in a water body is statistically significantly higher than a control water. Objectionable Bottom Deposits: The bottom that is covered by sewage sludge, trash, or other materials reaching the water due to anthropogenic sources exceeds the amount in reference or control streams by more than 20 percent. Note: Waters in mixing zones and unclassified waters that support aquatic life on an intermittent basis shall be subject to acute toxicity criteria for protection of aquatic life. Waters in the initial Zone of Dilution shall not be subject to acute toxicity criteria.	
Protection of	Toxic	1-4	Full: No more than one acute toxic event	**Compliance with Water Quality Standards Note**: The test

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BENEFICIAL USES	DATA TYPE	DATA QUALITY CODE	COMPLIANCE WITH WATER QUALITY STANDARDS[ii]	Notes
Aquatic Life	Chemicals		in three years (does not include die-offs of aquatic life due to natural origin). No more than one exceedance of acute or chronic criterion in three years for all toxics. Non-Attainment: Requirements for full attainment not met.	result must be representative of water quality for the entire time period for which acute or chronic criteria apply. For ammonia the chronic exposure period is 30 days, for all other toxics 96 hours. The acute exposure period for all toxics is 24 hours, except for ammonia which has a one hour exposure period. The department will review all appropriate data, including hydrographic data, to ensure only representative data are used. Except on large rivers where storm water flows may persist at relatively unvarying levels for several days, grab samples collected during storm water flows will not be used for assessing chronic toxicity criteria. **Compliance with Water Quality Standards Note:** In the case of toxic chemicals occurring in benthic sediment rather than in water, the numeric thresholds used to determine the need for further evaluation will be the Probable Effect Concentrations proposed in "Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems" by MacDonald, D.D. *et al.* Arch. Environ. Contam. Toxicol. 39,20-31 (2000). These Probable Effect Concentrations are as follows: 33 mg/kg As; 4.98 mg/kg Cd; 111 mg/kg Cr; 149 mg/kg Cu; 48.6 mg/kg Ni; 128 mg/kg Pb; 459 mg/kg Zn; 561 µg/kg naphthalene; 1170 µg/kg phenanthrene; 1520 µg/kg pyrene; 1050 µg/kg benzo(a)anthracene, 1290 µg/kg chrysene; 1450 µg/kg benzo(a)pyrene; 22,800 µg/kg total polycyclic aromatic hydrocarbons; 676 µg/kg total PCBs; chlordane 17.6 ug/kg; Sum DDE 31.3 ug/kg; lindane (gamma-BHC) 4.99 ug/kg. Where multiple sediment contaminants exist, the Probable Effect Concentrations Quotient shall not exceed 0.75. See Appendix D and Section II. D for more information on the Probable Effect Concentrations Quotient.

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BENEFICIAL USES	DATA TYPE	DATA QUALITY CODE	COMPLIANCE WITH WATER QUALITY STANDARDS[ii]	Notes
Protection of Aquatic Life	Biological: Aquatic Macro-invertebrates sampled using DNR Protocol.	3-4	Full: For seven or fewer samples and following DNR wadeable streams macroinvertebrate sampling and evaluation protocols, 75% of the stream condition index scores must be 16 or greater. Fauna achieving these scores are considered to be very similar to regional reference streams. For greater than seven samples or for other sampling and evaluation protocols, results must be statistically similar to representative reference or control stream. Non-Attainment: For seven or fewer samples and following DNR wadeable streams macroinvertebrate sampling and evaluation protocols, 75% of the stream condition index scores must be 14 or lower. Fauna achieving these scores are considered to be substantially different from regional reference streams. For more than seven samples or for other sampling and evaluation protocols, results must be statistically dissimilar to control or representative reference streams.	**Data Type Note:** DNR invert protocol will not be used for assessment in the Mississippi Alluvial Basin (bootheel area) due to lack of reference streams for comparison. **Data Type Note:** See Section II.D. for additional criteria used to assess biological data. **Compliance with Water Quality Standards Note:** See Appendix D. For test streams that are significantly smaller than bioreference streams where both bioreference streams and small candidate reference streams are used to assess the biological integrity of the test stream, the assessment of the data should display and take into account both biocriteria reference streams and candidate reference streams.
Protection of Aquatic Life	Biological: MDC Fish Community (RAM) Protocol (Ozark Plateau only)	3-4	Full: For seven or fewer samples and following MDC RAM fish community protocols, 75% of the fIBI scores must be 36 or greater. Fauna achieving these scores are considered to be very similar to regional reference streams. For greater than seven samples or for other sampling	**Data Type Note:** See Section II.D. for additional criteria used to assess biological data. **Compliance with Water Quality Standards Note:** MDC fIBI scores are from "Biological Criteria for Streams and Fish Communities in Missouri" by Doisy et al. (2008). If habitat limitations (as measured by either the QCPH1 index or other appropriate methods) are judged to contribute to low fish

