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EVALUATION OF A SELECTED SITE FOR A PROPOSED JOPLIN WATER SUPPLY RESERVOIR ON BAYNHAM BRANCH

PHASE 1 REPORT

December 29, 2020

Thomas Aley, Missouri Registered Geologist 0989
Senior Hydrogeologist and President
and
David Woods, Senior Project Scientist
Ozark Underground Laboratory

A contract investigation conducted by the Ozark Underground Laboratory, Inc.

for Glenn Brown, Diamond, MO.

Missouri American Water Company (MAWC) prepared a document dated February 2019 and titled as a Section 404 pre-application for a new water supply reservoir for Joplin. The Ozark Underground Laboratory, Inc. (OUL) was retained to conduct an independent and non-invasive evaluation of the MAWC proposal and of the proposed reservoir. Tom Aley, who led this evaluation, has extensive experience with dam and reservoir leakage investigations using tracer dyes at sites in Missouri, Arkansas, Florida, Alabama, Indiana, Texas, Arizona, Colorado, Utah, Idaho, Washington, Australia, Peru, and Ghana.

The OUL report is divided into 8 issue-specific sections. Section 1 summarizes features of the MAWC proposal and provides information lacking from the MAWC document. The proposal has major deficiencies; two are especially noteworthy. First, the proposal does not recognize that impoundments in southwest Missouri have a high risk of failure due to excessive leakage through karst groundwater systems. Second, MAWC apparently did not even make simple field observations of flow rates of Baynham Branch at readily available public access points under low flow conditions. Had such observations been made and included in the document they would have shown that most of the low flow of the stream enters groundwater upstream of the planned dam site. That is inconsistent with a good dam site in a karst landscape. The result of these deficiencies is an unrealistically optimistic document for a technically risky project.

Section 2 deals with losing stream segments within the reservoir area. Losing streams are surface watercourses that lose part of their flow into the karst groundwater system. The MAWC document, using an inappropriate definition of losing stream for assessing reservoir leakage, states that there are 3,488 linear feet of losing stream within the planned impoundment area. The correct value is approximately 19,200 feet; there are three major losing stream segments within the reservoir.

The OUL introduced a separate tracer dye into each of the three losing stream segments. All three dyes ultimately discharged from the Hunley Springs Complex. None of the water discharging from the Hunley Springs Complex would be captured by the planned dam. MAWC claimed that losing streams inundated by the reservoir were not anticipated to impact reservoir storage. The three groundwater traces demonstrated that the MAWC claim is both illogical and false; the reservoir will experience major leakage and will not function as proposed.

Section 3 provides OUL stream flow measurements. They show that most (and approaching all) of the flow of the springs in the Hunley Springs Complex is derived from water sinking in Baynham Branch upstream of the planned dam.

Section 4 provides estimates of likely leakage rates from the planned reservoir. The flow rate of the Hunley Springs Complex has been measured under spring-time conditions at 20 million gallons per day (mgd). The OUL concludes that this is a reasonable value under natural conditions when water in the channel of Baynham Branch is approximately 5 feet deep in the losing stream downstream of Lime Kiln Road. Under these conditions the groundwater gradient between the stream and the main spring feeding Hunley Lake is 2.8 feet per thousand feet. If a reservoir existed at the planned pool elevation the groundwater gradient would increase to 20.9 feet per thousand feet. This would dramatically increase the leakage to rates that would be unacceptable for a water supply reservoir.

Section 5 discusses reservoir impacts on Ozark Cavefish, a federally listed Threatened species. Environmental DNA (eDNA) studies indicate that the planned reservoir would inundate three cavefish habitats. Dissolved oxygen concentrations in bottom waters of reservoirs in southern Missouri in warm weather are commonly so low as to be lethal to aquatic life.

Section 6 evaluates likely effects of reservoir leakage through the Hunley Springs Complex to Shoal Creek. This discharge water would be low in dissolved oxygen and would likely impact six mussel species of conservation concern in Shoal Creek.

Section 7 discusses the hydrogeology of the planned dam site. The bedrock is Burlington-Keokuk Limestone which is a routinely cavernous karst unit. Pinnacled bedrock beneath the dam is anticipated. This increases leakage hazards and construction costs. MAWC states that the site is anticipated to have materials suitable for both impervious core material and shell material. No reference is cited to support this "anticipation" and it is inconsistent with severe limitations identified in the soil mapping done by professionals with the U.S. Department of Agriculture.

Section 8 summarizes the OUL's findings and conclusions related to the planned project. These findings and conclusions clearly demonstrate that this is a high-risk project very likely to not provide the additional water supply that MAWC desires.

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EXECUTIVE SUMMARY

Missouri American Water Company (MAWC) is the public utility that supplies water to Joplin, Missouri and some surrounding areas. MAWC prepared a document dated February 2019 identified as a Section 404 pre-application for a new water supply reservoir for Joplin. Section 404 relates to a section of the federal Clean Water Act requiring a permit for actions that would include the construction of a dam; such 404 permits are issued by the U.S. Army Corps of Engineers (USACE).

The Ozark Underground Laboratory, Inc. (OUL) was retained by a landowner in the area of the planned Baynham Branch reservoir to conduct an independent and non-invasive evaluation of the MAWC proposal and of the proposed dam and reservoir. This report is a result of that evaluation and is divided into eight issue-specific sections.

Section 1 summarizes key features of the MAWC document and provides important information lacking from that document. A copy of the MAWC document is in Appendix A. The proposal has major deficiencies; two are worthy of comment here. First, the proposal does not recognize that impoundments in southwest Missouri have a high risk of failure due to excessive leakage through karst groundwater systems. Second, MAWC apparently did not make even simple field observations of flow rates of Baynham Branch at readily available public access points under low flow conditions. Had such observations been made and included in the document they would have shown that most of the low flow of the stream enters groundwater upstream of the planned dam site. That is inconsistent with a good dam site in a karst landscape. The result of these deficiencies is an unrealistically optimistic document for a technically risky project.

Section 2 deals with losing stream segments within the reservoir area. Losing streams are surface watercourses that lose a portion or all of their flow into the karst groundwater system. The MAWC document, using an inappropriate definition of losing stream for assessing reservoir leakage, states that there are 3,488 linear feet of losing stream within the planned impoundment area. The correct value is approximately 19,200 feet; there are three major losing stream segments within the reservoir.

The OUL introduced a separate tracer dye into each of the three losing stream segments. All three dyes ultimately discharged from the Hunley Springs Complex. None of the water discharging from the Hunley Springs Complex would be captured by the planned dam. MAWC claims that losing streams inundated by the reservoir are not anticipated to impact reservoir storage. The three groundwater traces demonstrate that the MAWC claim is both illogical and false; the reservoir will experience major leakage and will not function as proposed.

Section 3 provides stream flow measurements made by the OUL. The measurements show that most (and approaching all) of the flow of the springs in the Hunley Springs Complex is derived from water sinking in Baynham Branch upstream of the planned dam.

Section 4 deals with estimates of the volume of leakage likely to occur from the planned reservoir. The owner of the Hunley Springs Complex measured the flow of the springs under spring-time conditions at 20 million gallons per day (mgd). The OUL concludes that this is a reasonable value when water in the channel of Baynham Branch is approximately 5 feet deep in the losing stream downstream of Lime Kiln Road. Under these conditions the groundwater gradient between the stream and the main spring feeding Hunley Lake is 2.8 feet per thousand feet. If a reservoir existed at the planned pool elevation the groundwater gradient would increase to 20.9 feet per thousand feet. This would dramatically increase the leakage to rates that would be unacceptable for a water supply reservoir.

Section 5 discusses reservoir impacts on Ozark Cavefish, a federally listed Threatened species. Environmental DNA (eDNA) studies indicate that the planned reservoir would inundate three cavefish habitats. Dissolved oxygen concentrations in bottom waters of reservoirs in southern Missouri in warm weather are commonly so low as to be lethal to aquatic life. Additional work focused on Ozark cavefish is planned during Phase 2 work by the OUL.

Section 6 evaluates likely effects of reservoir leakage through the Hunley Springs Complex to Shoal Creek. This discharge water would be low in dissolved oxygen and would likely impact six mussel species of conservation concern in Shoal Creek.

Section 7 discusses the hydrogeology of the planned dam site. The bedrock is Burlington-Keokuk Limestone which is a routinely cavernous karst unit. Hillslopes in the vicinity of the dam are steep and overlain by soils with moderate to moderately rapid permeability. Pinnacled bedrock beneath the dam is anticipated. The MAWC document states that the Baynham Branch site is anticipated to have materials suitable for both impervious core material and shell material. No reference is cited to support this “anticipation” and it is inconsistent with the severe limitations identified in the soil mapping done by professionals with the U.S. Department of Agriculture.

Section 8 summarizes the OUL’s findings and conclusions related to the planned project. These findings and conclusions clearly indicate that this is a high-risk project that is very likely to not provide the additional water supply that Joplin needs.

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INTRODUCTION

Background

Baynham Branch is a small stream underlain by rock units that are mostly limestone. Large surface flow rates are of short duration and major stream segments with several square miles of topographic basin only have intermittent flow. The explanation for the scarcity of surface stream flow is the underlying karst draining network of solutionally enlarged conduits in the limestone that rapidly transport water to springs both inside and outside of the topographic basin of Baynham Branch.

Landowners likely to be impacted by the proposed reservoir project learned of the plans from various sources. Some landowners had visits from Missouri American Water Company (MAWC) personnel or consultants to that company. Other learned of the potential project through discussions with neighbors or contacts with employees of public agencies involved with conservation programs. There was a lack of meaningful assessment of the potential viability of the project. To many it appeared that the decision to build the reservoir had been recklessly made without conducting meaningful and essential non-invasive field work. A major concern for many of the landowners was the prospect that their lives would be disrupted for years by an ill-conceived project that could take their lands whether they wished to sell or not. Concerns about the project and the absence of a meaningful technical evaluation of the likely feasibility of the project led to a landowner retaining the Ozark Underground Laboratory (OUL) to conduct this assessment.

Objectives of the Evaluation

The Ozark Underground Laboratory (OUL) is a 10-person contract studies and consulting firm that conducts water and land use investigations with special emphasis on projects in cave and karst regions in the Ozarks. The OUL was retained to do the following:

1. Provide a technical assessment of the adequacy and accuracy of the MAWC document.
2. Evaluate whether or not the proposed project is likely to function as planned.
3. Determine if the planned project is likely to provide the water supply benefits anticipated by MAWC.
4. Identify impacts of the reservoir on the federally “Threatened” Ozark Cavefish if the reservoir is located and operated as planned in the MAWC proposal.

Qualifications of the Authors

Tom Aley is the founder, owner, and President of Ozark Underground Laboratory, Inc. The Laboratory has been in fulltime operation since 1973. Tom holds B.S. and M.S. degrees from the University of California (Berkeley) and holds national certification as a Professional

Hydrogeologist (PHG 179) from the American Institute of Hydrology. Tom is a Registered Geologist in Missouri (license 0989) and is licensed as a Professional Geologist in Arkansas, Kentucky, and Alabama.

Tom is the senior author of "Groundwater Contamination and Sinkhole Collapse Induced by Leaky Impoundments in Soluble Rock Terrain", an Engineering Geology Monograph published in 1972 by the Missouri Geological Survey and Water Resources. He has worked as a consultant on dam and reservoir leakage investigations using tracer dyes at sites in Missouri, Arkansas, Florida, Alabama, Indiana, Texas, Arizona, Colorado, Utah, Idaho, Washington, Australia, Peru, and Ghana. In addition, Tom and the OUL have delineated recharge areas for at least 20 Ozark Cavefish sites in Missouri, Arkansas, and Oklahoma.

Dave Woods holds B.S. and M.S. degrees from Missouri State University and worked as a Fisheries Biologist with the Missouri Department of Conservation for 12 years before joining the OUL as a Senior Project Scientist.

Organization of this Report

This report is divided into 8 subsequent sections:

- The reservoir proposal.
- Losing stream segments within the proposed reservoir. This includes information on four dye traces conducted for this investigation.
- Stream flow measurements.
- Estimation of reservoir leakage.
- Reservoir impacts on Ozark Cavefish.
- Reservoir leakage impacts on Shoal Creek.
- Hydrogeology of the dam site.
- Findings and conclusions.

There are four appendixes to this report.

- Appendix A is a copy of the Section 404 pre-proposal document for the Joplin Water Supply Reservoir.
- Appendix B presents data from the groundwater tracing studies.
- Appendix C outlines criteria and procedures used in the groundwater tracing studies.
- Appendix D provides rules of Missouri Department of Natural Resources, Dam and Reservoir Safety Council.

THE RESERVOIR PROPOSAL

A document titled "Joplin Water Supply Reservoir Section 404 Pre-Application" was prepared for Missouri American Water Company (MAWC) by the Olsson consulting firm. The title page also shows the firm name of Black and Veatch, which has apparently been purchased by Olsson. MAWC is a private water utility that services multiple areas in Missouri including Joplin and nearby communities. The report prepared by Olsson on behalf of MAWC is dated February 2019 and will be called "The MAWC Proposal" in this evaluation. A copy of the proposal is included in this evaluation as Appendix A.

The MAWC Proposal outlines a plan to construct a water supply reservoir on Baynham Branch, a surface stream basin located southwest of Diamond, Missouri. Baynham Branch is a surface tributary to Shoal Creek about 11 miles upstream of the current water supply intake for the City of Joplin. **Figure 1** shows the location of the proposed reservoir and is a copy of Figure 4 in The MAWC Proposal.

The MAWC Proposal plans to pump water from Shoal Creek into the reservoir during periods of high runoff in Shoal Creek. The water from Shoal Creek would augment natural runoff from the Baynham Branch watershed to fill (if the project works as planned) the reservoir to the level shown in Figure 1. Water from the reservoir would be discharged as needed to Shoal Creek where it would flow downstream for about 11 miles to the MAWC Joplin water intake point. Among other requirements, construction of the proposed dam and associated reservoir are anticipated to require:

1. A permit from the U.S. Army Corps of Engineers under Section 404 of the Federal Clean Water Act.
2. Compliance with State of Missouri dam safety requirements (see Mo. 10 CSR 22). Also see Appendix D to this report.
3. Formal consultation with the U.S. Fish and Wildlife Service as required under the federal Endangered Species Act.
4. An Environmental Assessment and almost certainly an Environmental Impact Statement as required by the National Environmental Protection Act (NEPA).

Figure 1. Location and normal size of the proposed reservoir. From Figure 4 in MAWC proposal.

Joplin Water Supply Reservoir
Project No. 017-3660

Section 404 Preapplication
February 2019

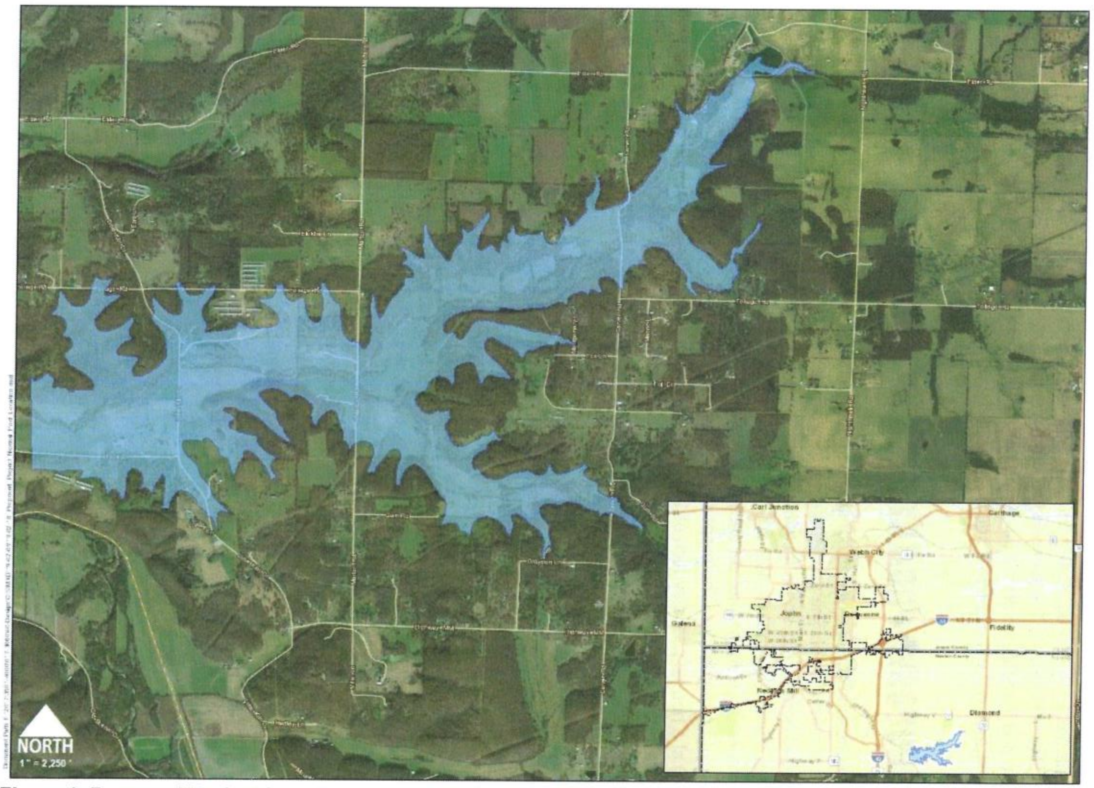

Figure 1. Proposed Project Location.

BLACK & VEATCH olsson

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The MAWC Proposal provides the following basic information:

- The impoundment would inundate approximately 1,200 acres at normal pool elevation.
- Normal pool elevation would be 1,051 feet above mean sea level.
- The reservoir would provide up to 30 million gallons of water per day. This water would be discharged to Shoal Creek.
- The watershed area for the proposed dam is 15.7 square miles.
- Bedrock at the dam and in the watershed is expected to consist of Burlington-Keokuk Limestones.

Some relevant OUL measurements and calculations:

- At normal pool elevation water at the present stream channel would be:
    - Approximately 100 feet deep at the dam.
    - Approximately 80 feet deep at Lime Kiln Road.
    - Approximately 65 feet deep at Marten Road.
    - Approximately 30 feet deep at Carver Road.
- Mean annual runoff in this portion of Newton County is 11.5 inches (Schroeder, 1982). For a basin of 15.7 square miles this would equal 3,136 million gallons per year = 8.59 million gallons per day (mgd).
- Annual lake evaporation rate based on Class A pan evaporation data is about 62 inches per year (Schroeder, 1982). A common coefficient for estimating lake evaporation from Class A pan data is 0.7; thus 62 inches/yr. X 0.7 = 43.4 inches per year. For a 1,200-acre lake this equals 1,415 million gallons per year of water loss to evaporation = 3.87 mgd.
- Total annual basin water yield with the reservoir (assuming no groundwater movement into or out of the basin) = 3,136 million gallons minus evaporation of 1,415 million gallons = 1,721 million gallons per year = 4.72 mgd
- If the reservoir is to provide 30 million gallons of water per day this equals 10,950 million gallons per year. 84% of all water extracted from the reservoir would need to be pumped into the reservoir from Shoal Creek. This presumes that there would be no leakage out of the reservoir.

The land within the proposed impoundment is privately owned and would need to be acquired prior to filling of a reservoir. As a public utility MAWC can use condemnation to acquire lands, and through court action, is reported to be currently obtaining access rights to lands within the proposed reservoir to conduct investigations they deem necessary for their project. Even if a fair price is ultimately paid, the lives and plans of landowners are being, and will likely continue to be, adversely affected. With this in mind, and in recognition that customers of MAWC will ultimately pay for the project regardless of whether or not it is successful, it should have been incumbent on MAWC to not propose a project that does not have a high probability of success.

Impoundments such as the one proposed for Baynham Branch are rare in the karst regions of Missouri because they have a high risk of failure due to excessive leakage into karst groundwater systems. This risk is discussed in a published report titled "Water Resources of the Joplin Area, Missouri" published by the Missouri Geological Survey and Water Resources (Feder et al., 1969, p. 58). Under the heading "Seepage Losses" this report states:

"An evaluation of seepage losses is an integral part of reservoir design. [Note: the MAWC Proposal has no evaluation of likely seepage losses.] *Although a study of the reservoir site is necessary for a precise evaluation of this factor, a general appraisal of seepage losses will be of value in the design of small, general-purpose reservoirs.*

"According to James H. Williams, Missouri Geologic Survey and Water Resources (written communication): 'Seepage losses are directly related to physiography in the study area. In the Springfield Plateau area, permeable cherty clay soils and permeable residuum underlain by moderately cavernous bedrock have contributed to a high rate of seepage with comparatively little surface runoff except during intense storms. Topographically this region is relatively level. Locally, intense sinkhole development surrounded by areas of broad and poorly defined valleys, which in effect are sinkholes from the aspect of a high surface water loss, create tremendous pollution and reservoir leakage hazards."

Baynham Branch is within the Springfield Plateau and the statement of Dr. Williams relative to tremendous reservoir leakage hazards within this karst region (and within the Baynham Branch basin) is clearly accurate. One only needs to drive roads that cross Baynham Branch and its tributaries under low to moderate flow conditions to see that there are large volume water losses from surface waters into groundwater. There are four points, each separated by about a mile, where one can easily observe the volume of surface flow in Baynham Branch. These are, in order from upstream to downstream:

- Carver Road crossing of Baynham Branch,
- Marten Road crossing of Baynham Branch,
- Lime Kiln Road crossing of Baynham Branch, and
- Kansas City Southern railroad crossing of Baynham Branch. It is easy to drive to the rail line and walk about 400 feet to this stream crossing.

If Baynham Branch were a reasonable candidate for a 1,200-acre impoundment one would expect increasing volumes of surface flow as one progressed down the basin. This is not the case. While Baynham Branch at Carver Road routinely has flow, under low to moderate flow conditions there is little or no flow at Marten Road. At the Lime Kiln Road crossing there is again flow in the stream, but at the rail line crossing the flow rate has been substantially diminished. The proposed dam is located on Baynham Branch between Lime Kiln Road and the rail line. Stream flow measurements under low to moderate flow conditions show that the proposed reservoir has major leakage problems, yet MAWC failed to conduct, or at least failed to report, obvious and relevant field observation under appropriate flow conditions.