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BENEFICIAL USES	DATA TYPE	DATA QUALITY CODE	COMPLIANCE WITH WATER QUALITY STANDARDS[ii]	Notes
			and evaluation protocols, results must be statistically similar to representative reference or control streams. Suspected of Impairment: Data not conclusive (Category 2B or 3B). For first and second order streams fIBI score < 29. Non-Attainment: First and second order streams will not be assessed for non-attainment. When assessing third to fifth order streams with data sets of seven or fewer samples collected by following MDC RAM fish community protocols, 75% of the fIBI scores must be lower than 36. Fauna achieving these scores are considered to be substantially different from regional reference streams. For more than seven samples or for other sampling and evaluation protocols, results must be statistically dissimilar to control or representative reference streams.	community scores and this is the only type of data available, the water body will be included in Category 4C, 2B, or 3B. If other types of data exist, the weight of evidence approach will be used as described in this document. **Compliance with Water Quality Standards Note:** For determining influence of poor habitat on those samples that are deemed as impaired, consultation with MDC RAM staff will be utilized. If, through this consultation, habitat is determined to be a significant possible cause for impairment, the water body will not be rated as impaired, but rather as suspect of impairment (categories 2B or 3B). **Compliance with Water Quality Standards Note:** See Appendix D. For test streams that are significantly smaller than bioreference streams where both bioreference streams and small candidate reference streams are used to assess the biological integrity of the test stream, the assessment of the data should display and take into account both biocriteria reference streams and candidate reference streams.
Protection of Aquatic Life	Other Biological Data	3-4	Full: Results must be statistically similar to representative reference or control streams. Non-Attainment: Results must be statistically dissimilar to control or representative reference streams.	**Data Type Note:** See Section II.D. for additional criteria used to assess biological data

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METHODS FOR ASSESSING COMPLIANCE WITH WATER QUALITY STANDARDS USED FOR 303(d) LISTING PURPOSES: NARRATIVE CRITERIA BASED ON NUMERIC THRESHOLDS NOT CONTAINED IN STATE WATER QUALITY STANDARDS (10 CSR 20-7.031)

BENEFICIAL USES	DATA TYPE	DATA QUALITY CODE	COMPLIANCE WITH WATER QUALITY STANDARDS[ii]	Notes
Protection of Aquatic Life	Toxicity testing of streams or lakes using aquatic organisms	2	Full: No more than one test result of statistically significant deviation from controls in acute or chronic test in a three-year period. Non-Attainment: Requirements for full attainment not met.	
Human Health - Fish Consumption	Chemicals (tissue)	1-2	Full: Contaminant levels in fish tissue levels in fillets, tissue plugs, and eggs do not exceed guidelines. Non-Attainment: Requirements for full attainment not met.	**Compliance with Water Quality Standards Note**: Fish tissue threshold levels are; chlordane 0.1 mg/kg (Crellin, J.R. 1989, *"New Trigger Levels for Chlordane in Fish-Revised Memo"* Mo. Dept. of Health inter-office memorandum. June 16, 1989); mercury 0.3 mg/kg based on "Water Quality Criterion for Protection of Human Health: Methylmercury" EPA-823-R-01-001. Jan. 2001. http://www.epa.gov/waterscience/criteria/methylmercury/merctitl.pdf; PCBs 0.75 mg/kg, MDHSS Memorandum August 30, 2006 *"Development of PCB Risk-based Fish Consumption Limit Tables;"* and lead 0.3- mg/kg (World Health Organization 1972. *"Evaluation of Certain Food Additives and the Contaminants Mercury, Lead and Cadmium."* WHO Technical Report Series No. 505, Sixteenth Report on the Joint FAO/WHO Expert Committee on Food Additives. Geneva 33 pp. Assessment of Mercury will be based on samples solely from the following higher trophic level fish species: Walleye, Sauger, Trout, Black Bass, White Bass, Striped Bass, Northern Pike, Flathead Catfish and Blue Catfish. In a 2012 DHSS memorandum (not yet approved, but are being considered for future LMD revisions) threshold values are proposed to change as follows: chlordane 0.2 mg/kg ; mercury 0.27 mg/kg ; and PCBs = 0.540 ; lead has not changed, but they do add atrazine and PDBEs **(Fish Fillet Advisory Concentrations (FFACs) in Missouri).**