LOSING STREAMS WITHIN THE PROPOSED RESERVOIR

Differing Definitions of Losing Streams

The authors of the MAWC Proposal did not recognize the important difference between "losing streams" as used in regulations by the Missouri Department of Natural Resources (MDNR) and as used in technical literature and defined in "Lexicon of Cave and Karst Terminology with Special Reference to Environmental Karst Hydrology" (USEPA, 1999).

The MDNR definition of losing streams is found in 10 CSR 20-7 and is as follows:
"A losing stream is a stream which distributes thirty percent (30%) or more of its flow through natural processes such as through permeable geologic materials into a bedrock aquifer within two (2) miles flow distance downstream of an existing or proposed discharge. Flow measurements to determine percentage of water loss must be corrected to approximate the seven (7)-day Q10 stream flow. If a stream bed or drainageway has an intermittent flow or a flow insufficient to measure in accordance with this rule, it may be determined to be a losing stream on the basis of channel development, valley configuration, vegetation development, dye tracing studies, bedrock characteristics, geographical data, and other geological factors."

The 7-day Q10 means the lowest flow rate that persists for a continuous seven-day period with a return frequency of once every 10 years. It should be emphasized that a stream does not need to lose all of its flow in order to meet the losing stream definition.

USEPA (1999) defines a losing stream as: "a stream or reach of a stream in which water flows from the stream bed into the ground. In karst terranes, losing streams may slowly sink into fractures or completely disappear down a ponor." A ponor in the US is typically called a sinkhole.

Under the MDNR definition a losing stream extends upstream for 2 miles from the point where the water sinks. While losing streams under this definition are important in evaluating the discharge of contaminated waters to surface watercourses, such stream designations are not relevant for evaluating potential reservoir leakage. With respect to reservoir leakage, the locations of surface stream segments that lose flow to groundwater are very important features if: 1) they are within proposed reservoir areas, and 2) if water entering groundwater through them discharges outside of the reservoir area.

Relevance of Losing Streams to Reservoir Leakage

In the Ozarks losing streams commonly contribute water to springs and wells miles away from where the water sinks and often in different topographic basins. A good local illustration is provided by Hearrell Spring.

Hearrell Spring is located at the U.S. National Fish Hatchery in Neosho and is one of the springs supplying water to that facility. This spring also provides habitat for the Ozark Cavefish, which is federally listed as "Threatened" under provisions of the federal Endangered Species Act. Groundwater traces to this spring and other springs that share water with this spring have been conducted by the Missouri Division of Geology and Land Survey and by the Ozark Underground Laboratory (Vandike and Brookshire, 1997; Aley and Aley, 1997; Aley and Aley, 1998). These traces have demonstrated that Hearrell Spring receives water from two separate topographic basins. These are the basins in which Hearrell Spring is located and the Buffalo Creek Basin. The unnamed basin in which Hearrell Spring is located flows northward and is tributary to Hickory Creek in Neosho and then to Shoal Creek. Buffalo Creek flows west and southwestward to Oklahoma where it is tributary to Elk River in the Lake of the Cherokees. Aley and Aley (1997) report that the area contributing water to Hearrell Spring encompasses 5.67 square miles. Of this, 2.26 square miles (40%) is within the unnamed basin in which the spring is located and the other 3.41 square miles is in the Buffalo Creek basin.

Hearrell Spring also shares water with South Big Spring. South Big Spring is located in a city park in downtown Neosho and is in a different topographic basin from Hearrell Spring. A number of similar examples could be cited.

Figure 2 shows stream segments in the proposed reservoir area that are losing streams under the EPA definition. In other words, they are streams that contribute directly to groundwater. The total length of losing stream segments in the proposed reservoir area is 19,200 feet; total perennial stream length in the proposed reservoir is 9,800 feet. Losing streams are thus 66% of all main stem stream channels in the proposed reservoir area. This mapping is by the OUL and there are three principal losing stream segments:

- Baynham Branch from a point about 1,000 feet downstream of Carver Road to Henson Spring.
- All of the South Fork of Baynham Branch.
- Baynham Branch from a point approximately 1215 feet downstream of Lime Kiln Road to a point about 5,970 feet downstream of Lime Kiln Road. The centerline of the proposed dam is in this losing stream segment and is about 3,990 feet downstream of Lime Kiln Road. The distances are as the stream flows, not straight-line distances.

Figure 2. Losing streams in the reservoir area.

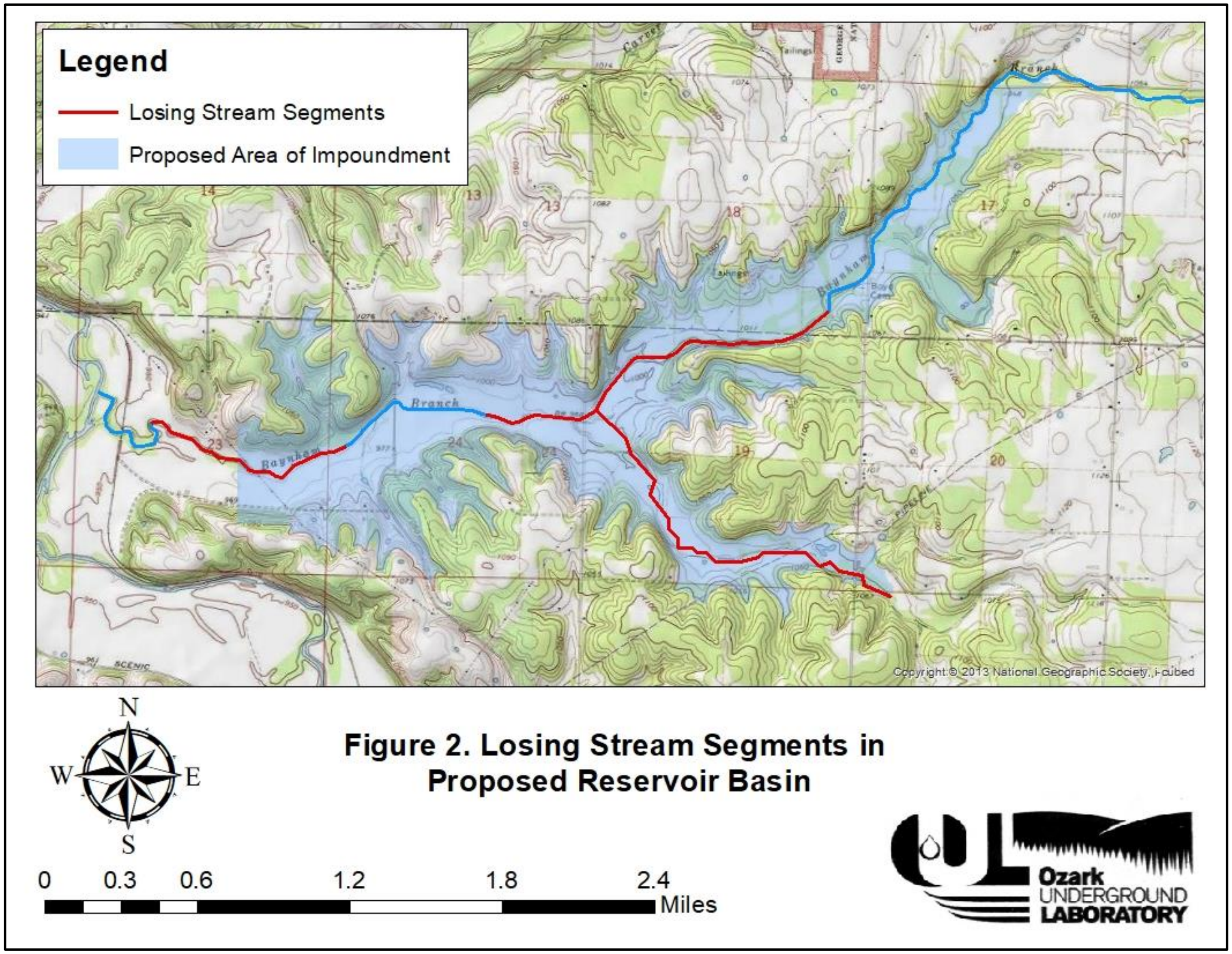


Figure 2. Losing Stream Segments in Proposed Reservoir Basin

The MAWC Proposal (page 16) states that there are 3,488 linear feet of losing stream segments in the proposed impoundment area and further states that: *"The losing stream would be entirely inundated by the proposed reservoir and is not anticipated to impact reservoir storage."* This conclusion is wrong and without any factual support. OUL work discussed in the next section of this report shows that the proposed impoundment area, even without a reservoir, already experiences major groundwater transport to springs outside of the area proposed for impoundment.

OUL Dye Tracing from Losing Stream Segments

A different tracer dye was introduced into each of the three losing stream segments identified within the proposed Baynham Branch impoundment area. In addition, a fourth dye introduction was made upstream of a major losing stream segment in Carver Branch (the surface stream north of Baynham Branch). **Figure 3** shows the locations of all four dye introduction points and all sampling stations used in the dye tracing investigations. **Table 1** provides information on all dye sampling points. All dye analysis data are found in Appendix B; Table B-1 shows analysis data for activated carbon samplers and Table B-2 shows analysis data for all grab samples of water analyzed. Appendix C is a copy of the OUL's Procedures and Criteria document and outlines how tracer studies using fluorescent tracer dyes are conducted and criteria used to determine positive dye detections.

OUL Trace 20-01 from Gary Dug Well

Three pounds of rhodamine WT dye mixture containing approximately 20% dye equivalent was introduced into the Gary Dug Well by Tom Aley and Dave Woods of the OUL on October 6, 2020 at 1410 hours. **Figure 4** shows the Gary Dug Well. The Color Index Name for rhodamine WT is Acid Red 388. Coordinates for the dye introduction point are 36.95733 and -94.36689. The water level in the Gary Dug Well was approximately 12.6 feet below ground surface at the time of dye introduction.

Gary Dug Well is a karst window; a karst window is a sinkhole or spring that intersects a karst conduit transporting groundwater laterally. It is literally a "window" into a significant karst drainage conduit. The Gary Dug Well was initially a spring with intermittent flow; it was excavated and converted into a well 15 feet deep. Mr. Gary reports that it was a dependable water source even in years with severe drought.

Figure 3. Dye introduction points and sampling stations used in the tracer studies.

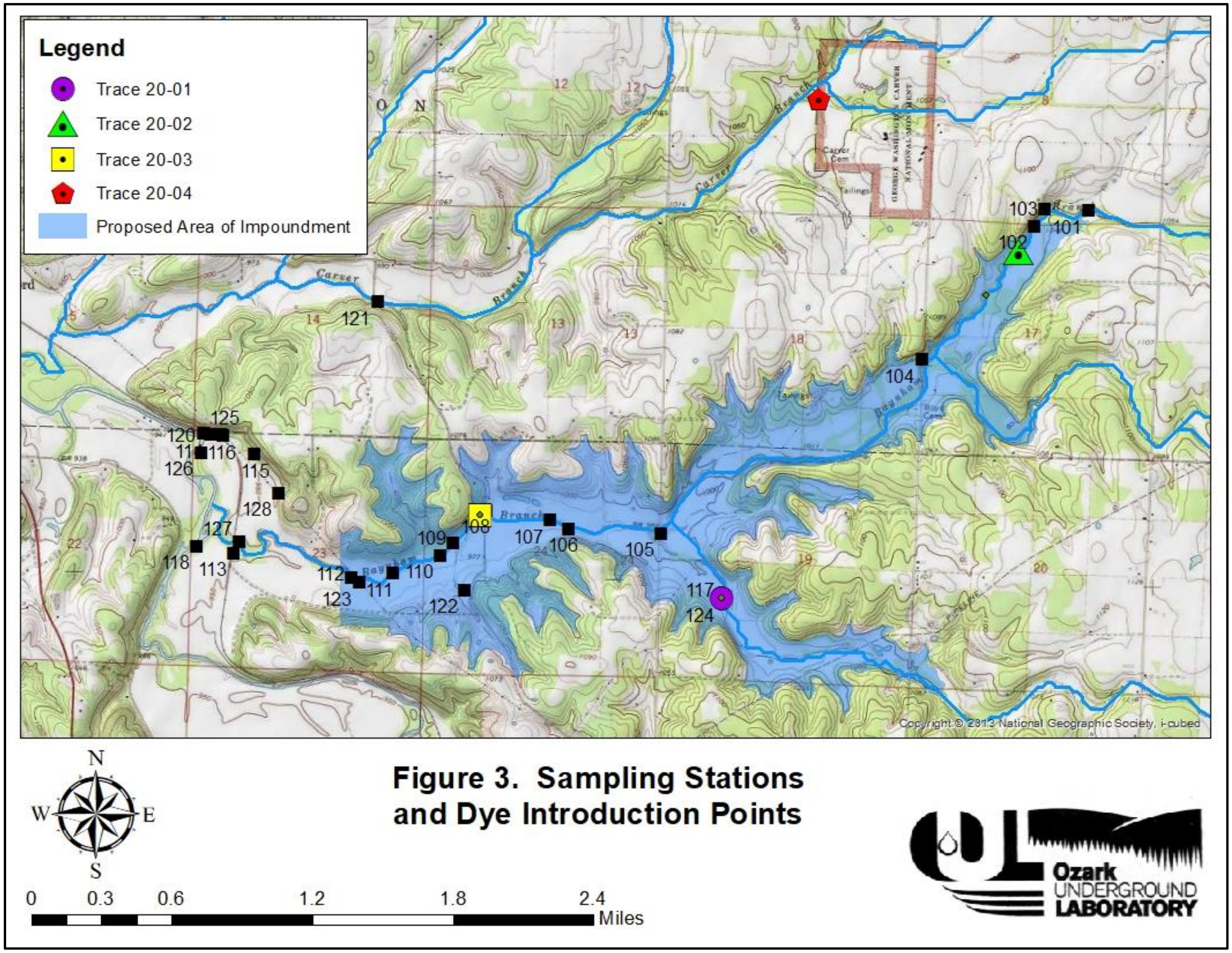


Figure 3. Sampling Stations and Dye Introduction Points

Table 1. Basic data on dye sampling stations.

Station	Station Location	Northing	Easting	Approx. Elevation
101	Baynham Br. u/s Brown Lake*	36.98171	-94.33897	1050
102	Baynham Br. d/s Brown Lake	36.98068	-94.34314	1045
103	Brown's Spring*	36.98174	-94.34238	1061
104	Baynham Br. u/s Carver Road	36.97011	-94.35147	1020
105	Baynham Br. d/s Marten Road	36.96131	-94.37160	992
106	Bayham Br. d/s Henson Spring	36.96150	-94.37879	977
107	Henson well pipe	36.96205	-94.38019	980
108	Baynham Br. u/s Lime Kiln Road	36.96260	-94.38515	976
109	Parks Spring #1	36.96054	-94.38768	970
110	Parks Spring #2	36.95975	-94.38865	965
111	Baynham Br. u/s dam site 1	36.95861	-94.39227	958
112	Bayham Br. u/s dam site 3	36.95829	-94.39545	954
113	Baynham Br. @ Railroad bridge	36.95970	-94.40460	945
114	Hunley Spring Branch @ Railroad bridge	36.96702	-94.40651	945
115	Spring flow up-gradient of Hunley Spring Lake	36.96585	-94.40316	948
116	Hunley Spring Lake outflow	36.96698	-94.40554	945
117	Gary Well overflow	36.95733	-94.36689	1005
118	Shoal Creek u/s Baynham Branch	36.96010	-94.40749	947
119	Station Not Established	-	-	-
120	Shoal Creek d/s Hunley Spring Branch	36.96713	-94.40709	942
121	Carver Branch d/s Lime Kiln Road	36.97542	-94.39377	975
122	Dockins dug well *	36.95765	-94.38671	980
123	Baynham Branch u/s dam site 2	36.95800	-94.39488	955
124	Gary dug well water level 10/8/20	36.95733	-94.36689	993
125	Spring d/s Hunley Lake outflow	36.96705	-94.40571	945
126	Shoal Cr. b/w Baynham Br. and Hunley Spring Br.	36.96592	-94.40726	946
127	Spring u/s Railroad on Baynham Br.	36.96043	-94.40417	947
128	Powerline Spring	36.96348	-94.40119	955

*** No samples analyzed.** Abbreviations: u/s = upstream. d/s = downstream. b/w = between. Br = Branch. Cr = Creek

Figure 4. Gary Dug Well in South Fork Baynham Branch.

As shown in **Table 2**, rhodamine WT from Trace 20-01 was detected in activated carbon samplers in place at 13 sampling stations. The sampling period in which the greatest concentration of rhodamine WT was detected at each sampling station in carbon samplers is also indicated in Table 2. Where duplicate samples were analyzed the mean dye concentration value is shown. Distances shown in the table are straight line distances between the dye introduction point and the dye detection location.

There are two different groundwater flow routes that could account for the observed dye detections.

- The first possibility is groundwater flow from the Gary Dug Well to Henson Spring, surface flow down Baynham Branch to a short distance downstream of Lime Kiln Road, and then water and dye re-entering groundwater in the losing stream segment between Lime Kiln Road and the railroad and subsequently discharging from springs in the Hunley Springs Complex.
- The second possibility is groundwater flow for the entire distance between Gary Dug Well and springs in the Hunley Springs complex.

Table 2. Maximum rhodamine WT dye concentrations in carbon sampler elutants from positive dye detection stations, OUL Trace 20-01. Dye introduced October 6, 2020. If duplicate samplers were analyzed dye concentration shown is the mean value.

Station Number	Station Name	Maximum Dye Concentration (ppb)	Sampling Period (Days After Dye Introduction)	Distance from Dye Introduction Point (ft)
106	Baynham Br. d/s Henson Spr.	7135	0 to 8	3,865
108	Baynham Br. u/s Lime Kiln Rd.	3655	0 to 8	5,670
109	Parks Spring 1 (upstream spring)	2890	0 to 8	6,180
110	Parks Spring 2 (downstream spring)	825	0 to 8	6,420
111	Baynham Br. u/s dam site 1	738	0 to 8	7,430
112	Baynham Br. u/s dam site 3	981	0 to 8	8,350
113	Baynham Br. @ rail road bridge	2.5	8 to 16	11,050
114	Hunley Spr. Br. @ rail road bridge	257	16 to 23	12,100
115	Spring flow u/g Hunley Spr. lake	106	8 to 16	11,040
116	Hunley Spring Lake outflow	399	8 to 16	11,825
120	Shoal Cr. d/s Hunley Spr. Branch.	9.2	8 to 16	12,270
123	Baynham Br. u/s dam site 2	1600	0 to 8	8,180
125	Spring d/s Hunley Lake outflow	286	16 to 23	11,880

Abbreviations: d/s = downstream. u/s = upstream. u/g = upgradient. ND = None Detected

While the first possible flow route would account for all dye detections, the second possibility could also operate concurrently. OUL Trace 20-03 (discussed in a following section) demonstrated that water from the losing stream segment between Lime Kiln Road and the railroad does in fact discharge from springs in the Hunley Springs Complex. None of the OUL tracing work indicates that the second possible flow route does not also operate. Under the natural conditions tested it appears that if the second potential flow route actually operates it probably transports less water than the first flow route. The balance between the two potential flow routes could change under reservoir conditions which would include dramatically increased hydraulic heads operating on all leakage areas within the reservoir. Due to the extensive karst groundwater system in the area, any competent risk assessment work dealing with leakage or sudden failure of the proposed dam and reservoir must recognize that discharges of appreciable volumes of reservoir water to multiple points outside of the reservoir area will undoubtedly occur.

Station 106 (Baynham Branch downstream of Henson Spring) was the furthest upstream sampling point where rhodamine WT was detected. All dye at this station discharged from Henson Spring. **Figure 5** is a photo of Henson Spring. Water rises from a solutionally enlarged bedrock opening. The straight-line distance from the dye introduction point to Henson Spring is approximately 3,865 feet. The difference in water level elevations between these two points is 16 feet for a mean groundwater gradient of 4.1 feet per 1,000 feet.

Figure 5. Henson Spring on the main stem of Baynham Branch.

Rhodamine WT dye discharging from Henson Spring continued down Baynham Branch as surface flow to a point about 1,215 feet stream distance downstream of Lime Kiln Road. From this point during the tracer study period the flow rate of the stream began to decrease at multiple points until a point (dye sampling station 12) approximately 3,540 feet downstream of Lime Kiln Road where, on October 8, 2020, there was no longer surface flow in Baynham Branch. There was again flow in the channel of Baynham Branch beginning at a point about 5,970 feet downstream (stream distance) of Lime Kiln Road. **Figure 6** shows the dry stream channel at Station 112 on October 8, 2020.

Rhodamine WT dye entered groundwater at multiple points along approximately 2,325 feet of losing stream channel in Baynham Branch upstream of the proposed dam centerline. This dyed water subsequently discharged from springs in the Hunley Springs Complex; these springs were sampled by Stations 114, 115, 116, and 125. First arrival of rhodamine WT dye at the four stations in the Hunley Springs Complex was in carbon samplers collected on October 14, 2020; this was 8 days after dye introduction in the Gary Dug Well.

Figure 6. Dry stream channel of Baynham Branch at Station 112 on October 8, 2020. View looking upstream.

Figure 7 shows sampling stations in the Hunley Springs Complex. Springs discharge over a linear distance of 2,175 feet from the edge of the limestone hillside where it contacts the Shoal Creek floodplain to Station 125, a spring downstream of the spring-fed lake.

Station 114 is Hunley Spring Branch at the Railroad Bridge. This sampling point receives all water from Stations 116 and 125 and approximately half of the water from Station 115. Mr. Mike Hunley, the property owner, reported in an email to the OUL that he measured the flow rate at this sampling location during the spring of 2002 or 2003 and found it to be 20 million gallons per day (30.94 cfs). The flow measurement was based on timing floating objects and measuring water depths and channel widths at multiple points. The OUL accepts this value as a reasonable estimate of moderate to high flow discharges from this complex of groundwater discharge points operating under natural water level conditions.

Station 115 is Spring Flow Upgradient of Hunley Spring Lake. There are multiple groundwater discharge points along a ditch that runs on the east side of the Shoal Creek floodplain. The ditch is hydraulically connected with a wetland area. The OUL has installed a transducer at this location to permit determinations of flow rates.

Station 116 is Hunley Spring Lake Outflow. It is the largest single contributor of water to Station 114. Discharge from this spring-fed lake flows through a culvert 3 feet in diameter. The OUL has installed a transducer and is developing a rating curve so that continuous flow rates from Station 116 can be measured. Water supply for this lake is undoubtedly derived from multiple springs, but the largest spring is located about 415 feet southeast of Station 116.

Station 125 is Spring Downstream of Hunley Lake Outflow. Rhodamine WT concentrations in grab samples of water collected on October 22, October 29, and November 5 were sufficiently similar to concentrations at Station 116 (Hunley Spring Lake Outflow) to conclude that these two waters have the same source.

The main spring feeding the lake in the Hunley Springs Complex is approximately 4,700 feet straight line distance from Station 111 which is at approximately the mid-point of the losing stream segment where water was sinking in Baynham Branch during most of the dye tracing study period in October and November, 2020. Based on US Geological Survey topographic maps the elevation of Station 111 is approximately 958 feet and the elevation of Hunley Springs Lake is approximately 950 feet. The main spring feeding Hunley Spring Lake is beneath the lake surface. The mean gradient of the flow route between Station 111 and Hunley Spring Lake was 1.7 feet per 1,000 feet during the OUL 2020 study period.

Figure 7. Sampling locations in the Hunley Springs

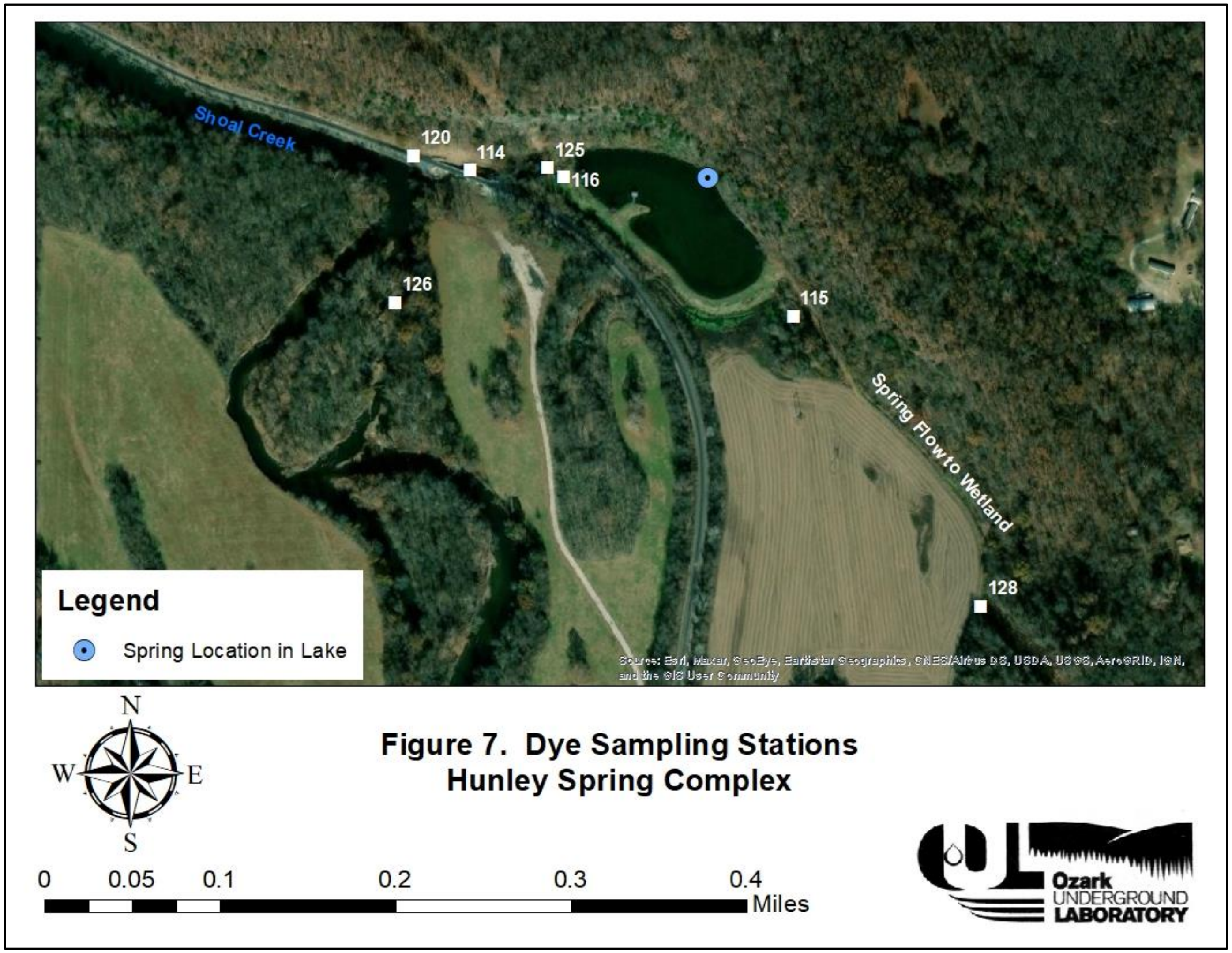


Figure 7. Dye Sampling Stations
Hunley Spring Complex

Figure 8 is a diagram of flow routes for rhodamine WT dye introduced into the Gary Dug Well. Although not shown in Figure 8, an alternate flow route for rhodamine WT dye arriving at the Hunley Springs Complex would be entirely through groundwater from the Gary Dug Well to the Hunley Springs Complex. There is no way to prove or disprove this flow path from the tracing data collected during the OUL work. If this alternate flow route exists, Gary Dug Well, with a surface elevation of approximately 1005 feet, would be inundated by approximately 46 feet of water at normal pool and would probably be a significant point for reservoir leakage.

OUL Trace 20-02 from Baynham Branch Upstream of Carver Road.

Three pounds of eosine dye mixture containing approximately 75% dye equivalent was introduced into water flowing at approximately 180 gallons per minute (gpm) in Baynham Branch on October 6, 2020 at 1505 hours. This dye introduction point was upstream of the major losing stream segment that extends from about 1,000 feet downstream of Carver Road to Henson Spring. The dye introduction was made by Tom Aley and Dave Woods of the OUL. The Color Index Name for eosine is Acid Red 87. Coordinates for the dye introduction point are 36.97634, -94.34680. While access could not be obtained to the actual location where dyed water entered the groundwater system, it is the OUL's opinion that most and approaching all dyed water entered groundwater at a point about 1,000 feet downstream of Carver Road. This point is based on MDNR mapping of losing streams.

As shown in **Table 3**, eosine dye from Trace 20-02 was detected in activated carbon samplers in place at 13 sampling stations. The sampling period in which the greatest concentration of eosine dye was detected at each sampling station in carbon samplers is also indicated in Table 3. When duplicate samples were analyzed the mean dye concentration is shown. All distances in the table are straight line distances between the dye introduction point and the dye detection location.

Station 106 (Baynham Branch downstream of Henson Spring) was the furthest upstream sampling point where eosine was detected. All dye at this station discharged from Henson Spring and there was no flow in the channel of Baynham Branch upstream of Henson Spring during the tracing period. The straight-line distance from the dye introduction point to Henson Spring is approximately 11,910 feet; some of this was as surface flow. The estimated distance through the groundwater system was approximately 7,480 feet. The difference in water level elevations between these two points is 29 feet for a mean groundwater gradient of 3.9 feet per 1,000 feet.

Figure 8. Diagram of groundwater flow routes for rhodamine WT dye introduced into the Gary Dug Well.

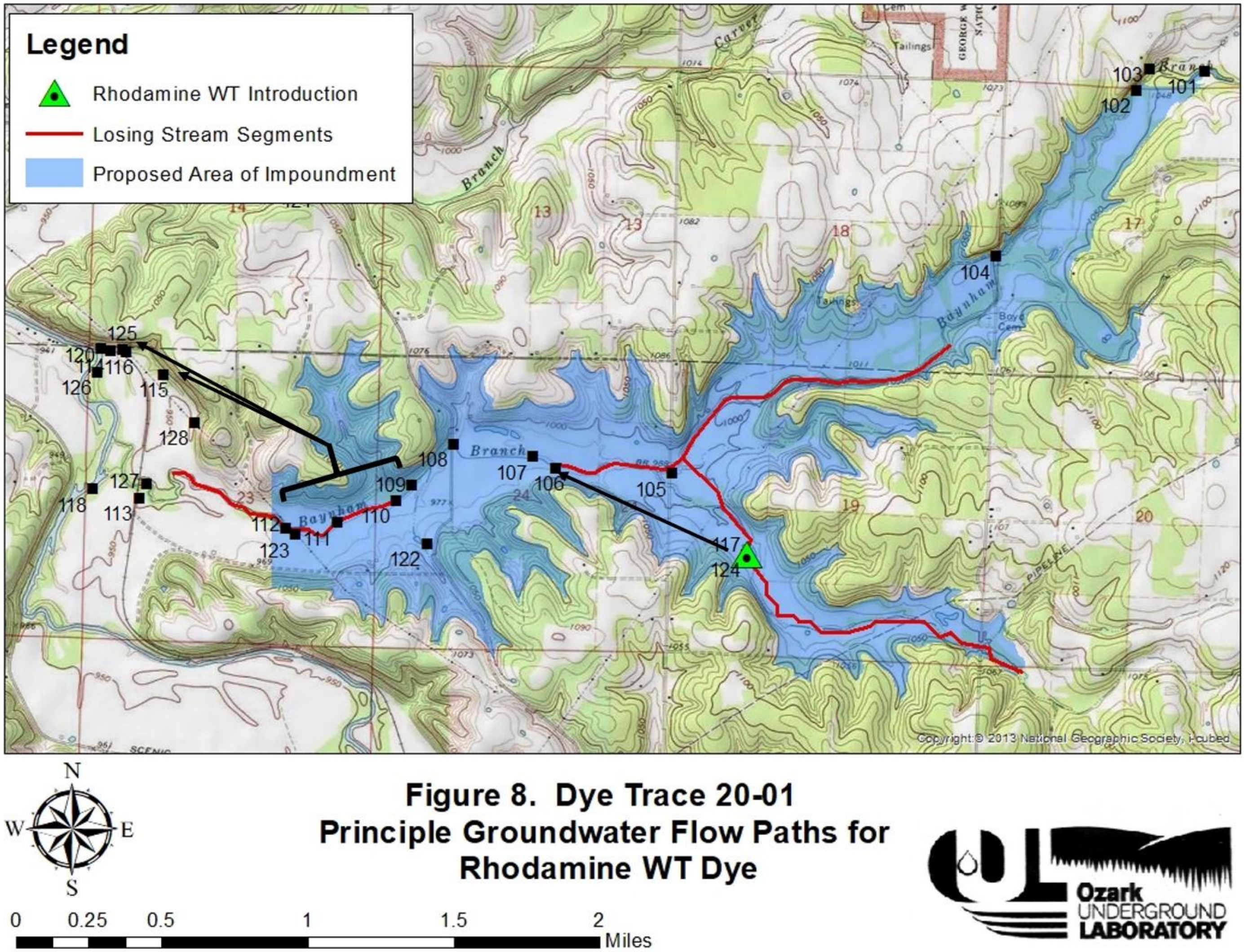


Figure 8. Dye Trace 20-01
Principle Groundwater Flow Paths for
Rhodamine WT Dye

Table 3. Maximum eosine dye concentrations in carbon sampler elutants from positive dye detection stations, OUL Trace 20-02. Dye introduced October 6, 2020.

Station Number	Station Name	Maximum Dye Concentration (ppb)	Sampling Period (Days After Dye Introduction)	Distance from Dye Introduction Point (ft)
104	Baynham Br. u/s Carver Rd.	1090	0 to 8	3,250
106	Baynham Br. d/s Henson Spr.	1210	0 to 8	11,910
108	Baynham Br. u/s Lime Kiln Rd.	517	0 to 8	13,325
109	Parks Spring 1 (upstream spring)	385	0 to 8	14,330
110	Parks Spring 2 (downstream spring)	112	0 to 8	14,715
111	Baynham Br. u/s dam site 1	70	0 to 8	15,840
112	Baynham Br. u/s dam site 2	77	0 to 8	16,720
113	Baynham Br. @ rail road bridge	2.38	45 to 57	18,945
114	Hunley Spr. Br. @ rail road bridge	12	8 to 16	18,665
115	Spring flow u/g Hunley Spr. Lake	13	8 to 16	17,825
116	Hunley Spring Lake outflow	25	8 to 16	18,395
120	Shoal Cr. d/s Hunley Spr. Branch.	0.93	8 to 16	18,820
123	Baynham Br. u/s dam site 2	86	0 to 8	16,620
125	Spring d/s Hunley Lake outflow	3.30	45 to 57	18,435

Abbreviations: d/s = downstream. u/s = upstream. u/g = upgradient.

As was the case with rhodamine WT dye from Trace 20-01, eosine discharging from Henson Spring continued down Baynham Branch as surface flow to a point about 1,215 feet stream distance downstream of Lime Kiln Road. From this point during the tracer study period the flow rate of the stream began to decrease at multiple points until a point approximately

3,540 feet downstream of Lime Kiln Road where, on October 8, 2020, there was no longer surface flow in Baynham Branch. There was again flow in the channel of Baynham Branch beginning at a point about 5,970 feet downstream (stream distance) of Lime Kiln Road.

Eosine dye re-entered groundwater at multiple points along approximately 2,325 feet of losing stream channel in Baynham Branch upstream of the proposed dam centerline. This dyed water subsequently discharged from springs in the Hunley Springs Complex; these springs were sampled by Stations 114, 115, 116, and 125. First arrival of eosine dye at the four stations in the Hunley Springs Complex was detected in carbon samplers collected on October 14, 2020; this was 8 days after dye introduction in the Gary Dug Well.

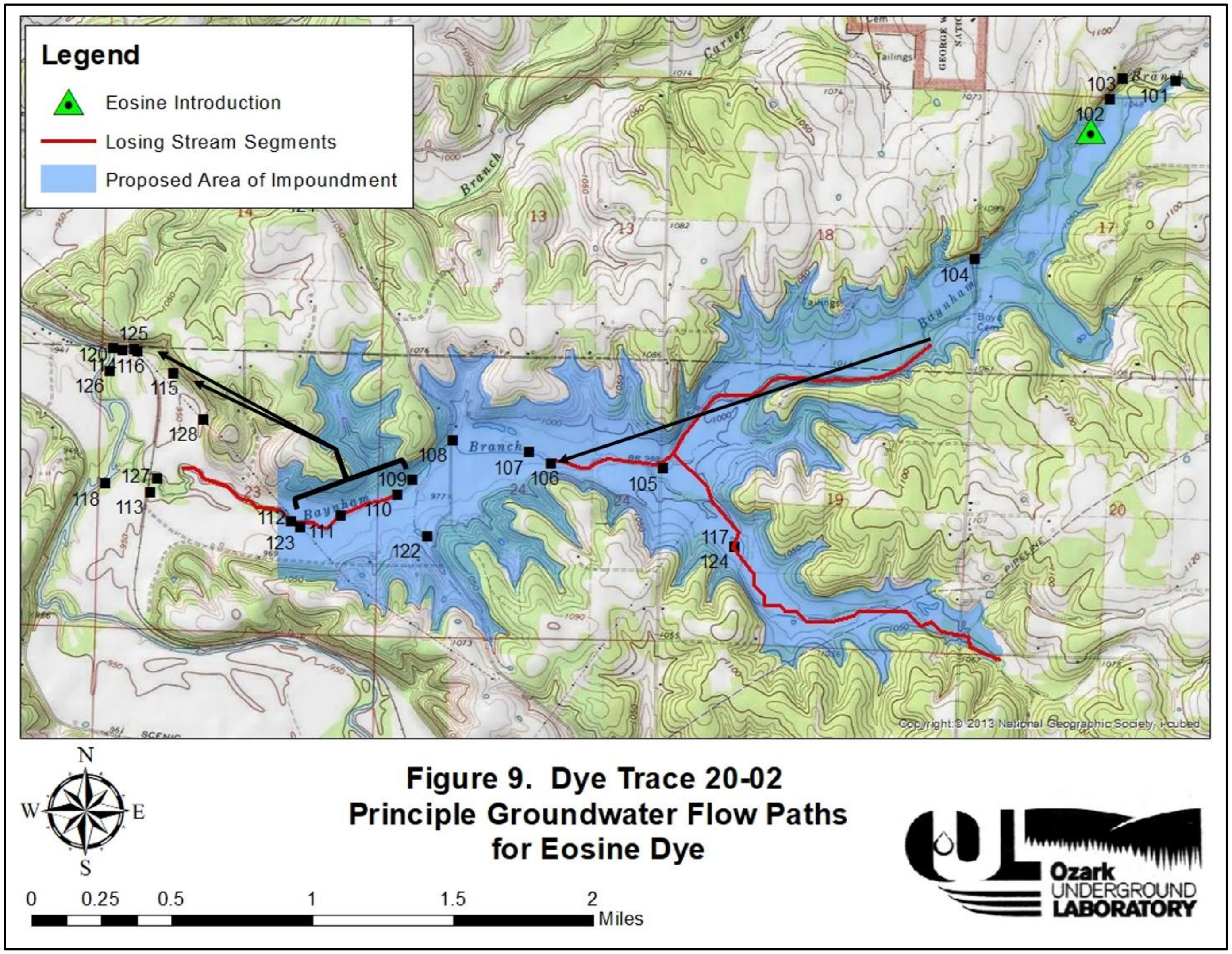
Figure 9 is a diagram of groundwater flow routes for eosine dye introduced into Baynham Branch upstream of Carver Road. Although not shown in Figure 9, an alternate flow route for eosine dye arriving at the Hunley Springs Complex would be entirely through groundwater from the sinking point downstream of the dye introduction point to the Hunley Springs Complex. There is no way to prove or disprove this flow path from the tracing data collected during the OUL work. If this alternate flow route exists it would probably be a significant zone for reservoir leakage since the sinking point is 45 feet below the planned normal pool elevation of the reservoir.

The main spring feeding the lake in the Hunley Springs Complex is approximately 4,700 feet straight line distance from Station 111 which is at approximately the mid-point of the losing stream segment where water was sinking during most of the dye tracing study period in October and November, 2020. Based on US Geological Survey topographic maps the elevation of Station 111 is approximately 958 feet and the elevation of the main spring feeding the Hunley Springs Lake is approximately 950 feet. The mean gradient of the flow route between these two points was 1.7 feet per 1,000 feet.

OUL Trace 20-03 from Losing Stream Segment Near Proposed Dam

One pound of fluorescein dye mixture containing approximately 75% dye equivalent was introduced into water flowing at approximately 925 gpm in Baynham Branch on October 22, 2020 at 1325 hours by Tom Aley and Dave Woods of the OUL. The dye introduction point is approximately 115 feet stream distance downstream of Lime Kiln Road. The Color Index Name for fluorescein is Acid Yellow 73. Coordinates for the dye introduction point are 36.96235, -94.38569. This trace was specifically designed to determine if water sinking in the channel of Baynham Branch downstream of Lime Kiln Road discharged from one or more of the springs in the Hunley Springs Complex.

Figure 9. Diagram of groundwater flow routes for eosine dye introduced into Baynham Branch upstream of Carver Road.



As shown in **Table 4**, fluorescein dye from Trace 20-03 was detected in activated carbon samplers in place at 11 sampling stations. The sampling period in which the greatest concentration of fluorescein was detected at each sampling station in carbon samplers is also indicated in Table 4. Where duplicate samplers were analyzed the mean dye concentration value is shown. Distances shown in the table are straight line distances between the dye introduction point and the dye detection location.

Table 4. Maximum fluorescein dye detection concentrations in carbon sampler elutants from positive dye detection stations, OUL Trace 20-03. Dye introduced October 22, 2020.

Station Number	Station Name	Maximum Dye Concentration (ppb)	Sampling Period (Days After Dye Introduction)	Distance from Dye Introduction Point (ft)
109	Parks Spring 1 (upstream spring)	1080	0 to 7	750
110	Parks Spring 2 (downstream spring)	146	0 to 7	1,155
111	Baynham Br. u/s dam site 1	984	0 to 7	2,245
112	Baynham Br. u/s dam site 3	65	0 to 7	3,115
113	Baynham Br. @ rail road bridge	7.3	0 to 7	5,545
114	Hunley Spr. Br. @ rail road bridge	43	0 to 7	6,310
115	Spring flow u/g Hunley Spr. Lake	505	0 to 7	5,255
116	Hunley Spring Lake outflow	42	0 to 7	6,040
120	Shoal Cr. d/s Hunley Spr. Branch.	15	0 to 7	6,485
123	Baynham Br. u/s dam site 2	149	0 to 7	3,015
125	Spring d/s Hunley Lake outflow	60	0 to 7	6,095

Abbreviations: d/s = downstream. u/s = upstream. u/g = upgradient

Fluorescein from Trace 20-03 was first detected in activated carbon samplers in place at Stations 114, 115, 116, and 127 in the Hunley Springs Complex for the period from October 22 to 29, 2020. The straight-line distance between the dye introduction point and dye detection Station 116 was 6,130 feet and the mean travel rate was greater than 875 feet per day. **Figure 10** is a diagram of the groundwater flow routes for fluorescein dye introduced into Baynham Branch at a point approximately 115 feet downstream of Lime Kiln Road. With a reservoir at the design water level elevation of 1,051 feet the depth of water over the leaking segments of Baynham Branch tested by the fluorescein dye introduction would vary from approximately 75 to 97 feet. This would dramatically increase leakage volumes through this segment of Baynham Branch upstream of the proposed dam.

OUL Trace 20-04 from Losing Stream Segment of Carver Branch.

Three pounds of eosine dye mixture containing approximately 75% dye was introduced into Carver Branch by Dave Woods of the OUL on November 19, 2020 at 1334 hours. The Color Index Name for eosine is Acid Red 87. Coordinates for the dye introduction point are 36.98837, -94.35995. At that time water in Carver Branch entered groundwater upstream of Marten Road and no more than 4,500 feet downstream of the introduction point. This trace was designed to determine if water sinking in Carver Branch discharged at any point in the Hunley Spring Complex. The estimated flow rate at the dye introduction point was approximately 70 gpm.