[ii] **See section on Statistical Considerations and Appendix D.**

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DESCRIPTION OF ANALYTICAL TOOLS USED FOR DETERMINING THE STATUS OF MISSOURI WATERS (11" X 14" FOLD OUT)

			Determining when waters are impaired			Determining when waters are no longer impaired			
Designated Use	**Analytes**	**Analytical Tool**	**Decision Rule/ Hypothesis**	**Criterion Used with the Decision Rule[iii]**	**Significance Level (α)**	**Decision Rule/ Hypothesis**	**Criterion Used with the Decision Rule**	**Significance Level (α)**	**Notes**
Narrative Criteria	Color	Hypothesis Test: Two Sample, one tailed t-Test	Null Hypothesis: There is no difference in color between test stream and control stream.	Reject Null Hypothesis if calculated "t" value exceeds tabular "t" value for test alpha	0.1	Same Hypothesis	Same Criterion	Same Significance Level	
	Bottom deposits	Hypothesis Test, Two Sample, one tailed "t "Test	Null Hypothesis: Solids of anthropogenic origin cover less than 20% of stream bottom where velocity is less than 0.5 feet/second.	Reject Null Hypothesis if 60% Lower Confidence Limit (LCL) of mean percent fine sediment deposition (pfsd) in stream is greater than the sum of the pfsd in the control and 20 % more of the stream bottom. i.e., where the pfsd is expressed as a decimal, test stream pfsd > (control stream pfsd)+(0.20)	0.4	Same Hypothesis	Same Criterion	Same Significance Level	**Criterion Note:** If data is non-normal a nonparametric test will be used as a comparison of medians. The same 20% difference still applies. With current software the Mann-Whitney test is used.

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Designated Use	**Analytes**	**Analytical Tool**	**Decision Rule/ Hypothesis**	**Criterion Used with the Decision Rule**[iii]	**Significance Level (α)**	**Decision Rule/ Hypothesis**	**Criterion Used with the Decision Rule**	**Significance Level (α)**	**Notes**
Aquatic Life	Biological monitoring (Narrative)	For DNR Invert protocol: Sample sizes of 7 or less, 75% of samples must score 14 or lower.	Using DNR Invert. Protocol: Null Hypothesis: Frequency of full sustaining scores for test stream is the same as for biological criteria reference streams.	Reject Null Hypothesis if frequency of fully sustaining scores on test stream is significantly less than for biological criteria reference streams.	Not Applicable	Same Hypothesis	Same Criterion	Same Significance Level	
		For RAM Fish IBI protocol: Sample sizes of 7 or less, 75% of samples must score less than 36.							
		For DNR Invert protocol and sample size of 8 or more: Binomial Probability	A direct comparison of frequencies between test and biological criteria reference streams will be made.	Rate as impaired if biological criteria reference stream frequency of fully biologically supporting scores is greater than five percent more than test stream.	0.1	Same Hypothesis	Same Criterion	Same Significance Level	**Criterion Note:** For inverts, the reference number will change depending on which EDU the stream is in (X%-5%), for RAM samples the reference number will always be 70 (75%-5%).
		For RAM Fish IBI protocol and sample size of 8 or more: Binomial Probability.							
		For other biological data an appropriate parametric or	Null Hypothesis, Community metric(s) in	Reject Null Hypothesis if metric scores for test stream are	0.1	Same Hypothesis	Same Criterion	Same Significance Level	