Eosine from Trace 20-04 was first detected in activated carbon samplers in place at Station 121 (Carver Branch downstream of Lime Kiln Road) from November 19 to December 1, 2020. The mean concentration in the elutant from the 2 carbon samplers in place during this period at Station 121 was 1,170 ppb. The straight-line distance between the dye introduction point and dye detection Station 121 was 10,930 feet and the mean travel rate was greater than 994 feet per day. A mean groundwater gradient is not calculated since the location where the dye entered the groundwater system is not known.

Previous Groundwater Tracing in the Baynham Branch Basin

Aley and Aley (1985), under contract to the National Park Service, conducted a groundwater trace in 1984 to Big Baynham Spring. In the current report this spring is called Brown Spring. The 1984 groundwater trace used 2 pounds of fluorescein dye mixture containing approximately 50% dye equivalent and was introduced on November 14, 1984 into a flow of approximately 15 gpm discharging from the East Diamond sewage treatment lagoon and sinking in a losing stream segment of Baynham Branch approximately 8,800 feet east of Brown Spring. Estimated time of first dye arrival at the spring was 5.5 days after dye introduction. The mean groundwater gradient was 7.5 feet per 1000 feet.

Figure 10. Diagram of groundwater flow routes for fluorescein dye introduced into Baynham Branch downstream of Lime Kiln Rd.

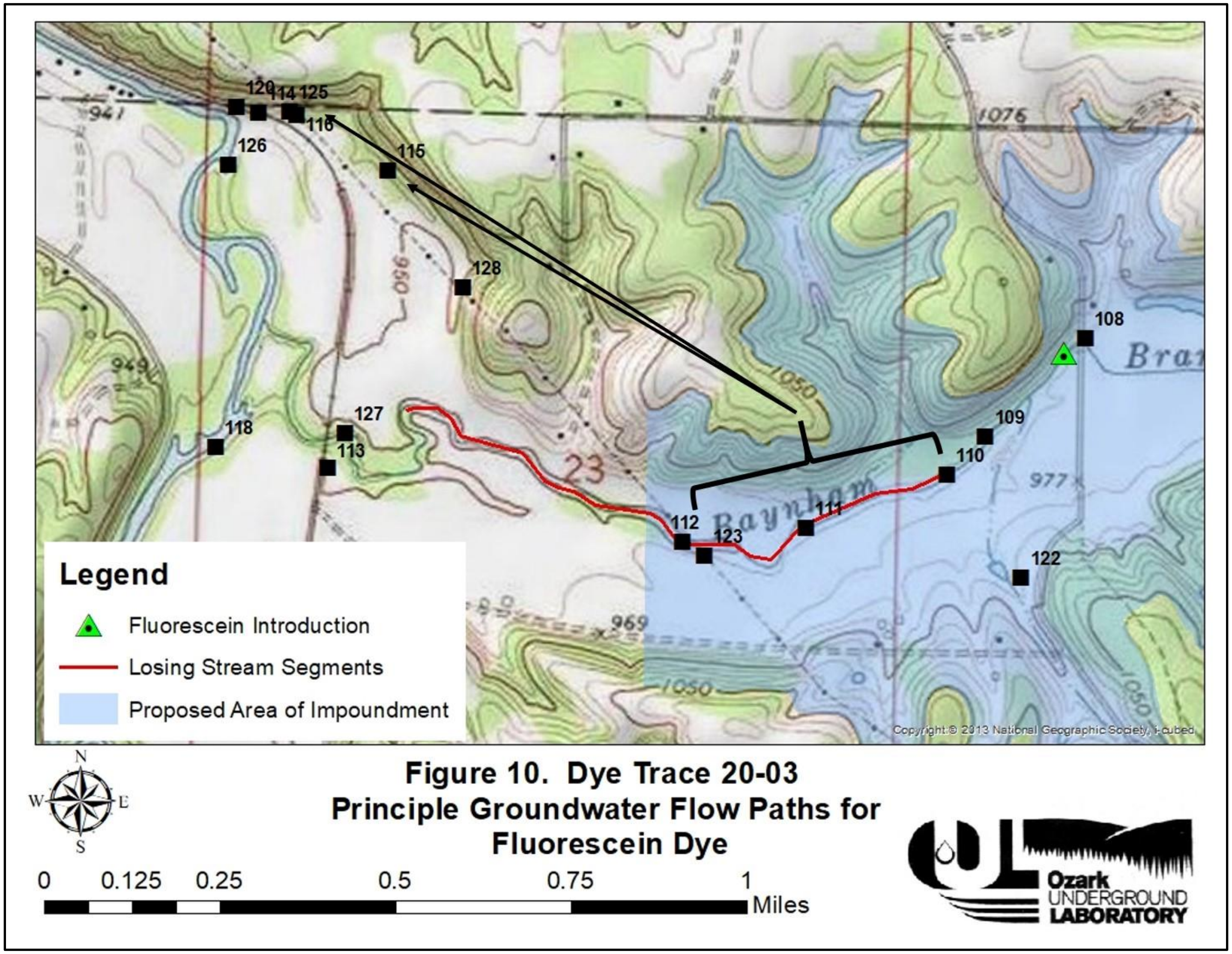


Figure 10. Dye Trace 20-03
Principle Groundwater Flow Paths for Fluorescein Dye

Aley and Aley (1988) conducted another dye trace that was detected in Baynham Branch at the point where this stream is crossed by Carver Road. The dye undoubtedly discharged from Brown Spring and flowed down Baynham Branch to the dye detection point. The trace used 2 pounds of rhodamine WT dye mixture containing approximately 20% dye. The dye mixture was placed as a dry set in the culvert under a county road; the dye introduction point was at the NW corner of the SW ¼ Section 9, T26N, R31W at a point approximately 3,100 feet northeast of Brown Spring. The dye was flushed into groundwater by a subsequent stormflow. Based on other sampling in the area the travel time for first arrival of dye at the spring was probably less than 3 days.

These previous groundwater traces demonstrate that the regional karst groundwater system extends at least 1.7 miles east of Brown Spring and the eastern end of the proposed Baynham Branch reservoir. The trace conducted in 1984 demonstrated rapid and long-distance groundwater transport through the karst aquifer to a major spring (Brown Spring) near the upstream end of the proposed Baynham Branch reservoir. Additional tracing work was conducted during the 1984 to 1988 studies in the Carver Branch basin in response to National Park Service concerns about groundwater contamination from municipal sewage and mercury in springs within George Washington Carver National Monument.

STREAM FLOW MEASUREMENTS

During the fall of 2020 the OUL made flow rate measurements on multiple dates at locations in the Baynham Branch basin and in the Hunley Springs Complex. Flow rates were measured with a Pygmy Price current meter and a top-setting wading rod and US Geological Survey standard methodologies were used to calculate stream flow rates. **Table 5** includes all flow rate measurements made during the Phase 1 work. Flow measurements in Baynham Branch downstream of Lime Kiln Road demonstrate significant leakage from stream segments upstream of the proposed dam site. Measurements made on October 8, November 5, and November 19, 2020 show that all surface water flow ceased and the channel of Baynham Branch was dry for a substantial distance before reaching the centerline of the proposed dam.

On October 8 and November 5, 2020, the OUL made a number of flow rate measurements and other observations in Baynham Branch between Lime Kiln Road and the railroad crossing of the stream (**Table 6**). The results show that no more than 5 to 20% of the flow lost upstream of the dam site could be accounted for by streamflow at the railroad crossing. Small dye detections at the railroad crossing indicate that much of the measured flow at this location was probably not water that was lost from the Baynham Branch channel upstream of the dam.

Table 7 displays flow rate measurements taken at the Hunley Spring complex on November 5 and November 19 and shows that water sinking in Baynham Branch between Park Springs 2 and the railroad accounts for between 90 to 111% of the flow measured at the Hunley Springs Complex at Station 114. Under the conditions tested most and possibly all of the flow at the Hunley Springs was derived from water sinking in Baynham Branch upstream of the railroad (and also upstream of the planned dam). This is consistent with OUL Trace 20-04 that showed no connection between water sinking in a major losing segment of Carver Branch and springs in the Hunley Springs Complex. The data also suggest that under the conditions tested there was little or no groundwater flow directly from either of the major losing stream segments upstream of Lime Kiln Road to the Hunley Springs Complex. It should not be inferred that this would also be the case under higher flow conditions or under conditions with water in a reservoir inundating parts or all of the losing stream segments.

Table 5. All flow rate measurements made during Phase 1. Station numbers indicate location used as sampling stations in dye tracing investigations. Values followed by letter E indicate visual estimates.

Gauging Station Name	2020 Measured Flow Rates (gpm)					
	9/11	9/23	10/8	11/5	11/19	12/1
Baynham Branch crossing u/s of Brown's Lake. Station 101.	-	76E	-	-	-	-
Brown's Lake discharge	5E	-	-	-	-	-
Baynham Branch d/s of Brown's Lake. Station 102.	-	214	-	-	-	-
Baynham Branch at Marten Road	0	0	0	0	0	-
Baynham Branch d/s Henson Spring. Station 106.	718	-	-	920	-	-
Baynham Branch u/s of Lime Kiln Rd. Station 108.	870	-	-	-	1423	-
Baynham Branch u/s of Parks Springs. Station 109.	-	947	-	-	-	-
Baynham Branch d/s of Parks Springs. Station 110	-	1031	950	1239	1742	-
Dockins Crossing	-	-	929	-	-	-
Apex of bend upstream of dam site	-	-	693	-	-	-
Baynham Branch u/s dam site 1. Station 111	-	-	763	1221	-	-
Baynham Branch u/s dam site 2. Station 123	-	-	356	642	-	-
Upstream end of no flow zone	-	0	0	0	0	-
Centerline of proposed dam		0	0	0	0	-
Baynham Branch at railroad. Station 113	-	-	49	245	295	-
Station 113 % of Station 110	-	-	5	20	17	-
Baynham Branch flow resumed on 10/8	-	-	119	76	-	-
Hunley Spring Lake outflow. Station 116.	-	143	-	-	-	2038
Hunley Spring Branch at railroad. Station 114	-	-	-	898	1602	2244

Dam centerline as shown in MAWC report of February 19, 2019.
d/s = downstream. u/s = upstream.

Table 6. Flow rate measurements made on Baynham Branch on October 8 and November 5, 2020 downstream of Lime Kiln Road. Station numbers indicate location used as sampling stations in dye tracing investigations. All distances are measured stream distances.

Feature	Distance from Lime Kiln Road (feet)	Measured flow rate (gpm) 10/8/20	Measured flow rate (gpm) 11/5/20
Baynham Branch at Lime Kiln Rd.	0	873*	---
Fluorescein dye introduced 10/22/20	115	---	---
Parks Spring 1. Station 109.	620	---	---
Parks Spring 2. Station 110	1050	---	---
Baynham Branch downstream of Parks Spring 2. u/s end of losing stream	1215	950	1239
Baynham Branch at Dockins crossing	1670	929	---
Baynham Branch upstream of bend. Station 111.	2210	763	1221
Baynham Branch bend	2600	693	---
Branch downstream of bend. Station 123	2915	356	642
Upstream end of no flow zone on 10/8. Station 112.	3540	0	0
Centerline of proposed dam	3990	0	0
Flow resumed on 10/8/20	5970	119	76
Baynham Branch at railroad. Station 113.	7175	49	245

Notes: * This measurement made on 9/11/20.
Dam location as shown in MAWC report of February 19, 2019.

Table 7. Comparison of measured flow rates of water sinking in Baynham Branch with flow rates of Hunley Springs Complex at railroad. All dates 2020, all values gpm.

Measurement Point	**10/8**	**11/5**	**11/19**	**12/1**
Station 110. Baynham Branch d/s of Park Spring. 2.	950	1239	1742	-
Station 113. Baynham Branch at Railroad	49	245	295	-
Difference: Station 110 minus Station 113	901	994	1447	-
Station 114. Hunley Springs Complex at Railroad	-	898	1602	2244
Baynham Branch flow as % of Hunley Springs Complex	-	111%	90%	-

Figure 11. Measured Flow Rates of Baynham Branch downstream of Lime Kiln Road on 10-8-2020.

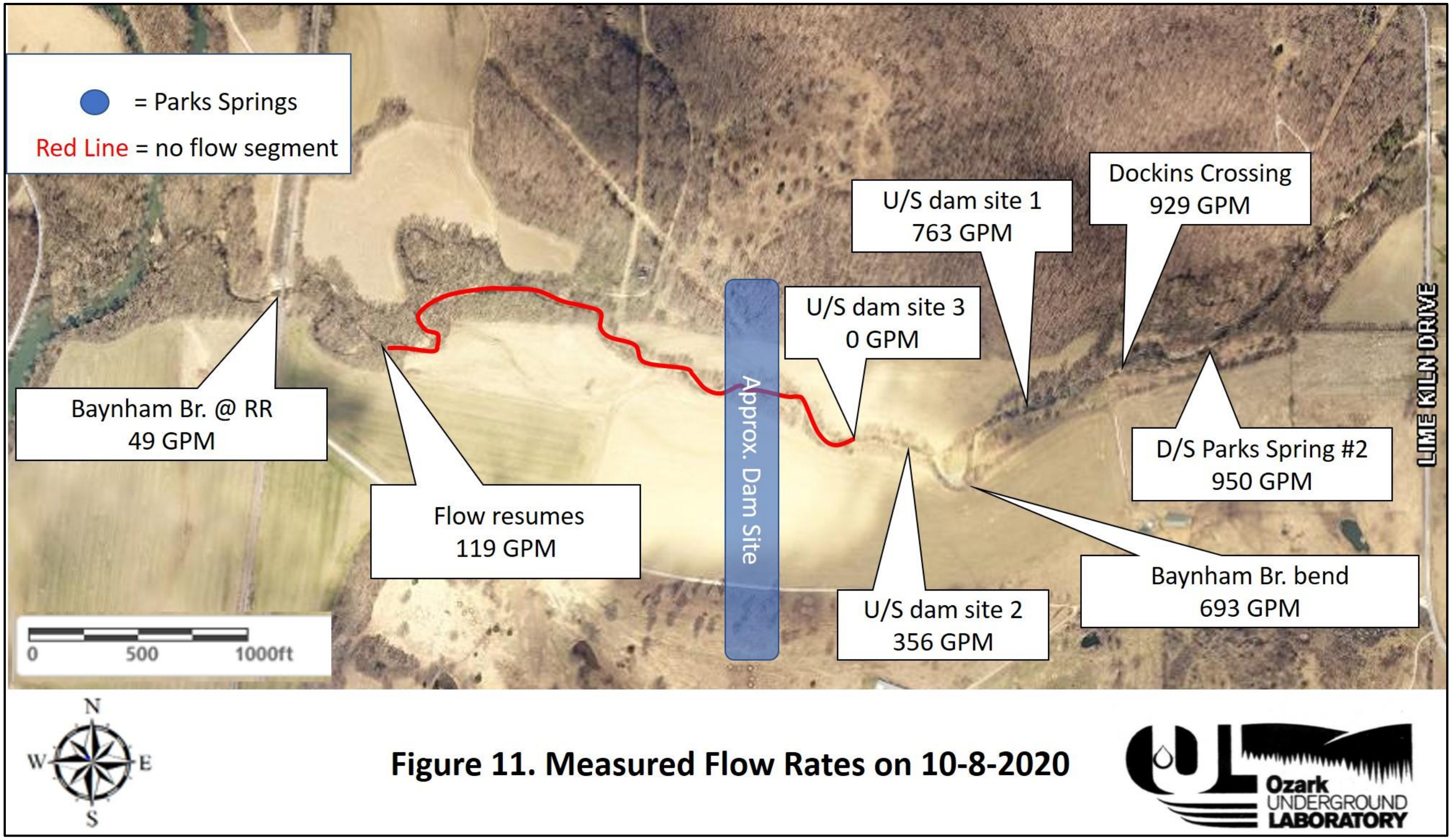


Figure 12. Measured flow rates of Baynham Branch downstream of Lime Kiln Road on 11-5-2020.

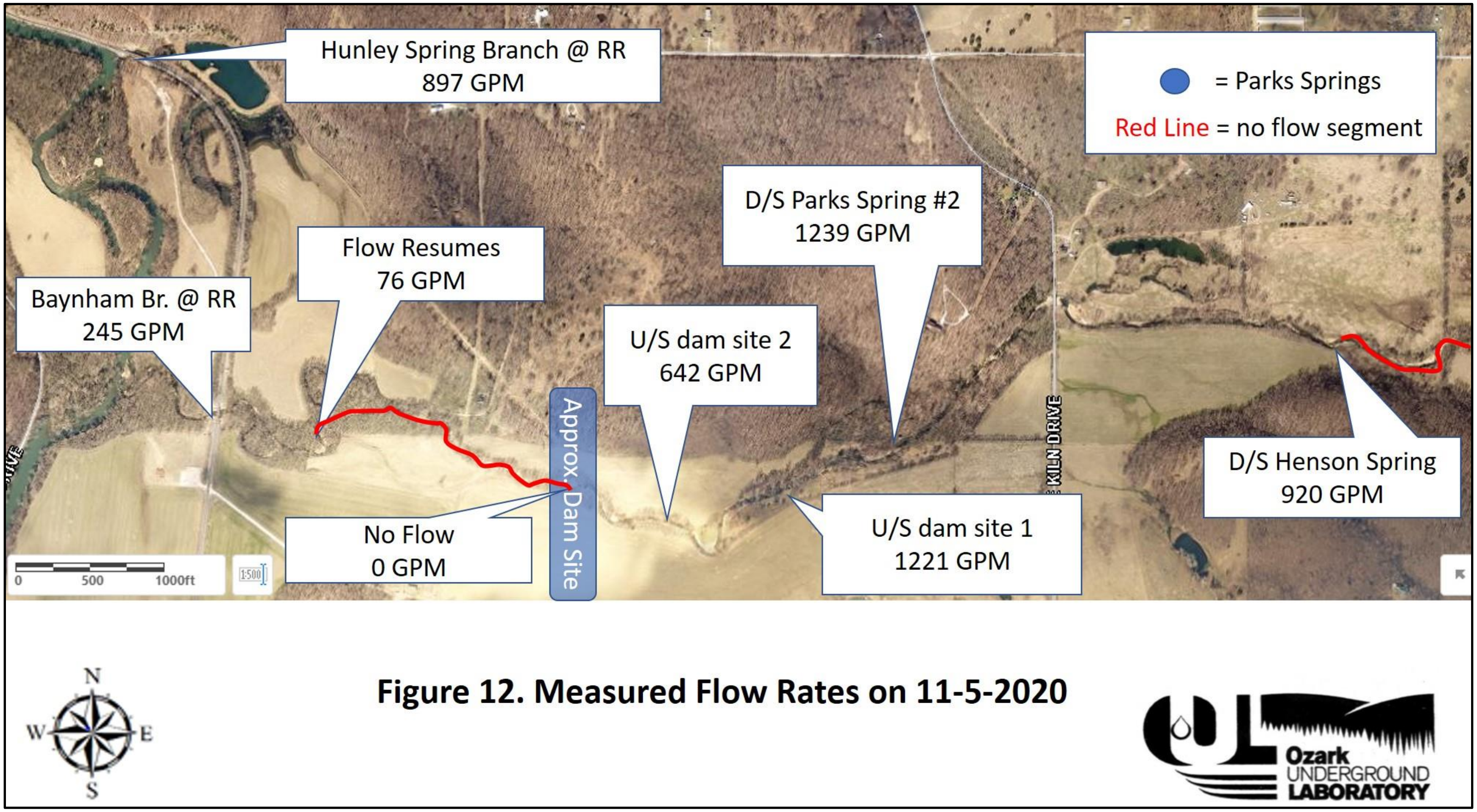


Figure 12. Measured Flow Rates on 11-5-2020

RESERVOIR IMPACTS ON OZARK CAVEFISH

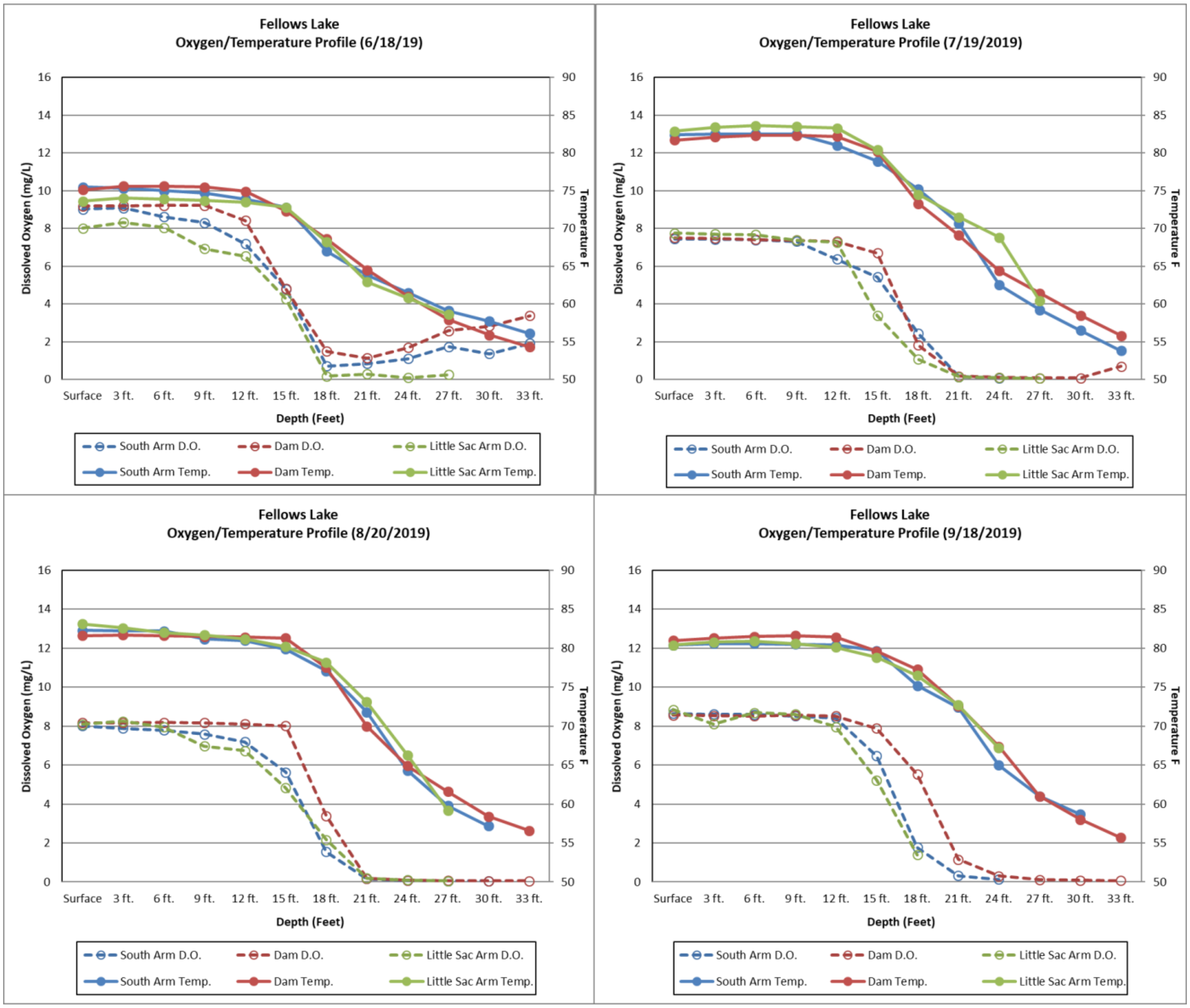
The Ozark Cavefish (*Troglichtys roasae*, formerly *Amblyopsis rosae*) is federally listed as a Threatened Species under the provisions of the federal Endangered Species Act. This rare, blind cavefish can survive only in groundwater and cannot move through surface streams or lakes from one population site to another. Environmental DNA (eDNA) studies indicate that the proposed Baynham Branch Reservoir would inundate at least three habitat sites for this species. At the planned pool level, the water depth at the three cavefish habitat sites would be 70, 40, and 20 feet.