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Designated Use	**Analytes**	**Analytical Tool**	**Decision Rule/ Hypothesis**	**Criterion Used with the Decision Rule[iii]**	**Significance Level (α)**	**Decision Rule/ Hypothesis**	**Criterion Used with the Decision Rule**	**Significance Level (α)**	**Notes**
Aquatic Life (cont.)		nonparametric test will be used.	test stream is the same as for a reference stream or control streams.	significantly less than reference or control streams.					
			Other biological monitoring to be determined by type of data.	Dependent upon available information.	Dependent upon available information.	Same Hypothesis	Same Criterion	Same Significance Level	
	Toxic chemicals in water: (Numeric)	Not applicable	No more than one toxic event, toxicity test failure or exceedance of acute or chronic criterion in 3 years.	Not applicable	Not applicable	Same Hypothesis	Same Criterion	Same Significance Level	
	Toxic chemicals in sediments: (Narrative)	Comparison of geometric mean to PEC value, or calculation of a PECQ value.	Waters are judged to be impaired if parameter geomean exceeds PEC, or site PECQ is exceeded.	For metals use 150% PEC threshold. The PECQ threshold value is 0.75.	Not applicable	Water is judged to be unimpaired if parameter geomean is equal to or less than PEC, or site PECQ equaled or not exceeded.	For metals use 150% of PEC threshold. The PECQ threshold value is 0.75.	Not applicable	**Compliance with Water Quality Standards Note:** In the case of toxic chemicals occurring in benthic sediment rather than in water, the numeric thresholds used to determine the need for further evaluation will be the Probable Effect Concentrations proposed in “Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems” by MacDonald, D.D. *et al.* Arch. Environ. Contam. Toxicol. 39,20-31 (2000). These Probable Effect Concentrations are as follows:

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Designated Use	**Analytes**	**Analytical Tool**	**Decision Rule/ Hypothesis**	**Criterion Used with the Decision Rule[iii]**	**Significance Level (α)**	**Decision Rule/ Hypothesis**	**Criterion Used with the Decision Rule**	**Significance Level (α)**	**Notes**
Aquatic Life (cont.)									33 mg/kg As; 4.98 mg/kg Cd; 111 mg/kg Cr; 149 mg/kg Cu; 48.6 mg/kg Ni; 128 mg/kg Pb; 459 mg/kg Zn; 561 µg/kg naphthalene; 1170 µg/kg phenanthrene; 1520 µg/kg pyrene; 1050 µg/kg benzo(a)anthracene, 1290 µg/kg chrysene; 1450 µg/kg benzo(a)pyrene; 22,800 µg/kg total polycyclic aromatic hydrocarbons; 676 µg/kg total PCBs; chlordane 17.6 ug/kg; Sum DDE 31.3 ug/kg; lindane (gamma-BHC) 4.99 ug/kg. Where multiple sediment contaminants exist, the Probable Effect Concentrations Quotient shall not exceed 0.75. See Appendix D and Section II. D for more information on the Probable Effect Concentrations Quotient.
	Temperature, pH, total diss. gases, oil and grease, diss. oxygen (Numeric)	Binomial probability	Null Hypothesis: No more than 10% of samples exceed the water quality criterion.	Reject Null Hypothesis if the Type I error rate is less than 0.1.	Not applicable	Same Hypothesis	Same Criterion	Same Significance Level	Continuous Sampling (i.e. time series or sonde data collection): Data collected in a time series fashion will be looked at on a 4 day period. If an entire 4 day period is outside of the 6.5 – 9.0 criterion range that will count as a chronic toxicity event. More than one of these events will constitute an impairment listing of the stream. Grab Samples: Data collected as grab samples will be treated as is and the binomial probability calculation will be used for assessment.