Previous studies delineating recharge areas of Ozark Cavefish populations have been conducted by the OUL in the Shoal Creek valley and in several of its tributary basins. The nearest confirmed Ozark Cavefish site to Baynham Branch is in an adjoining basin less than two miles from the proposed dam site on Baynham Branch. The recharge area for that cavefish site is approximately one-half mile from the nearest areas that would be inundated by the proposed Baynham Branch reservoir. If Phase 2 of the OUL's current investigation is funded the OUL will conduct detailed work to determine the importance of Baynham Branch watershed and the proposed reservoir area to the recovery of the threatened Ozark Cavefish.

Reservoirs in Missouri experience thermal stratification in the summer. In warm weather, water at the surface has warm temperatures and ample dissolved oxygen for aquatic life. However, water at the bottom will have cool temperatures and little or no dissolved oxygen. Low dissolved oxygen in the water results from decomposition of the large volume of organic material that sinks to the bottom of impoundments. Dissolved oxygen concentrations of less than 3 milligrams per liter (mg/L) are harmful to most aquatic life and concentrations of less than about 1 or 2 mg/L are lethal to almost all aquatic life.

Figure 14 shows measured temperature and dissolved oxygen values from Fellows Lake at Springfield, Missouri and clearly illustrates the problem. Fellows Lake is an 820-acre water supply lake for Springfield. This reservoir often stratifies as early as mid-May and can remain this way until early October. During 2019 water deeper than 21 feet had essentially no dissolved oxygen for almost 5 months. If it were to hold water, the same severe oxygen depletion in the cavefish habitat at the bottom of the proposed MAWC reservoir would occur. This would be lethal to cavefish and other groundwater animals. Where substantial hydraulic heads occur over cavefish habitat low dissolved oxygen conditions would extend along the associated underground stream systems until the elevation of the water in the underground stream equaled the elevation of water in the reservoir. Those impacts could extend far beyond the edge of the proposed reservoir.

Figure 14. Temperature and dissolved oxygen profiles as a function of depth in Fellows Lake under warm weather conditions. Source: *2019 Fellows Lake Annual Report,* Missouri Department of Conservation, open-file report.



RESERVOIR LEAKAGE IMPACTS ON SHOAL CREEK

If the reservoir is constructed as proposed the OUL flow rate measurements and dye tracing results demonstrate that there will be major leakage from the bottom portions of the reservoir. This leakage will rapidly flow through dissolved out openings in the limestone and discharge from springs in the Hunley Springs Complex. Leaking water from the reservoir will often be low in dissolved oxygen and this water is unlikely to receive adequate re-oxygenated prior to discharging from the springs. It is likely that these discharging waters will not be in compliance with Missouri water quality standards and, if allowed to enter nearby Shoal Creek, will adversely impact aquatic life in this stream. This is likely to adversely impact six mussel species of conservation concern living in Shoal Creek; these are:

- Neosho Mucket (federally and state Endangered)
- Rabbitsfoot Mussel (federal Threatened, state Endangered)
- Purple Lilliput (Rank S1-Critically Imperiled)
- Elktoe (Rank S2-Imperiled)
- Black Sandshell (Rank S2-Imperiled)
- Ouachita Kidneyshell (Rank S3-Vulnerable)

The streamflow data in Table 6 clearly show that the proposed reservoir dam is located in a major losing stream portion of Baynham Branch. The groundwater trace with fluorescein shows that water sinking in the losing stream segment between Lime Kiln Road and the proposed dam discharges from springs in the Hunley Springs Complex. Water entering the groundwater system in this losing stream segment would not be captured by the proposed reservoir dam.

HYDROGEOLOGY OF THE DAM SITE

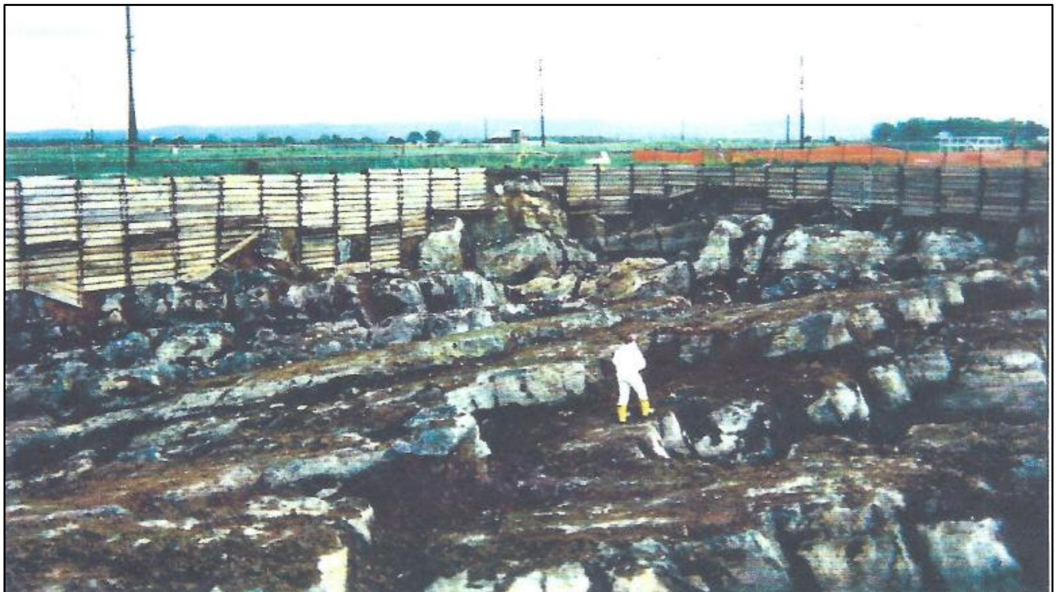
The MAWC Proposal states (page 10) that field reconnaissance and geotechnical investigations were performed on potential dam sites A, B, and C with site C being the selected location on Baynham Branch. The MAWC Proposal states that bedrock near Site C appears to be of better quality than at the other two sites but indicates that further investigation of the subsurface is needed to verify that the quality of the bedrock is representative of the site. While the brief assessment of Site A (located on Beef Branch) notes that the bedrock foundation is anticipated to require treatment to cut off pathways of groundwater flow believed to be present in the karstic bedrock, no similar recognition is afforded the Baynham Branch site.

The hillside on the north side of Baynham Branch in the vicinity of the proposed dam site is steep, forested, and the soils are mapped by the US Soil Conservation Service (Aldrich, 1989) as Clarksville very cherty silt loam 14 to 35% slopes. Permeability rates are 2 to 6 inches per hour for soil depths up to 37 inches and 0.6 to 2 inches per hour for soil depths of 37 to 60 inches. These permeability rates are classed as moderate to rapid. Clarksville soils would not provide an effective barrier between the reservoir and fractured and solutionally modified limestone. Outcrops of limestone bedrock are small and localized and any assessment of the quality of bedrock for a dam abutment without major subsurface investigations is speculative.

The MAWC proposal (page 14) states that the bedrock in the project area is expected to consist of the Burlington-Keokuk Limestone. Other than brief mention of faults and sinkholes in the region no consideration is given to the fact that the Burlington-Keokuk Limestones in southwest Missouri are routinely cavernous geologic units, and in the Newton County area have been substantially modified by karst processes and mineral emplacement. Relative to the cavernous nature of the Burlington-Keokuk Limestones it should be noted that they are the host rocks for Fantastic Caverns near Springfield; this cave is large enough that tour groups are driven through on trams pulled by jeeps.

In the experience of the OUL the upper surface of the Burlington-Keokuk Limestones beneath losing streams is likely to present a highly irregular cutter and pinnacle topography such as described by Fellows (1965). Figure 15 illustrates these types of irregularities observed by the OUL during remediation of a leaking industrial wastewater lagoon in Pennsylvania. Not only does this create construction difficulties in excavations to key a dam into the bedrock, but solutionally enlarged openings in the bedrock sufficiently large to permit turbulent flow and sediment transport are common. These features can extend to substantial depths in the area due in part to the extensive paleokarst development associated with the Tri-State mining district, which includes Newton County. The zinc and lead deposits in Newton County were localized in karst features that were probably of hypogenic origin. This mode of origin is consistent with relatively high permeability in the Burlington-Keokuk Limestones and in the underlying Elsey and Reeds Spring Formations. This creates the potential for long distance lateral groundwater transport through solutionally-modified features.

Figure 15. Bedrock irregularities in limestone under a leaking industrial wastewater lagoon in Pennsylvania.



IWTP LAGOON CLOSURE EXCAVATION VIEW LOOKING EAST

IWTP LAGOON CLOSURE EXCAVATION VIEW LOOKING SOUTHEAST

Figure 16 is a copy of figure 4 in Feder et al. (1969); that report was a study of the water resources of the Joplin area. The figure provides a comparison of an unaltered geologic section of Mississippian rocks with one affected by solution and mineralization and shows difference in porosity. It also shows the extent to which the thickness of various geologic units in the area has been reduced due to solution and collapse. As shown in the illustration the Burlington-Keokuk Limestone has been reduced to only 59% of its initial thickness due to these processes. While the degree of formation thinning varies from point to point, it is a regional condition and must be expected in and around the dam site. Within the vicinity of the impoundment solutional activity, interactions between mineral deposits and bedrock, and fracturing would have increased the permeability of the rock units and should be expected to have done so to substantial depths below the ground surface.

Decreases in the thickness of the Burlington-Keokuk is important in evaluating the risk of failures of dams to minimize subsurface leakage and resulting sinkhole collapse. Localized dissolution of limestone resulted in subsurface collapses and subsequent mineralization in the collapse zones and produced breccia deposits that are substantially more permeable than the unaltered rock. These processes also increased fracturing of overlying rock units. Where these processes have operated, they increase the risk of subsurface leakage from impoundments and resulting land subsidence or sinkhole collapse.

The proposed dam is located within a losing stream segment of Baynham Branch and is thus within a stream area where surface water currently sinks into the karst aquifer. This is an inherently undesirable location for a dam. Based on dye tracing results and flow rate measurements, much of the groundwater flow from the losing stream area downstream of Lime Kiln Road to the Hunley Springs Complex would bypass, not be intercepted by, the proposed dam. The result would be massive leakage from the reservoir area along the course of Baynham Branch from the dam site upstream to at least the vicinity of Park Springs. The possibility exists that these springs might function as reservoir leakage zones when inundated by water about 90 feet deep. If so, severe reservoir leakage would be expected to extend further upstream along Baynham Branch.

The MAWC proposal (page 10) states that the Baynham Branch site is anticipated to have materials suitable for both impervious core material and shell material. No reference is cited to support this “anticipation” and it is inconsistent with the detailed soils mapping of the area around the dam site by professionals with the U.S. Soil Conservation Service (Aldrich, 1989). Soils mapped on the valley floor of Baynham Branch and reasonably accessible to the proposed dam site include mapping units 55 (Huntington Series); 92A (Secesh or Cedargap Series); and 93B (Waben or Cedargap Series).

Figure 16. Comparison of an unaltered geologic section of Mississippian rocks with one affected by solution and mineralization, showing the differences in porosity. Source: Feder et al. (1969).

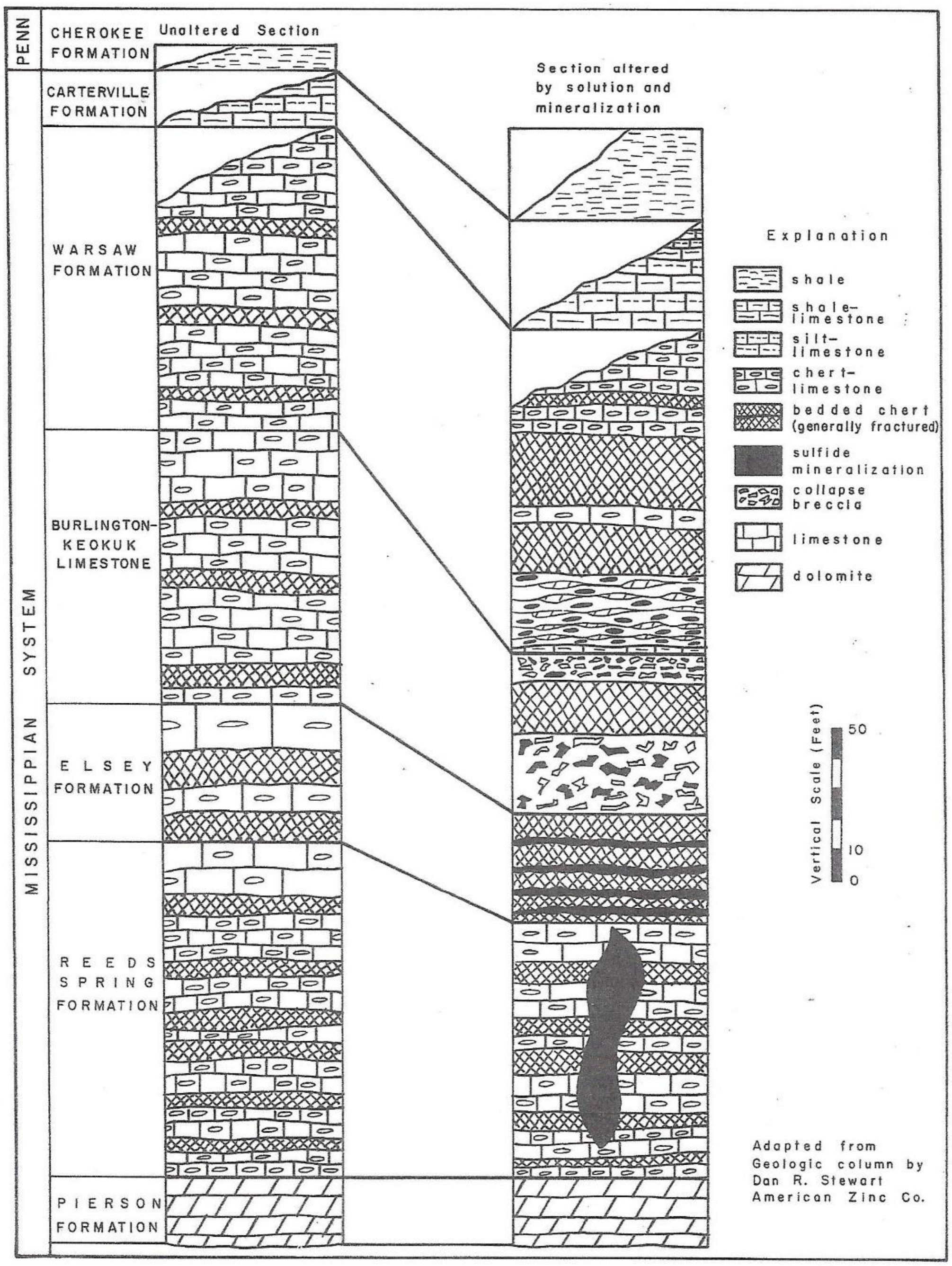


Figure 4. Comparison of an unaltered geologic section of Mississippian rocks with one affected by solution and mineralization, showing the difference in porosity.

Table 8 (derived from Table 14 of Aldrich, 1989) provides an assessment of water management limitations for the soil units mapped on the valley floor of Baynham Branch in the vicinity of the proposed dam. This is the presumed source area for soils for constructing the dam. Of particular importance in evaluating the MAWC proposal are the identified limitations of the mapped soils for pond reservoir areas and for embankments, dikes, and levees.

Table 8. Water management limitations for soil units on the valley floor near the proposed dam. Source: Aldrich (1989).

Mapping Unit	Soil Type	Limitations for Pond Reservoir Areas	Limitations for Embankments, Dikes, and Levees
55	Huntington	Moderate: seepage	Severe: piping
92A	Secesh	Severe; seepage	Slight
92A	Cedargap	Severe: seepage	Severe: seepage
93B	Waben	Severe: seepage	Severe: seepage
93B	Cedargap	Severe: seepage	Severe: seepage

Sinkhole collapses are common in the Ozarks when impoundments are constructed in losing stream valleys (Aley et al., 1972). These problems are exacerbated by the presence of soils with high seepage rates. Both conditions exist at the proposed Baynham Branch dam and reservoir site.

ESTIMATION OF RESERVOIR LEAKAGE

This evaluation is based on the planned dam being located as shown in the MAWC Proposal and it presumes that the reservoir would need to function reasonably close to the manner outlined in the MAWC Proposal. That would require the reservoir to be routinely capable of impounding water without significant leakage (no allowance was made in the MAWC Proposal for leakage). Additionally, the reservoir would need to be capable of maintaining a normal pool elevation of 1,051 feet. The MAWC Proposal plans to pump water into the reservoir from Shoal Creek only during periods of high flow on the stream. These conditions seldom occur during summer and fall.

Even without considering leakage, natural streamflow in Baynham Branch is minimal during most of the year. During the OUL studies the location on Baynham Branch with the highest measured flow rates was located immediately downstream of the Park Springs. During the period September 23 to November 19, 2020, the flow at this location was measured four times; the mean value was 1,241 gpm which equals 1.79 mgd. This is not even sufficient to offset evaporation from a 1,200-acre lake; the OUL calculated the mean annual evaporation rate for the lake at 3.87 mgd. Even if there were no leakage the proposed reservoir cannot maintain a normal pool level and supply 30 mgd for downstream use during periods of low flow on Shoal Creek. Supplying water for Joplin during periods of low flow on Shoal Creek is the identified objective of the MAWC Proposal.

While ignored in the MAWC Proposal, there will be massive leakage of water out of the planned reservoir. The existence of a major stream leakage zone between Lime Kiln Road and the planned dam is shown by OUL flow measurements. Leakage occurs at numerous points along a stream distance of approximately 2,775 feet between the planned dam and a point a short distance downstream of the Park Springs. The OUL dye tracing and flow rate measurement results show that this major leakage zone is the primary source of water for the Hunley Springs Complex.

As discussed earlier in the dye tracing section of this report OUL Station 111 is approximately the mid-point of the losing stream segment. The elevation difference of water surfaces between Station 111 and Hunley Lake during low flow conditions is about 8 feet, the distance is 4,700 feet, and the mean gradient for the groundwater flow route is 1.7 feet per 1,000 feet. Based on flow rate measurements made on November 19, 2020 leakage from the channel of Baynham Branch was 2.1 mgd; this water discharged at the Hunley Springs Complex outside of the reservoir area. The leakage rate would have been greater if there had been sufficient flow to reach all of the losing stream area.

Figure 17 shows the 36" diameter outflow pipe installed at the Hunley Spring lake. This is one of the points where water from Baynham Branch discharges to the Hunley Springs

Complex. Discharge was measured at 2.9 mgd at the time the photo was taken during moderately low flow conditions in Baynham Branch. As reported earlier, Mr. Hunley once measured the flow rate of the Hunley Springs Complex in spring-time and found it to be 20 mgd. Under these conditions water surface elevations would have been approximately 5 feet higher than during the autumn of 2020. The lake level would also have been somewhat higher, but a 5-foot increase in hydraulic head is reasonable and would result in an elevation difference of 13 feet for a mean groundwater gradient of 2.8 feet per 1,000 feet. The increased area of wetted surfaces in Baynham Branch would also have been involved in the nearly 10-fold increase in leakage from Baynham Branch.

Figure 17. Hunley Lake outflow discharging approximately 2.9 mgd on December 1, 2020.

The planned reservoir at designed capacity would increase hydraulic head at Station 111 by approximately 85 feet over that operating under typical spring-time conditions. That would increase the mean groundwater gradient for flow from Station 111 to the major spring in Hunley Lake to 98 feet for a mean groundwater gradient of 20.9 feet per 1,000 feet. This is 7.5 times greater and, using standard groundwater equations, would be expected to increase the leakage rate from 20 to 150 mgd. Additionally, water would infiltrate into massive amounts of limestone hillside and inundated bottomland and further increase the anticipated volume of reservoir leakage.

In reality, we will never know if leakage from the reservoir could reach or exceed 150 mgd. The leakage rates will be so great that the impoundment will never fill even with massive pumping of water out of Shoal Creek.

Engineering can make good dam sites better. Engineering cannot make terrible sites good and MAWC has proposed a hydrologically terrible site. However, let us briefly consider engineering modifications that might be made. A program to grout 2,775 feet of losing stream channel might be attempted, but there is no reason to expect that the steep limestone hill would be reasonably water tight; it probably would not be. Also, grouting programs are expensive and frequently fail to produce desired effects, especially in karst settings where much of the flow is though highly localized features that may not be intersected by grouting holes.

Finding a better dam site further up the Baynham Branch valley is another option. However, OUL data indicate that any potential site would need to be upstream of Lime Kiln Road and this would substantially decrease the size of the reservoir (but probably not its cost) and, given the karst setting of the basin, would still be a high-risk plan.

Two hills close together does not indicate a good dam site, especially in karst topography. It is the conclusion of the OUL that MAWC has proposed a terrible reservoir site that will have massive leakage problems while also failing to provide the water supply desired for Joplin.