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Designated Use	**Analytes**	**Analytical Tool**	**Decision Rule/ Hypothesis**	**Criterion Used with the Decision Rule**[iii]	**Significance Level (α)**	**Decision Rule/ Hypothesis**	**Criterion Used with the Decision Rule**	**Significance Level (α)**	**Notes**
Losing Streams	*E.coli*	Binomial probability	Null Hypothesis: No more than 10% of samples exceed the water quality criterion.	Reject Null Hypothesis if the Type I error rate is less than 0.1.	0.1	Same Hypothesis	Same Criterion	Same Significance Level	
Human Health – Fish Consumption	Toxic chemicals in water (Numeric)	Hypothesis test: 1-sided confidence limit	Null Hypothesis: Levels of contaminants in water do not exceed criterion.	Reject Null Hypothesis if the 60% LCL is greater than the criterion value.	0.4	Same Hypothesis	Reject Null Hypothesis if the 60% UCL is greater than the criterion value.	Same Significance Level	
	Toxic chemicals in tissue (Narrative)	Four or more samples: Hypothesis test 1-sided confidence limit	Null Hypothesis: Levels in fillet samples or fish eggs do not exceed criterion.	Reject Null Hypothesis if the 60% LCL is greater than the criterion value.	0.4	Same Hypothesis	Reject null hypothesis if the 60% UCL is greater than the criterion value.	Same Significance Level	
Drinking Water Supply (Raw)	Toxic chemicals (Numeric)	Hypothesis test: 1-sided confidence limit	Null Hypothesis: Levels of contaminants do not exceed criterion.	Reject Null Hypothesis if the 60% LCL is greater than the criterion value.	0.4	Same Hypothesis	Reject null hypothesis if the 60% UCL is greater than the criterion value.	Same Significance Level	

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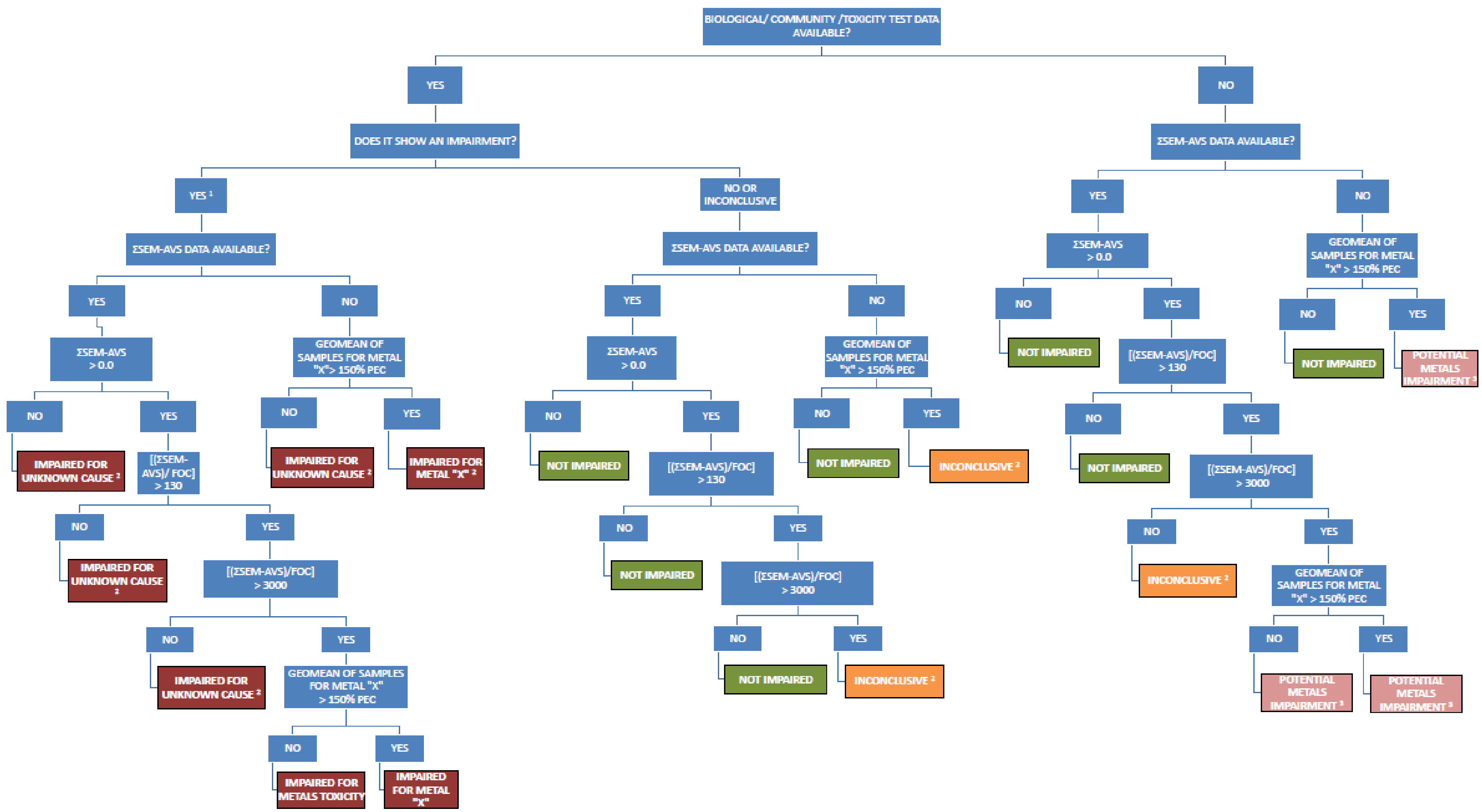