SUMMARY OF FINDINGS AND CONCLUSIONS

Summary of Findings

Finding 1. MAWC plans for the reservoir to have a normal pool elevation of 1,051 feet and an impounded area of approximately 1,200 acres. MAWC indicates that the topographic basin upstream of the planned dam site is 15.7 miles. The planned dam would be approximately 2,535 feet east of the Kansas City Southern rail line. The MAWC document claims that the planned reservoir would provide up to 30 million gallons per day (mgd) of discharge to Shoal Creek at a point about 11 miles upstream of the water intake point for the City of Joplin.

Based on a normal pool elevation of 1,051 feet and topographic contours on the Granby 7.5-minute quadrangle map, the approximate depth of water in the reservoir above the current channel of Baynham Branch would be:

- 100 feet at the dam.
- 80 feet at the Lime Kiln Road Crossing
- 65 feet at the Marten Road Crossing
- 30 feet at the Carver Road Crossing

Finding 2. MAWC plans to pump water from Shoal Creek into the reservoir during periods of high runoff in Shoal Creek. MAWC does not estimate the volume or frequency of such water extraction from Shoal Creek but does state that the reservoir would provide 30 million gallons per day (mgd). Based on technical literature and the size of the watershed the OUL calculated the following mean annual values for a 1,200-acre reservoir assuming no leakage out of the reservoir.

- Annual volume of runoff water to reservoir = 8.59 mgd
- Evaporation from 1,200-acre reservoir = 3.87 mgd
- Net water production from the reservoir = 4.72 mgd
- Deficit to be extracted from Shoal Creek = 25.28 mgd. This is 84% of the planned water supply.

Finding 3. Geologic literature published by the State of Missouri states that reservoirs in this portion of Missouri have tremendously high pollution and reservoir leakage hazards. MAWC ignored the issue of reservoir leakage in their Section 404 pre-application document and made no estimate or allowance for the magnitude of reservoir leakage.

Finding 4. Streamflow observations under low to moderate flow conditions show that the proposed reservoir site has major leakage problems, yet MAWC failed to conduct, or at least failed to report, obvious and relevant field observation under appropriate flow conditions.

Finding 5. OUL identified three major losing stream segments within the planned reservoir area. A different tracer dye was introduced into each of the three losing stream segments. All three losing stream segments yielded their respective tracer dye to the Hunley Springs Complex. This springs complex is outside of the area that would be impounded by the planned reservoir. If the planned dam had been in place it would not have intercepted water moving out of the reservoir area and into the Hunley Springs Complex. The dye tracing work demonstrated that the planned reservoir will experience major water leakage that will discharge outside of the impounded area.

Finding 6. Rhodamine WT for OUL Trace 20-01 was introduced into Gary Dug Well in the South Fork Baynham Branch losing stream segment on October 6, 2020. This dye subsequently discharged from Henson Spring; first dye arrival at this spring was within 8 days of the time of dye introduction. The straight-line distance from the dye introduction point to Henson Spring is 3,865 feet and mean travel rate was greater than 483 feet per day. Mean groundwater gradient for this flow segment was 4.1 feet per 1,000 feet. Rhodamine WT re-entered the groundwater system downstream of Lime Kiln Road and discharged from the Hunley Springs Complex.

Finding 7. Eosine dye for OUL Trace 20-02 was introduced in Baynham Branch upstream of Carver Road on October 6, 2020. This dye subsequently entered the losing stream segment on Baynham Branch downstream of Carver Road and upstream of Henson Spring. The dye subsequently discharged from Henson Spring; first dye arrival at this spring was within 8 days of the time of dye introduction. The straight-line distance from the dye introduction point to Henson Spring is 11,910 feet and the mean travel rate was greater than 1,489 feet per day. The groundwater flow portion of this distance is approximately 7,480 feet and the mean gradient for this groundwater flow segment was 3.9 feet per 1,000 feet. The eosine re-entered the groundwater system downstream of Lime Kiln Road and discharged from the Hunley Springs Complex.

Finding 8. Fluorescein dye for OUL Trace 20-03 was introduced into Baynham Branch approximately 115 feet downstream of Lime Kiln Road on October 22, 2020. This trace verified that the losing stream segment on Baynham Branch between Lime Kiln Road and the Kansas City Southern rail line contributes water rapidly to springs in the Hunley Springs Complex. The straight-line distance from Station 111 (approximately in the middle of the segment of the stream that was sinking on October 22, 2020) to the main spring feeding Hunley Lake was 4,700 feet and dye first began arriving at this spring within 7 days of dye introduction. The mean gradient between Station 111 and Hunley Lake is 1.7 feet per 1,000 feet.

Finding 9. Eosine dye for OUL Trace 20-04 was introduced upstream of a major losing stream segment on Carver Branch. This trace was designed to determine if any water from downstream portions of Carver Branch contributed to the flow of springs in the Hunley Springs Complex; no such connection was identified. The only sampling point where dye from this dye introduction was detected was in Carver Branch downstream of Lime Kiln Road.

Finding 10. Flow rate measurements made on November 5 and 19, 2020 show that water sinking in Baynham Branch between Park Springs 2 and the railroad accounts for between 90 to 111% of the flow measured at the Hunley Springs Complex. Under the conditions tested almost all of the flow at the Hunley Springs Complex was derived from water sinking in Baynham Branch upstream of the railroad (and also upstream of the planned dam). This is consistent with OUL Trace 20-04 that showed no hydrologic connection between water sinking in a major losing segment of Carver Branch and springs in the Hunley Springs Complex.

Finding 11. Leaking water from the planned reservoir will discharge through the Hunley Springs Complex and possibly other points and then into Shoal Creek. It is likely that such discharging waters will not be in compliance with Missouri water quality standards. There are six mussel species of conservation concern in Shoal Creek and all are likely to be significantly impacted by low dissolved oxygen waters leaking from lower levels of the planned reservoir.

Finding 12. The MAWC plan (page 10) states that the Baynham Branch site is anticipated to have materials suitable for both impervious core material and shell material. No reference is cited to support this “anticipation” and it is inconsistent with the soils mapping of the land at and around the dam by professionals with the U.S. Soil Conservation Service (Aldrich, 1989).

Summary of Conclusions

Conclusion 1. Calculated groundwater gradients for positive dye traces were as follows:

- 4.1 feet/1,000 feet for 3,865 feet straight line distance from Gary Dug Well to Henson Spring.
- 3.9 feet/1000 feet for 7,480 feet straight line distance from Baynham Branch downstream of Carver Road to Henson Spring.
- 1.7 feet/1,000 feet for low flow traces of 4,700 feet straight line distance from Station 111 on Baynham Branch to the spring feeding Hunley Lake.

These gradients demonstrate groundwater transport through solutionally-widened bedrock openings characteristic of karst aquifers. They are not characteristic of transport through alluvium.

Conclusion 2. The time of first dye arrival at sampling stations demonstrates rapid groundwater transport through solutionally-widened bedrock openings characteristic of karst aquifers. In addition, a large portion of the total amounts of dye detected in carbon samplers was in samplers collected during the first sampling period after dye introduction. These results are characteristic of transport through karst aquifer, but not of transport through alluvial aquifers.

Conclusion 3. The proposed dam on Baynham Branch is within a major losing stream segment. A major losing stream segment is a highly undesirable location for an earth fill dam intended to impound water to a depth of about 100 feet.

Conclusion 4. The planned dam is to be tied into Burlington-Keokuk Limestones. These geologic units are cavernous and are the host rocks for many caves in southwest Missouri and adjacent parts of Arkansas and Oklahoma where these units are included within the Boone Formation. Fantastic Caverns, a show cave at Springfield, is within the Burlington-Keokuk and passages are large enough that the cave is toured by trams drawn by jeeps. The proposed dam is within a highly unfavorable geologic setting and substantial leakage must be anticipated through solutionally enlarged openings in the limestone.

Conclusion 5. The MAWC proposal (page 16) states that there are 3,488 linear feet of losing stream segments in the proposed impoundment area. This is incorrect and is based on a MDNR definition of losing streams designed to regulate wastewater discharges. The relevant definition of losing streams for reservoir evaluations is that of USEPA (1999) that defines a losing stream as: "a stream or reach of a stream in which water flows from the stream bed into the ground. In karst terranes, losing streams may slowly sink into fractures or completely disappear down a ponor." With respect to reservoir leakage, the locations of surface stream segments that lose flow to groundwater are very important features if: 1) they are within proposed reservoir areas, and 2) if water entering groundwater through them discharges outside of the reservoir area. Both conditions are met for the three losing stream segments identified by the OUL within the reservoir area.

The MAWC proposal conclusion that: *"The losing stream would be entirely inundated by the proposed reservoir and is not anticipated to impact reservoir storage"* is both illogical and false. There are three major losing stream segments within the reservoir area; they are:

A. South Fork of Baynham Branch including Gary Dug Well.
B. Main stem Baynham Branch from about 1,000 feet downstream of the Carver Road Crossing to Henson Spring.
C. Main stem Baynham Branch from about 1,215 feet downstream of the Lime Kiln Road crossing to and including the planned dam site.

The length of identified losing stream segments in the reservoir area is 19,200 feet; this is approximately 66% of all main stream channels within the planned reservoir area.

Conclusion 6. Mr. Hunley, owner of the Hunley Springs Complex, measured the flow of the springs under springtime conditions and calculated the flow rate at 20 mgd. The OUL has measured spring discharges at the Hunley Springs Complex as large as 2,244 gpm under low flow conditions; this equals 3.23 mgd. In the opinion of the OUL a mean annual flow rate of the Hunley Springs Complex on the order of 20 mgd is reasonable. The OUL has installed equipment at the lake discharge and at another spring flow station in the complex to record water depths from which we can determine flow rates during the planned Phase 2 work by the OUL.

Conclusion 7. Due to excessive leakage the reservoir, if constructed, will not be able to supply adequate volumes of water to Joplin during periods of low flow on Shoal Creek. This will require development of another alternate water supply for Joplin. Moving ahead with the reservoir project will likely delay the planning and construction of an adequate alternate water supply for Joplin. If the reservoir is constructed, water users in the MAWC service area will need to pay for two alternate water supplies, one of which will be of little if any value.

Conclusion 8. The reservoir, as planned, would create appreciably low dissolved oxygen concentrations in Ozark Cavefish habitats beneath the reservoir and beneath some adjacent lands. This would represent a significant loss of Ozark Cavefish habitat and would likely result in mortality of some Ozark Cavefish.

Conclusion 9. Water leaking from the proposed reservoir and discharging from springs in the Hunley Springs Complex would have very low dissolved oxygen concentrations and would not meet Missouri Water Quality standards. The discharge waters would adversely impact aquatic species in Shoal Creek including federally and state listed species of conservation concern.

Conclusion 10. Two hills close together does not necessarily indicate a good dam site, especially in karst topography. It is the conclusion of the OUL that MAWC has proposed a terrible reservoir site that will have massive leakage problems while also not providing the water supply desired for Joplin.

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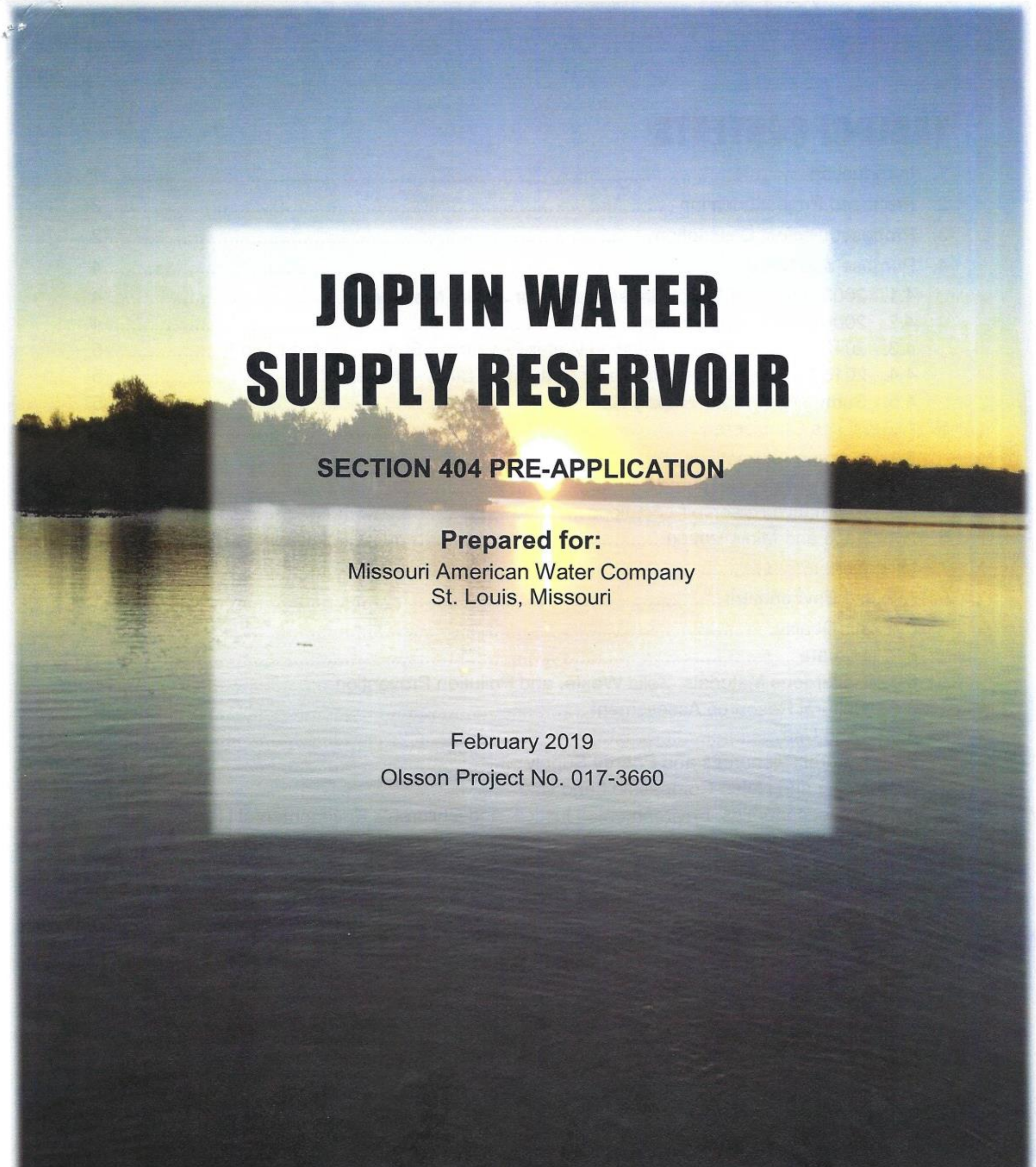
APPENDIX A.

Joplin Water Supply Reservoir Section 404 Pre-application



JOPLIN WATER SUPPLY RESERVOIR

SECTION 404 PRE-APPLICATION

Prepared for:
Missouri American Water Company
St. Louis, Missouri

February 2019

Olsson Project No. 017-3660

BLACK & VEATCH

olsson

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1. INTRODUCTION

The Missouri-American Water Company (MAWC, Project Proponent) is a private water utility that services the geographic area of the City of Joplin, Missouri and nearby communities. Current water sources for the MAWC service area include an intake on Shoal Creek and groundwater sources; however, these sources do not meet the existing or projected water demand for the Project service area. MAWC proposes the development of an approximately 1,200-acre reservoir and associated water supply components (Project) to meet the current and future water supply demands of the City of Joplin and nearby communities (Figure 1).

In 2001, the Missouri Department of Natural Resources (MDNR) did a presentation in Joplin that discussed water supplies in southwest Missouri and raised concerns over sustainability of the Ozark Aquifer. The MDNR presentation and intermittent issues with water availability, triggered the MAWC to commission a study by Wittman Hydro-Planning Associates to construct a hydro-geologic model of the Ozark Aquifer (Wittman et. al. 2003). From this study and its findings, the Tri-State Water Resource Coalition (Tri-State Coalition) was formed to "secure adequate, affordable long-term water supplies for a 16-county area in southwest Missouri" (Tri-State 2019). MAWC is a member of the Tri-State Coalition and has representation on their board of directors.

The Tri-State Coalition formed the Southwest Missouri Joint Municipal Utility Commission (SWMO Regional Water Commission) to develop regional infrastructure. SWMO Regional Water Commission is striving to gain water use rights at U.S. Army Corps of Engineers lakes (Stockton, Pomme de Terre, and Table Rock). MAWC shares the same goals of the Tri-State Coalition and the SWMO Regional Water Commission to supply affordable long-term water supplies to southwest Missouri. The proposed Project reflects the immediate water supply needs of the MAWC service area and is consistent with the Tri-State Coalition and SWMO Regional Water Commission goals.

The proposed Project construction will require the discharge of fill material into jurisdictional waters of the U.S., necessitating a permit from the U.S. Army Corps of Engineers (USACE) under Section 404 of the Clean Water Act. The USACE is the lead federal agency and is responsible for evaluation of the Section 404 permit application (federal action). MAWC is in the preapplication stage of a Clean Water Act Section 404 permit. The intent of this preapplication is to solicit information on the scope of issues and significant concerns to address related to the proposed Project.

2. PROPOSED PROJECT LOCATION

The proposed reservoir is located southwest of Diamond in Newton County, Missouri, within the Spring River Watershed (HUC 11070207). More specifically, the reservoir is located within the Baynham Branch drainage basin east of Interstate 49, west of Nighthawk Road, and north of Gum Road (Figure 1). The proposed reservoir would dam Baynham Branch, a tributary of Shoal Creek, and inundate an area 2 miles (mi) east of Interstate 49. The proposed reservoir contains an upstream watershed of 15.7 square miles (sq mi).

3. PROPOSED PROJECT DESCRIPTION

The proposed Project includes construction of a dam that would inundate approximately 1,200 acres at normal pool. The earthen dam would be created by borrow areas located in the proposed normal pool and in locations nearby the proposed dam. Borrow areas are preidentified locations where the appropriate soil properties are available to construct the dam. The spillway and intake structure are not yet designed; however, all infrastructure would meet state and federal dam regulations. The proposed Project would provide up to 30 million gallons per day (mgd) at a normal pool elevation of 1,051 feet above mean sea level (amsl). In addition to water dammed on Baynham Branch, water from Shoal Creek could be diverted to the reservoir by pumping from Shoal Creek during periods of high streamflow. The diverted water would be transported to the reservoir through a new water line.

Water stored by the reservoir would gravity flow via Shoal Creek from the proposed Project to MAWC's existing intake, pump station, and water treatment plant in south Joplin. The MAWC water treatment plant has a treatment capacity of 22 mgd. Upgrades to the water treatment plant would occur on-site as needed to increase the capacity to the proposed Project capacity to 30 mgd. Existing water distribution lines would be used to transfer water from the water treatment plant to the end customers. Roadway and utility relocation would occur to relocate electrical transmission and distribution lines, phone lines, and water lines inundated by the proposed Project. In summary, the following are included in the proposed Project:

- Dam along Baynham Branch and nearby borrow areas
- Inundation of approximately 1,200 acres at normal pool
- Pipeline and pumps to transfer water from Shoal Creek to the proposed Project during periods of high rainfall.
- Roadway and utility relocation to maintain existing services in the area.

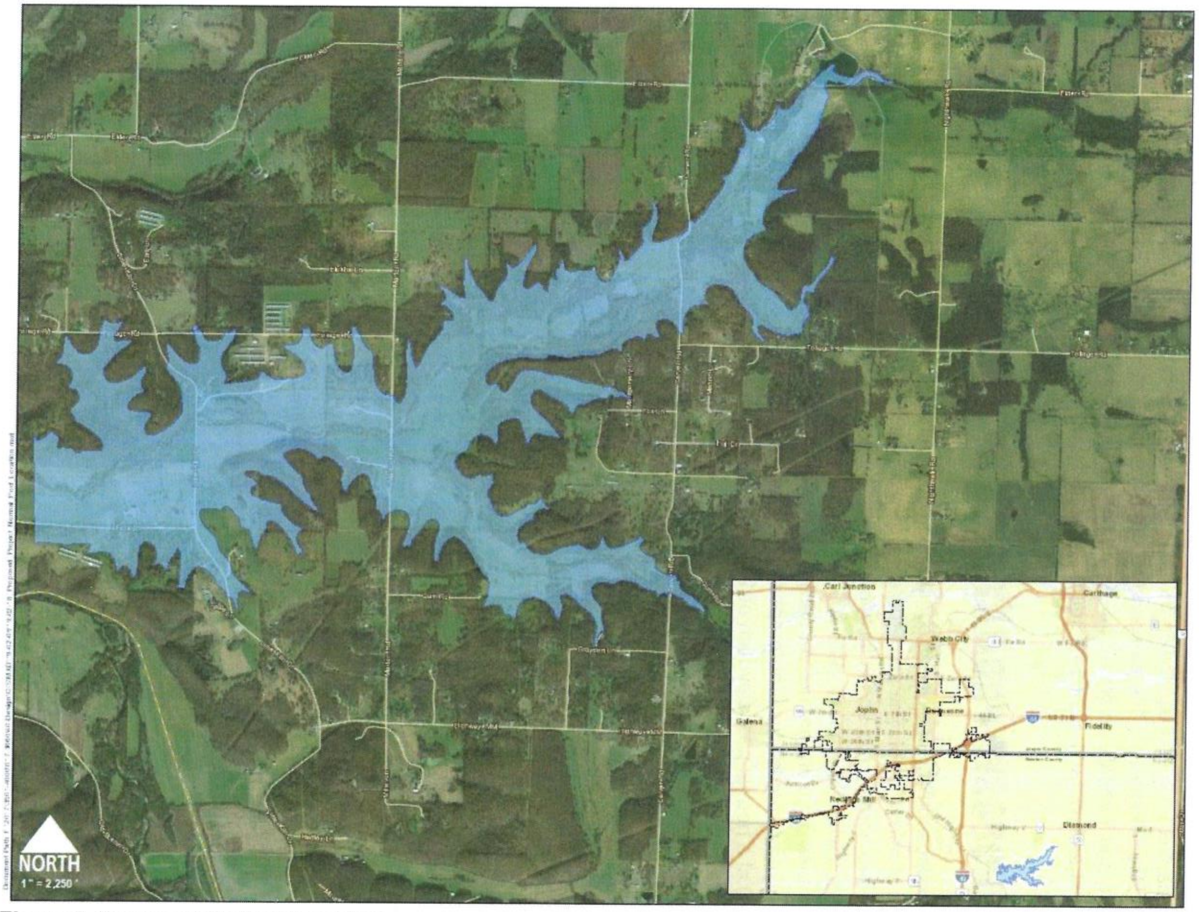

Figure 1. Proposed Project Location.