Designated Use	**Analytes**	**Analytical Tool**	**Decision Rule/ Hypothesis**	**Criterion Used with the Decision Rule**[iii]	**Significance Level (α)**	**Decision Rule/ Hypothesis**	**Criterion Used with the Decision Rule**	**Significance Level (α)**	**Notes**
	Non-toxic chemicals (Numeric)	Hypothesis test: 1-sided confidence limit	Null Hypothesis: Levels of contaminants do not exceed criterion.	Reject Null Hypothesis: if the 60% LCL is greater than the criterion value.	0.4	Same Hypothesis	Reject null hypothesis if the 60% UCL is greater than the criterion value.	Same Significance Level	
Drinking Water Supply (Finished)	Toxic chemicals	Methods stipulated by Safe Drinking Water Act.	Methods stipulated by Safe Drinking Water Act.	Methods stipulated by Safe Drinking Water Act.	Methods stipulated by Safe Drinking Water Act.	Same Hypothesis	Same Criterion	Same Significance Level	
Whole Body Contact and Secondary	Bacteria (Numeric)	Geometric mean	Null Hypothesis: Levels of contaminants do not exceed criterion.	Reject Null Hypothesis: if the geometric mean is greater than the criterion value.	Not Applicable	Same Hypothesis	Same Criterion	Not applicable	
Irrigation & Livestock Water	Toxic chemicals (Numeric)	Hypothesis test 1-Sided confidence limit	Null Hypothesis: Levels of contaminants do not exceed criterion.	Reject Null Hypothesis if the 60% LCL is greater than the criterion value.	0.4	Same Hypothesis	Reject null hypothesis if the 60% UCL is greater than the criterion value.	Same Significance Level	
Protection of Aquatic Life	Nutrients in lakes (Numeric)	Hypothesis test	Null hypothesis: Criteria are not exceeded.	Reject Null Hypothesis if 60% LCL value is greater than criterion value.	0.4	Same Hypothesis	Same Criterion	Same Significance Level	**Hypothesis Test Note:** State nutrient criteria require at least four samples per year taken near the outflow point of the lake (or reservoir) between May 1 and August 31 for at least four different, not necessarily consecutive, years.