4. PURPOSE AND NEED

The purpose of the MAWC reservoir is to provide a reliable, clean, long-term source of drinking water for the City of Joplin and the surrounding communities (MAWC service area). To provide a reliable drinking water source, the water supply source must meet water supply needs for the MAWC service area during the drought of record as well as current state and federal drinking water guidelines. The water supply need for southwest Missouri has been documented in multiple studies summarized below (Wittman et. al. 2003; Black and Veatch 2006; USACE 2012, 2014, 2018).

4.1. 2003 Source of Supply Investigation for Joplin, Missouri

Wittman Hydro Planning Associates (WHPA) conducted a regional groundwater study for Jasper and Newton counties. The study was designed to review the long-term viability of the Ozark aquifer. The Ozark aquifer is overlain by the Springfield Plateau aquifer which was mined in the 20th century (Wittman et. al. 2003). Historic mining has caused heavy metal contamination in areas of the Springfield Plateau aquifer and thus possible contamination of the Ozark aquifer. Additional pumping of the Ozark aquifer increases down gradient flows from the Springfield Plateau aquifer thus increasing the potential for its contamination (Wittman et. al. 2003).

Groundwater pumping in Jasper and Newton counties has increased from 8.2 mgd in 1990 to 18.1 mgd in 2000, an increase of 9.9 mgd (121 percent). Many cities have reported a decline in the groundwater level (Wittman et. al. 2003). The long-term sustainability of the Ozark aquifer is going to be influenced by potential groundwater contamination and increased water usage in the region (Wittman et. al. 2003).

4.2. 2006 Water Supply Study

The USACE funded a water supply study in 2006 that evaluated future water supply needs in the three-state region that included southwest Missouri, southeast Kansas, and northeast Oklahoma (Black and Veatch 2006). Population projections from 2000 to 2050 in Jasper County, Missouri were projected to increase from 101,207 to 147,900 people (46 percent) and population in Newton County, Missouri was projected to increase from 49,596 to 72,800 people (47 percent). The population projection from 2000 to 2050 for the MAWC service area was projected to increase from 47,000 to 97,000 people (106 percent, Black and Veatch 2006).

Consistent with the population growth in the region, the water demand is also projected to increase. The MAWC service area currently uses a total average day flow of 12.4 mgd. The projected 2050 average day flow is 33 mgd which represents a 166 percent increase in water demand (Black and Veatch 2006).

4.3. 2012-2014 Southwest Missouri Water Resources Study – Phase I and II

In 2012 and 2014, the USACE funded a regional water demand forecast (Phase I) and a regional supply availability study (Phase II) for southwest Missouri. In Newton County, the water demand was projected from 2010 to 2060 to increase from 8.1 mgd to 14.7 mgd (81.1 percent) and in Jasper County, the water demand from 2010 to 2060 was projected to increase from 19.8 mgd to 36.7 mgd (85.8 percent, USACE 2012). The southwest Missouri region projected a water demand increase from 339 mgd to 464 mgd (40 percent, USACE 2014).

The MAWC water sources include groundwater wells and Shoal Creek. Shoal Creek provides 9.6 mgd to 15.6 mgd of water to the cities of Joplin and Neosho. Shoal Creek's 7Q10 is 43 cubic feet per second (cfs) or 28 mgd at Joplin (USACE 2014). The 7Q10 evaluation is the lowest seven-day average flow that occurs once every 10 years. A 7Q10 threshold is used by the MDNR to protect the integrity of streams and is considered the threshold for available drinking water. By definition, a stream's flow will fall below the 7Q10 threshold because a drought with a 10-year probability will occur more often than the drought of record.

4.4. 2018 Southwest Missouri Water Resources Study – Phase III

The USACE-funded resource study (Phase III) focused on the Tri-State Coalition membership separately and identified the water demand needs of the MAWC Joplin service area. The 2010 average day water demand was 7.8 mgd and the max day water demand was 11.7 mgd. In 2060, the average day water demand is projected to increase to 17.0 mgd and the max day water demand is projected to increase to 38.6 mgd. This represents an average day water demand increase of 9.2 mgd (118 percent) and a max day water demand increase of 26.9 mgd (230 percent).

4.5. Summary of Water Supply Need

Based on the studies summarized above, the projected water demand for the MAWC service area is more than 30 mgd. The groundwater reliability and limitations in pumping Shoal Creek during the drought of record are a factor in providing a reliable water supply. The Project Proponent has selected a water supply reservoir that could provide a water supply of 30 mgd to reliably meet the water supply needs of the MAWC service area.

5. ALTERNATIVES CONSIDERED

To meet the need for a reliable, clean, long-term source of drinking water for the City of Joplin and surrounding communities, groundwater resources, pipeline construction to nearby reservoirs, and construction of a new reservoir were evaluated at multiple locations. The sections below summarize previous studies that assessed potential alternatives.

5.1. Pipeline Alternatives

The nearby USACE lakes do not currently have discretionary storage to pipe water to the MAWC service area; however, the USACE Chief of Engineers has discretionary authority to reallocate up to 15 percent or 50,000 acre-feet for water supply (Black and Veatch 2006).

Table Rock Lake, Pomme de Terre, and Stockton Lake were identified as potential alternative water supply sources for southwestern Missouri (CDM Smith 2016, 2017; USACE 2018). An assessment of pipeline options that included construction of a pipeline to Joplin was completed for the Tri-State Coalition (USACE 2018). The total opinion of probable cost was approximately $2 billion for each of the three pipeline alternatives (CDM Smith 2017; USACE 2018). These alternatives included a pipeline that would service southwest Missouri and was not specific to the MAWC service area. The cost to service only the MAWC service area and the availability of water specific to the MAWC service area have not been determined but are anticipated to be higher than developing a reservoir.

5.2. Groundwater Resources

WHPA conducted a regional groundwater study for Jasper and Newton counties. The study was designed to review the long-term viability of the Ozark aquifer. Potential groundwater contamination is discussed in Section 4.1 above.

As mentioned above groundwater pumping in Jasper and Newton counties has increased from 8.2 mgd in 1990 to 18.1 mgd in 2000, which represents an increase of 9.9 mgd (121 percent increase). Many cities have reported a decline in the groundwater level (Wittman et. al. 2003). The long-term sustainability of the Ozark aquifer could be influenced by potential groundwater contamination from historic mining as described above as well as increased water demand in the region (Wittman et. al. 2003).

5.3. Alternative Reservoir Locations

The Water Supply Study (Black and Veatch 2006) indicated that the river systems in the three-state study area did not have adequate water supply to meet the needs of the region "without constructing an impoundment." There have been four reports that evaluated a total of 17 alternative reservoir locations (Freese and Nichols 2009, 2010; Black and Veatch 2018a, 2018b). The alternative reservoir locations are included in Table 1.

Table 1. Alternative Reservoir Locations.

Alternative Reservoir	Report	Size (acres)	Water Supply (mgd)
Site 1	Black and Veatch 2018a and Freese and Nichols 2009; 2010	7,400/4,400/ 5,660*	54/35/30*
Site 2	Black and Veatch 2018a and Freese and Nichols 2009; 2010	3,800/3,500/ 4,090*	49/35/30*
Site 3	Freese and Nichols 2009	6,300	54
Site 4	Freese and Nichols 2009	6,500	54
Site 5	Freese and Nichols 2009	23,500	115
Site 6	Freese and Nichols 2009	7,600	67
Site 7	Freese and Nichols 2009	5,600	124
Site 7a	Freese and Nichols 2009	6,700	124
Site 8	Black and Veatch 2018a and Freese and Nichols 2009	3,800/2,210*	59/30*
Site 9	Freese and Nichols 2009	7,500	101
Site 10	Freese and Nichols 2009	4,300	70
Site 10a	Freese and Nichols 2009	2,300	59
Site 11	Black and Veatch 2018a and Freese and Nichols 2009	6,200/4,380*	55/30*
Prosperity	Freese and Nichols 2009	3,000	23
Site 12 (Site A)	Black and Veatch 2018a; 2018b and Freese and Nichols 2009; 2010	1,200/873*	27/30*
Site 12 Alt 1 (Site B)	Black and Veatch 2018a; 2018b	1,460	30
Site 12 Alt 2 (Site C, proposed Project)	Black and Veatch 2018a; 2018b	1,140	30

* Slashes indicate values in multiple studies.

5.3.1. Sites A, B, and C (Proposed Project) Evaluation

Sites A, B, and C (proposed Project) had the smallest project footprint and provided a water supply consistent with MAWC service area's needs. Thus, these three sites were evaluated further to determine environmental impacts and potential water quality issues. The desktop evaluation for impacts to cultural resources, threatened or endangered species, migratory birds, and eagles did not vary drastically between sites. Additionally, the yield and storage did not identify significant differences. A site visit identified the Walter Wood Conservation Area within the normal pool of Site A. Figure 2 shows the project foot print for the three sites.

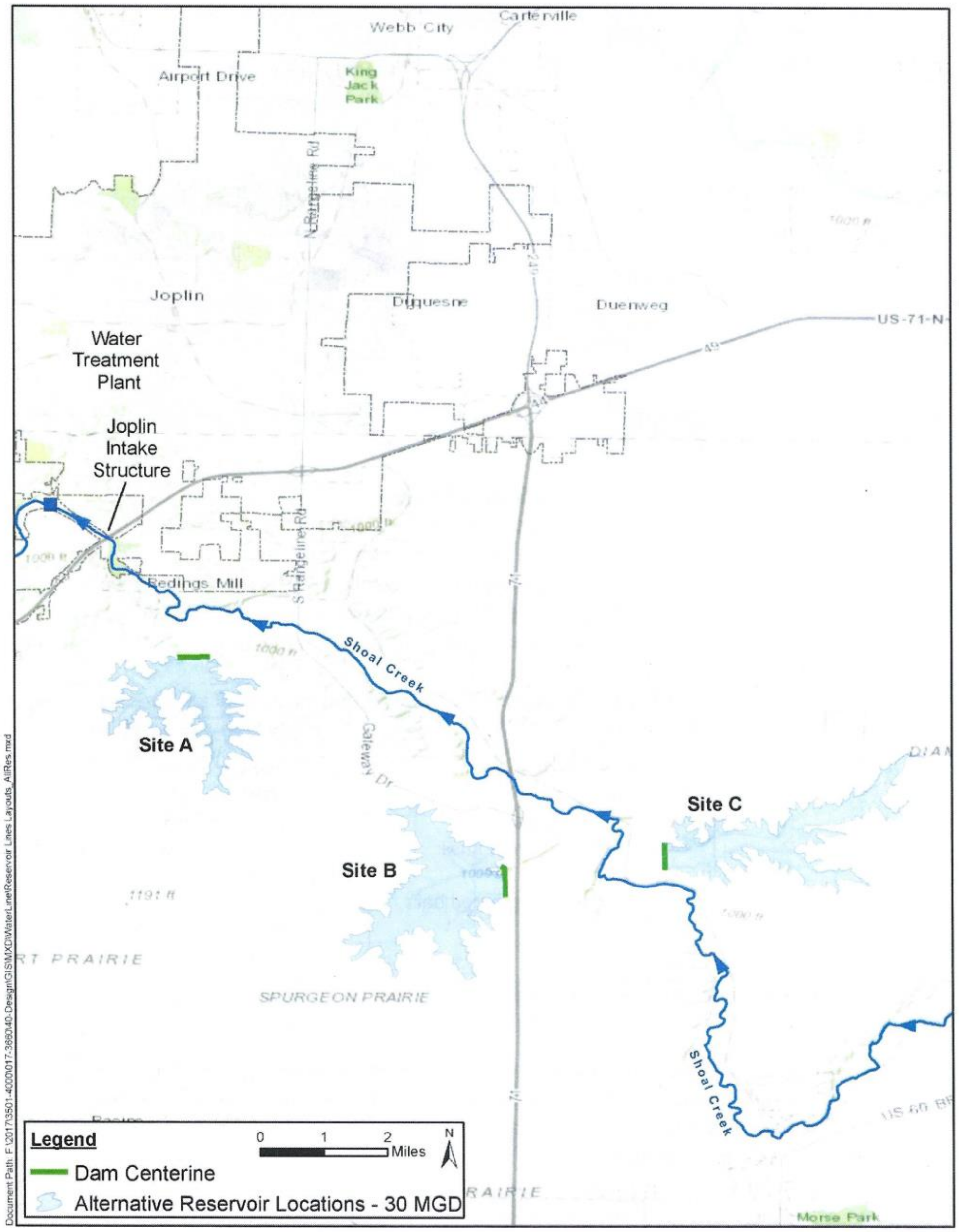

Figure 2. Site A, Site B, and Site C (proposed Project) Project Footprint.

5.3.1.1.1. National Wetland Inventory (NWI) and National Hydrography Dataset (NHD)

The NWI and NHD calculations for stream and wetland impacts are included in Table 2 for each reservoir site. Site C (proposed Project) has the lowest NWI wetland impacts, and Site A has the lowest NHD stream impacts.

Table 2. Wetland and Stream Impacts.

Alternative Reservoir	Reservoir Size (Acres)	Stream Length (Linear Feet)[1]	Wetland Area (Acres)[2]
Site A	873	46,225	3
Site B	1,460	62,753	2
Site C (proposed Project)	1,140	55,441	1

[1] Source: NHD (USGS 2017)
[2] Source: NWI (USFWS 2017)

5.3.1.2. Threatened and Endangered Species

A review of state- and federally-listed species identified six state-listed species and eight federally-listed species (Table 3). A desktop evaluation of the three reservoir locations did not identify major differences in impacts to the state- and federally-listed species. All three reservoirs drain to Shoal Creek, which has reaches designated as Neosho mucket critical habitat. Additionally, all three reservoirs have forest resources that may provide habitat to state- and federally-listed bat species.

Table 3. State- and Federally-Listed Threatened and Endangered Species.

Reservoir Site	State-Listed Species	Federally Listed Species
Site A Site B Site C (proposed Project)	1. Neosho mucket* 2. Rabbitsfoot 3. Cave crayfish 4. Northern harrier hawk 5. Gray bat 6. Northern long-eared bat	1. Neosho mucket 2. Rabbitsfoot 3. Cave crayfish 4. Neosho madtom 5. Ozark cavefish 6. Gray bat 7. Northern long-eared bat 8. Indiana bat

*** Note: Critical habitat is present in Shoal Creek.**

5.3.1.3. Mining

Lead, zinc, and coal mining activities were evaluated for the three sites. According to mine maps on the Missouri Digital Heritage website (Missouri Office of the Secretary of State 2019), Site B and Site C (proposed Project) each have one mine within the normal pool. Site B has 25 mines and Site C (proposed Project) has 11 mines within one mile of their normal pools. Site A has two prominent areas with mining activities within the normal pool. There were 134 mines within the normal pool and 147 mines within one mile of the normal pool.

5.3.1.4. Road Relocation/Transportation

Roadway relocations and road closures would occur for each of the three sites. Site A would include approximately 9.2 miles, Site B would include approximately 7.6 miles, and Site C would include approximately 5.7 miles of road relocations or road closures. Road configuration, resident access, and maintaining emergency services will be considered in determining relocation versus road closure.

5.3.1.5. Utility Relocation

Relocation of existing utilities will be needed to maintain existing services to the area. Electric distribution and transmission lines, water distribution lines, and phone lines (copper and fiber) were evaluated for the three sites. Site A would include approximately 30.7 miles, Site B would include 30.8 miles, and Site C would include approximately 28.2 miles of utility line relocations.

Major utility relocations including oil, gas, and petroleum pipelines and electrical transmission lines were evaluated further for Sites B and C. Site B has two electrical transmission lines, one oil pipeline, and one gas pipeline. Site C has two oil pipelines, one gas pipeline, and two electrical transmission lines.

5.3.1.6. Geology

Field reconnaissance and geotechnical investigations were performed on Sites A, B and C (proposed Project). Site A is expected to have materials suitable for use in construction of the embankment dam available on site. The bedrock foundation is anticipated to require treatment to cut off pathways of groundwater flow believed to be present in the karstic bedrock.

Site B was found to have granular materials suitable for shell material during construction. No impervious clay material was identified within the boring, though it is believed that areas within the site may contain lean clays suitable for use, which could be confirmed with additional borings. The bedrock foundation is anticipated to require treatment to cut off groundwater flows through the formation. Karstic features including a 6-inch clay seam was identified within the bedrock. This indicates that grouting techniques may not be effective, and construction of a cut-off wall may be required.

Bedrock near Site C appears to be of better quality than the other two sites. Further investigation of the subsurface is needed to verify that the quality of the bedrock is representative of the site. Differences in the quality of rock may be attributed to the limestone being of a different formation. Site C is also anticipated to have materials suitable for both impervious core material and shell material.

6. AVOIDANCE AND MINIMIZATION

Comparison of alternative sites that could meet the project purpose and need include a comparison of aquatic resources and threatened and endangered species impacts. The sites with the fewest aquatic resources and threatened and endangered species impacts were further evaluated before selecting the proposed Project location. Thus, through the site selection and alternatives analysis process aquatic and threatened and endangered species impacts were avoided and minimized to the extent possible.

Further avoidance and minimization are anticipated through the use of best management practices during the construction process and effectively sizing the reservoir to the minimum reservoir size that meets the Project purpose and need.

7. MITIGATION

The proposed mitigation plan will follow USACE and U.S. Environmental Protection Agency (EPA) joint regulations for compensatory mitigation. To the extent practicable the hierarchy of mitigation will occur in following order:

1. Mitigation bank
2. In-lieu fee program
3. Permittee responsible mitigation under a watershed approach
4. Permittee responsible mitigation through on-site and in-kind mitigation
5. Permittee responsible mitigation through off-site and/or out-of-kind mitigation

Because of the quantity of mitigation credits required and limited availability of mitigation banking credits, a combination of compensatory mitigation options may be necessary.

8. AFFECTED ENVIRONMENT

8.1. Air Quality

The proposed Project is in an attainment county and is therefore not subject to general conformity requirements. Air emissions are anticipated to occur temporarily during construction phases as a result of heavy construction equipment. Air quality impacts from the proposed Project are anticipated to be minor to negligible following reservoir construction.

8.2. Climate

Minimal greenhouse gas emissions are anticipated as a result of the proposed Project. The proposed Project is not anticipated to have a substantial effect on climate or climate change.

8.3. Hazardous Materials, Solid Waste, and Pollution Prevention

Increases in hazardous materials and solid waste are not anticipated with the proposed Project. During construction activities, best management practices will be implemented to prevent pollution of the aquatic environment.

8.4. Cultural Resource Assessment

The Boyd Cemetery was identified in the proposed Project area during a site visit. It is located along Carver Road south of the Baynham Branch. The George Washington Carver National Monument is located approximately one mile north of the proposed Project. There have not been any additional historical, architectural, archeological, or cultural resources identified.

8.5. Land Use

8.5.1. Existing Land Cover

The existing land cover was determined for the normal pool (Figure 3) by the National Land Cover Database (NLCD, Homer et. al. 2015). The land cover in the normal pool was approximately 50 percent natural area (primarily deciduous forest) and approximately 50 percent agricultural use (primarily pasture/hay).

Table 4. Proposed Project NLCD Land Cover (Homer et. al. 2015)

NLCD Classification	Area (acres)	Percent
Deciduous Forest	564	49
Pasture/Hay	510	45
Developed, Low Intensity	29	3
Grassland/Herbaceous	22	2
Woody Wetlands	7	1
Open Water	4	<1
Evergreen Forest	4	<1
Shrub/Scrub	<1	<1
Cultivated Crops	<1	<1
Total	**1,140**	**100**

8.5.2. Existing Land Use

Land use is predominantly agricultural production related to a swine operation along the north border of the normal pool and pasture, hay, and crop production.

8.5.3. Farmland

Under the Farmland Protection Policy Act (FPPA), federal agencies must identify and consider the adverse effects of federal programs on the preservation of prime or unique farmland. Farmland inundated by the proposed Project is estimated at 49 acres of row crop and 430 acres of pasture based on current aerial photography.

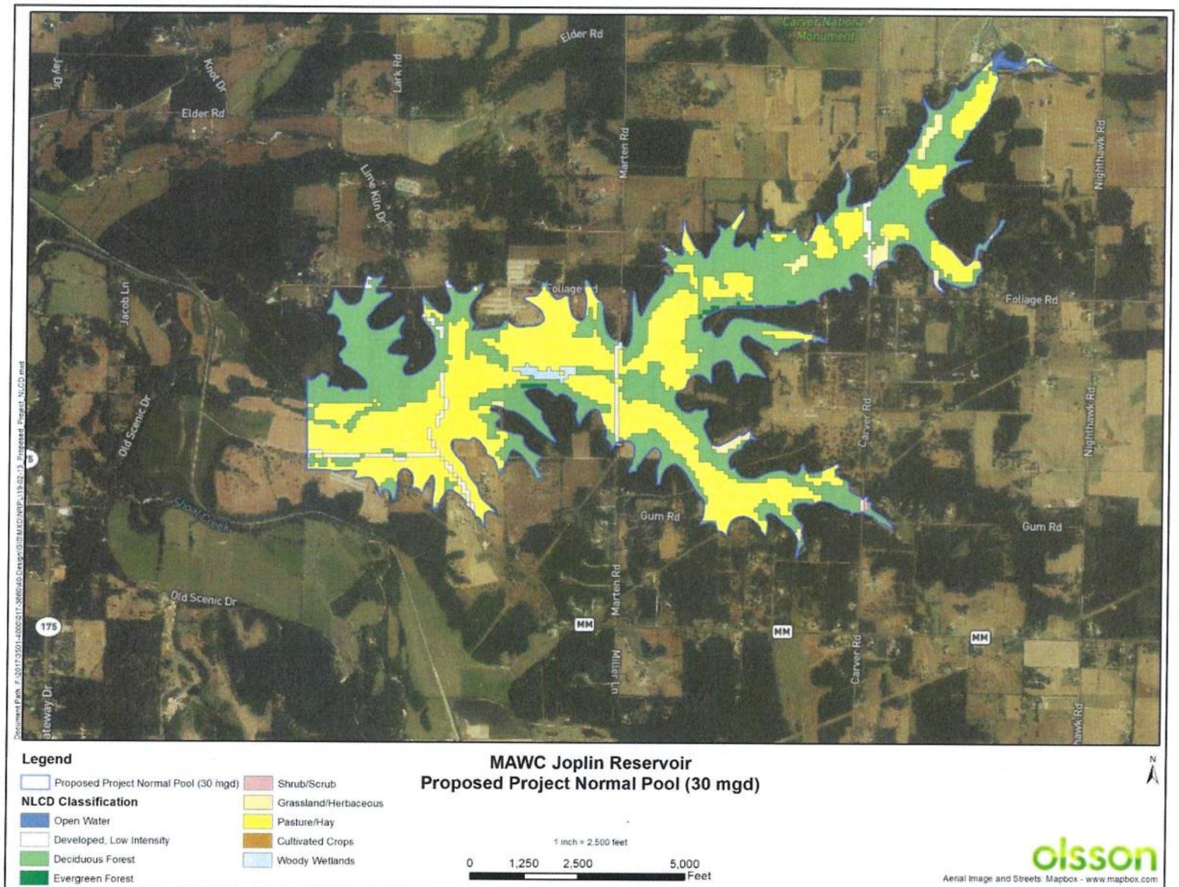

Figure 3. Proposed Project National Land Cover Database.