[iii] Where hypothesis testing is used for media other than fish tissue, for data sets with five samples or fewer, a 75 percent confidence interval around the appropriate central tendencies will be used to determine use attainment status. Use attainment will be determined as follows: (1) If the criterion value is above this interval (all values within the interval are in conformance with the criterion), rate as unimpaired; (2) If the criterion value falls within this interval, rate as unimpaired and place in Category 2B or 3B; (3) If the criterion value is below this interval (all values within the interval are not in conformance with the criterion), rate as impaired. For fish tissue, this procedure will be used with the following changes: (1) it will apply only to sample sizes of less than four and, (2) a 50% confidence interval will be used in place of the 75% confidence interval.

Appendix E

PICTORIAL REPRESENTATIONS OF THE WEIGHT OF EVIDENCE PROCEDURE FOR JUDGING TOXICITY OF SEDIMENT DUE TO METALS AND PAHS

Biological Weight of Evidence Decision Chart - Sediment Toxicity (Metals)



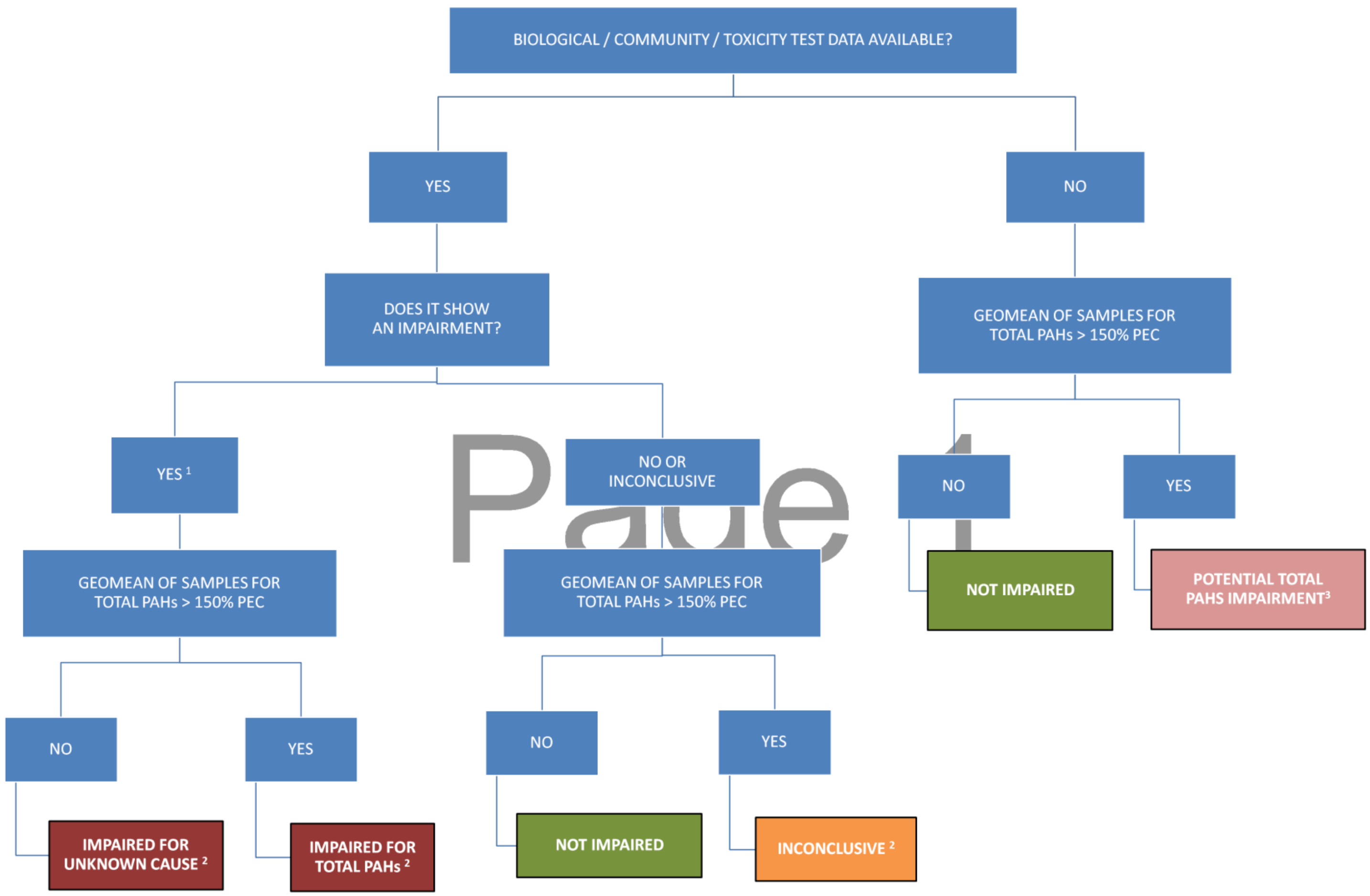
Notes:

1 - If there are Numeric WQS violations (unrelated to sediment) then follow LMD Procedure in LMD Appendix B. **Do Not Continue.**

2 - Note waterbody for further investigation related to metals or habitat issues.

3 - Note waterbody for Biological Sampling.

Biological Weight of Evidence Decision Chart - Sediment Toxicity (PAHs)



Notes:

1 - If there are Numeric WQS violations (unrelated to sediment) then follow LMD Procedure in LMD Appendix B. Do Not Continue.

2 - Note waterbody for further investigation.

3 - Note waterbody for Biological Sampling.