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8.5.4. Roadway and Utility Relocation

Road and utility relocations or potential abandonment are anticipated to occur as a result of the proposed Project. There are no impacts to railroad infrastructure and there have been no petroleum pipelines identified within the proposed Project boundary. An estimated 43,600 linear feet (LF) of transmission lines would be removed or relocated and 30,100 LF of distribution lines would be remove or relocate. Within the proposed Project footprint water lines total 30,100 LF and fiber phone lines total 30,000 LF. Approximately 5.7 miles of roads would be inundated and thus closed or rerouted.

8.6. Natural Resources and Energy Supply

8.6.1. State- and Federally Listed Threatened and Endangered Species

The state- and federally listed species occurring in the vicinity of the proposed Project are included in Table 3 (above). Depending on more detailed studies, threatened or endangered species may or may not be present.

8.6.2. Geology

Bedrock in the Project area is expected to consist of the Burlington-Keokuk Limestone based on bedrock mapping by MDNR (2003). Bedrock elevation ranges from approximately 1,000 to 1,050 feet-amsl.

The Seneca Fault is mapped approximately 2 miles to the northeast of the dam location. The Seneca Fault is shown to trend from the southwest to the northeast. The Ritchey Fault is also mapped as ending about 4 miles east of the dam, trending from west to east. Both faults are inactive and distant enough from the dam site that it is unlikely that foundation conditions have been affected.

Several sinkholes have been mapped to the east of the reservoir. Two losing streams have been identified to the northeast of the dam, one of which lies within the reservoir boundary. Several of the mapped sinkholes fall between the two losing streams, indicating a possible connection between the features in the subsurface. The 1972 USGS Tipton Ford and Grandy Quadrangles (USGS 2017) identified additional locations where possible sinkholes may be located based on topographic conditions, though these have not been field verified.

8.6.3. Mining

As shown in Figure 4, documented underground mining activity is located within the north finger of the proposed Project. Documented lead and zinc mining activities surround the proposed Project area. Twelve mines are identified within the vicinity of the proposed Project. One mine within the normal pool, and 11 mines within one mile of the proposed Project. In addition to the documented mines, the area contained mining camps. Undocumented mines and prospect holes that have been filled in could be present within or near the proposed Project.

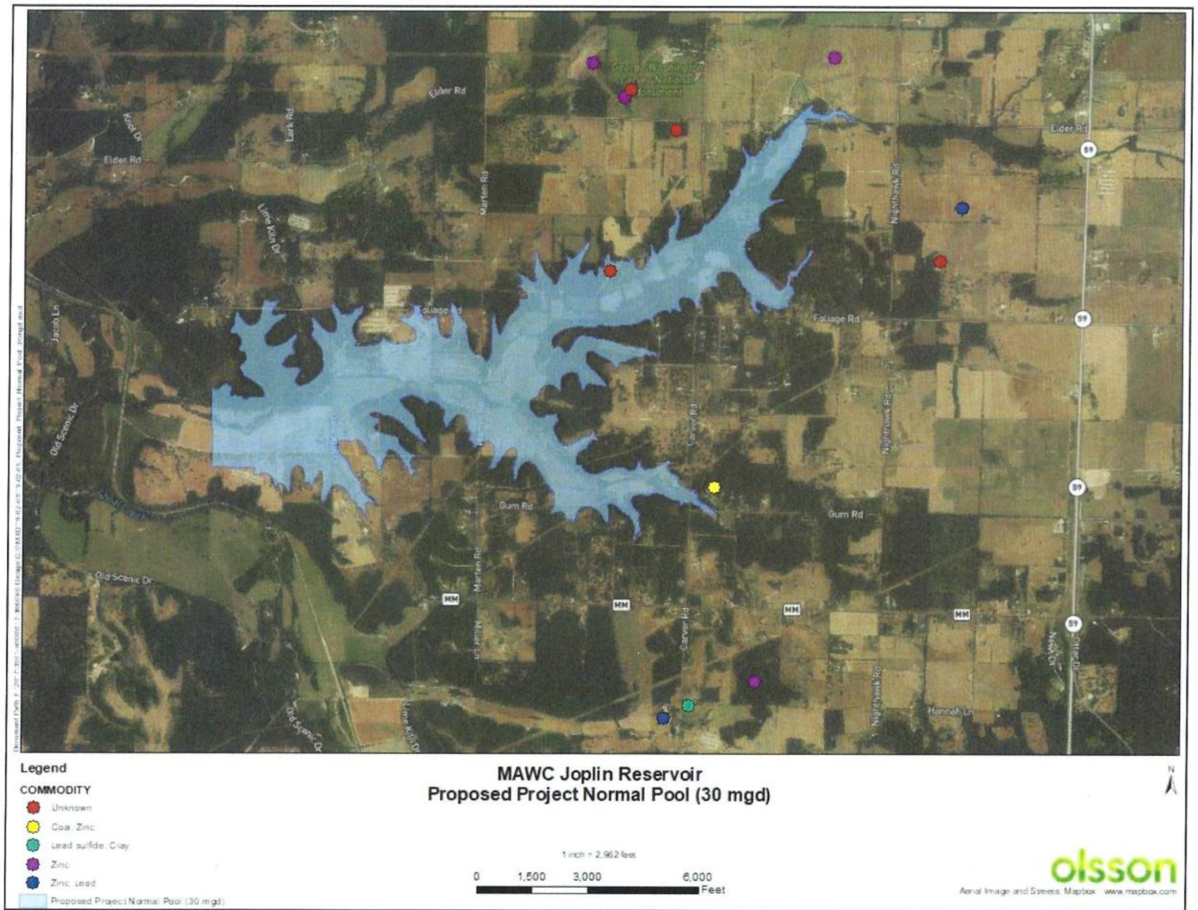

Figure 4. Mining Activities Near the Proposed Project.

8.7. Noise and Noise-Compatible Land Use

Temporarily, noise levels are anticipated to rise during construction related activities. Noise levels are expected to be unchanged post-construction during reservoir operation.

8.8. Socioeconomics, Environmental Justice, and Children's Environmental Health and Safety Risks

The proposed Project would relocate existing residences in accordance with the Uniform Relocation Act (URA). Surface vehicle traffic, roads, and utilities are anticipated to be impacted by the proposed Project; however, it is not anticipated that Level-of-Service would be substantially impacted following the appropriate relocations.

The proposed Project is not anticipated to cause disruption of established communities or to cause impacts to environmental justice or children's health and safety.

8.9. Visual Effects

The proposed project is not anticipated to have negative visual effects on the landscape.

8.10. Water Resources

8.10.1. Losing Stream

There are 3,488 LF of losing stream within the normal pool. The losing stream would be entirely inundated by the proposed reservoir and is not anticipated to impact reservoir storage.

8.10.2. Water Quality

There are 12 identified historic producers of coal, zinc, and lead mines in the proposed Project area. Bynham Branch has not been included on the 303(d) list of impaired waters for metals but is listed as having elevated bacteria levels from rural nonpoint source runoff (MDNR 2018).

8.10.3. Wetlands and Streams

The wetlands in the Project area were evaluated based on the NWI (USFWS 2017), and the streams were evaluated based on the NHD (USGS 2017). Field wetland and stream delineations have not been completed but are proposed to confirm the accuracy of the NWI and NHD data. Based on the NWI and NHD data, stream impacts include 55,411 feet and 1 acre of wetland impacts.

8.10.4. Wild and Scenic Rivers

There are no Wild and Scenic Rivers within the proposed Project area.

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JOPLIN WATER SUPPLY RESERVOIR

February 2019

Olsson Project No. 017-3660

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APPENDIX B

TABULAR DYE TRACING RESULTS

Table 1. Results for charcoal samplers analyzed for the presence of fluorescein, eosine, and rhodamine WT dyes.

Table 2. Results for water samples analyzed for the presence of fluorescein, eosine, and rhodamine WT dyes.

Table 1. Results for charcoal samplers analyzed for the presence of fluorescein, eosine and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

OUL	Station	Station Name	Date/Time	Date/Time	Fluorescein		Eosine		RWT	
Number	Number		Placed	Collected	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)
E7718	**102**	**Baynham Br. d/s Brown Lake**	**9/23/20 1000**	**10/6/20 1500**	**ND**		**ND**		**ND**	
E7953	102	Baynham Br. d/s Brown Lake	10/6/20 1505	10/14/20 1210	ND		ND		ND	
E7953D	102	Baynham Br. d/s Brown Lake	10/6/20 1505	10/14/20 1210	ND		ND		ND	
E8286	102	Baynham Br. d/s Brown Lake	10/14/20 1210	10/22/20 1558	ND		ND		ND	
E8647	102	Baynham Br. d/s Brown Lake	10/29/20 1341	11/5/20 0814	ND		ND		ND	
E8511	102	Baynham Br. d/s Brown Lake	NDT	10/29/20 NT	ND		ND		ND	
E7719	**104**	**Baynham Br. u/s Carver Rd**	**10/1/20 1245**	**10/6/20 0845**	**ND**		**ND**		**ND**	
E7954	104	Baynham Br. u/s Carver Rd	10/6/20 0845	10/14/20 1155	ND		541.6	1,170	ND	
E7954D	104	Baynham Br. u/s Carver Rd	10/6/20 0845	10/14/20 1155	ND		541.5	1,010	ND	
E8268	104	Baynham Br. u/s Carver Rd	10/14/20 1155	10/22/20 0844	ND		540.6	30.8	ND	
E8489	104	Baynham Br. u/s Carver Rd	10/22/20 0844	10/29/20 0808	ND		540.5	28.5	ND	
E8648	104	Baynham Br. u/s Carver Rd	10/29/20 0808	11/5/20 0841	ND		540.1	10.1	ND	
E8269	**105**	**Baynham Br. d/s Marten Rd**	**10/1/20 1224**	**10/22/20 0918**	**ND**		**ND**		**ND**	
E8491	105	Baynham Br. d/s Marten Rd	10/22/20 0918	10/29/20 0840	ND		ND		ND	
E7721	**106**	**Baynham Br. d/s Henson Spring**	**9/11/20 1111**	**10/6/20 0940**	**ND**		**ND**		**ND**	
E7955	106	Baynham Br. d/s Henson Spring	10/6/20 0940	10/14/20 0833	ND		542.6	1,250	566.0	7,340
E7955D	106	Baynham Br. d/s Henson Spring	10/6/20 0940	10/14/20 0833	ND		543.0	1,170	566.3	6,930
E8271	106	Baynham Br. d/s Henson Spring	10/14/20 0833	10/22/20 0940	ND		542.0	166	567.4	489
E8493	106	Baynham Br. d/s Henson Spring	10/22/20 0940	10/29/20 0905	ND		542.1	69.8	567.0	218
E8649	106	Baynham Br. d/s Henson Spring	10/29/20 0905	11/5/20 1110	ND		541.7	39.4	567.0	67.8
E8817	106	Baynham Br. d/s Henson Spring	11/5/20 1110	11/12/20 0828	ND		541.7	23.9	567.6	36.9
E8937	106	Baynham Br. d/s Henson Spring	11/12/20 0828	11/19/20 1002	ND		541.8	20.6	566.0	24.1
E8937D	106	Baynham Br. d/s Henson Spring	11/12/20 0828	11/19/20 1002	ND		541.0	26.5	565.8	31.2
E9136	106	Baynham Br. d/s Henson Spring	11/19/20 1002	12/1/20 1044	ND		541.0	23.6	568.6	26.1
E9477	106	Baynham Br. d/s Henson Spring	12/1/20 1044	12/21/20 0829	ND		541.4	13.5	565.6	10.6
E7722	**107**	**Henson well pipe**	**10/1/20 1110**	**10/6/20 0945**	**ND**		**ND**		**ND**	
E7956	107	Henson well pipe	10/6/20 0945	10/14/20 0825	ND		ND		ND	
E7956D	107	Henson well pipe	10/6/20 0945	10/14/20 0825	ND		ND		ND	
E8272	107	Henson well pipe	10/14/20 0825	10/22/20 0945	ND		ND		ND	
E8494	107	Henson well pipe	10/22/20 0945	10/29/20 0910	ND		ND		ND	

OUL	Station	Station Name	Date/Time	Date/Time	Fluorescein		Eosine		RWT	
Number	Number		Placed	Collected	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)
E8650	107	Henson well pipe	10/29/20 0910	11/5/20 1133	ND		ND		ND	
E8953	107	Henson well pipe	NDT	11/19/20 1008	ND		ND		ND	
E9145	107	Henson well pipe	11/19/20 1008	12/1/20 1049	ND		ND		ND	
E9478	107	Henson well pipe	12/1/20 1049	12/21/20 0834	ND		ND		ND	
E7723	**108**	**Baynham Br. u/s Lime Kiln Rd**	**10/1/20 1200**	**10/6/20 1000**	**ND**		**ND**		**ND**	
E7957	108	Baynham Br. u/s Lime Kiln Rd	10/6/20 1000	10/14/20 0839	ND		542.8	433	568.6	3,100
E7957D	108	Baynham Br. u/s Lime Kiln Rd	10/6/20 1000	10/14/20 0839	ND		543.1	600	566.3	4,210
E8273	108	Baynham Br. u/s Lime Kiln Rd	10/14/20 0839	10/22/20 0951	ND		542.0	77.8	567.6	281
E8273D	108	Baynham Br. u/s Lime Kiln Rd	10/14/20 0839	10/22/20 0951	ND		541.7	104	567.6	315
E8495	108	Baynham Br. u/s Lime Kiln Rd	10/22/20 0951	10/29/20 0926	ND		542.1	34.2	567.6	126
E8495D	108	Baynham Br. u/s Lime Kiln Rd	10/22/20 0951	10/29/20 0926	ND		542.0	33.8	567.7	124
E8651	108	Baynham Br. u/s Lime Kiln Rd	10/29/20 0926	11/5/20 1140	ND		541.8	14.3	566.5	33.9
E8651D	108	Baynham Br. u/s Lime Kiln Rd	10/29/20 0926	11/5/20 1140	ND		541.9	24.7	567.1	59.4
E8818	108	Baynham Br. u/s Lime Kiln Rd	11/5/20 1140	11/12/20 0835	ND		541.9	17.1	567.4	44.5
E8818D	108	Baynham Br. u/s Lime Kiln Rd	11/5/20 1140	11/12/20 0835	ND		541.8	18.0	567.8	47.9
E8938	108	Baynham Br. u/s Lime Kiln Rd	11/12/20 0835	11/19/20 1009	ND		541.9	13.6	566.2	27.8
E8938D	108	Baynham Br. u/s Lime Kiln Rd	11/12/20 0835	11/19/20 1009	ND		541.7	8.34	567.6	18.5
E9137	108	Baynham Br. u/s Lime Kiln Rd	11/19/20 1009	12/1/20 1052	ND		541.4	6.43	566.6	7.93
E9479	108	Baynham Br. u/s Lime Kiln Rd	12/1/20 1052	12/21/20 0841	ND		541.4	7.01	566.8	8.43
E7724	**109**	**Parks Spring #1 (upstream)**	**9/23/20 1130**	**10/6/20 1152**	**ND**		**ND**		**ND**	
E7958	109	Parks Spring #1 (upstream)	10/6/20 1152	10/14/20 0852	ND		542.6	478	566.0	3,320
E7958D	109	Parks Spring #1 (upstream)	10/6/20 1152	10/14/20 0852	ND		542.3	291	568.3	2,460
E8274	109	Parks Spring #1 (upstream)	10/14/20 0852	10/22/20 1020	ND		542.0	96.1	567.5	413
E8497	109	Parks Spring #1 (upstream)	10/22/20 1020	10/29/20 1002	516.2	1,150	ND		568.0	43.2
E8497D	109	Parks Spring #1 (upstream)	10/22/20 1020	10/29/20 1002	515.6	1,010	ND		568.0	46.1
E8652	109	Parks Spring #1 (upstream)	10/29/20 1002	11/5/20 1304	516.3	8.35	541.1	14.6	566.8	48.0
E8652	109	Parks Spring #1 (upstream)	10/29/20 1002	11/5/20 1304	515.4	7.40	541.3	10.8	567.2	37.0
E8819	109	Parks Spring #1 (upstream)	11/5/20 1304	11/12/20 0851	515.5	5.74	541.5	9.71	568.0	40.0
E8819D	109	Parks Spring #1 (upstream)	11/5/20 1304	11/12/20 0851	515.5	3.48	541.5	5.79	568.1	21.8
E8939	109	Parks Spring #1 (upstream)	11/12/20 1304	11/19/20 1100	515.6	1.09	541.5	3.57	567.3	10.5
E8939D	109	Parks Spring #1 (upstream)	11/12/20 1304	11/19/20 1100	515.2	0.794	541.6	2.70	567.2	7.90
E9138	109	Parks Spring #1 (upstream)	11/19/20 1100	12/1/20 1109	516.4	1.54	541.4	10.8	566.4	20.4

OUL	Station	Station Name	Date/Time	Date/Time	Fluorescein		Eosine		RWT	
Number	Number		Placed	Collected	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)
E9481	109	Parks Spring #1 (upstream)	12/1/20 1109	12/21/20 0859	514.8	1.07	542.0	8.94	566.8	15.8
E7725	**110**	**Parks Spring #2 (downstream)**	**9/23/20 1115**	**10/6/20 1211**	**ND**		**ND**		**ND**	
E7959	110	Parks Spring #2 (downstream)	10/6/20 1211	10/14/20 0859	ND		542.0	116	568.0	830
E7959D	110	Parks Spring #2 (downstream)	10/6/20 1211	10/14/20 0859	ND		542.1	108	567.9	820
E8275	110	Parks Spring #2 (downstream)	10/14/20 0859	10/22/20 1025	ND		542.0	39.3	568.0	188
E8275D	110	Parks Spring #2 (downstream)	10/14/20 0859	10/22/20 1025	ND		541.9	31.2	567.9	128
E8498	110	Parks Spring #2 (downstream)	10/22/20 1025	10/29/20 0957	515.4	161	ND		568.6	41.8
E8498D	110	Parks Spring #2 (downstream)	10/22/20 1025	10/29/20 0957	515.2	130	ND		568.4	33.1
E8653	110	Parks Spring #2 (downstream)	10/29/20 0957	11/5/20 1300	516.3	8.03	541.1	14.7	566.5	39.5
E8653D	110	Parks Spring #2 (downstream)	10/29/20 0957	11/5/20 1300	515.6	6.18	540.5	6.69	568.2	22.3
E8821	110	Parks Spring #2 (downstream)	11/5/20 1300	11/12/20 0845	515.4	3.40	541.5	5.51	568.2	20.9
E8821D	110	Parks Spring #2 (downstream)	11/5/20 1300	11/12/20 0845	514.8	1.64	541.1	2.16	567.9	9.73
E8941	110	Parks Spring #2 (downstream)	11/12/20 1300	11/19/20 1042	516.0	1.74	541.3	6.14	566.8	17.0
E8941D	110	Parks Spring #2 (downstream)	11/12/20 1300	11/19/20 1042	516.2	1.84	541.4	6.54	567.6	18.0
E9139	110	Parks Spring #2 (downstream)	11/19/20 1042	12/1/20 1101	516.2	0.888	541.0	5.48	566.4	11.2
E9482	110	Parks Spring #2 (downstream)	12/1/20 1101	12/21/20 0853	514.2	0.418	540.6	3.50	566.4	5.57
E7949	**111**	**Baynham Br. u/s dam site 1**	**10/6/20 1100**	**10/8/20 0956**	**ND**		**ND**		**ND**	
E7949D	111	Baynham Br. u/s dam site 1	10/6/20 1100	10/8/20 0956	ND		ND		ND	
E7961	111	Baynham Br. u/s dam site 1	10/8/20 0956	10/14/20 0908	ND		542.6	79.5	568.5	850
E7961D	111	Baynham Br. u/s dam site 1	10/8/20 0956	10/14/20 0908	ND		542.9	61.1	568.0	625
E8276	111	Baynham Br. u/s dam site 1	10/14/20 0908	10/22/20 1034	ND		542.4	11.2	567.0	71.5
E8276D	111	Baynham Br. u/s dam site 1	10/14/20 0908	10/22/20 1034	ND		542.2	11.5	567.6	67.3
E8499	111	Baynham Br. u/s dam site 1	10/22/20 1034	10/29/20 1015	516.2	1,020	ND		564.6	25.5
E8499D	111	Baynham Br. u/s dam site 1	10/22/20 1034	10/29/20 1015	515.6	948	ND		567.8	16.2
E8654	111	Baynham Br. u/s dam site 1	10/29/20 1015	11/5/20 1330	515.7	7.49	540.9	8.80	567.5	37.5
E8654D	111	Baynham Br. u/s dam site 1	10/29/20 1015	11/5/20 1330	515.0	3.30	540.6	1.93	567.6	10.9
E8822	111	Baynham Br. u/s dam site 1	11/5/20 1330	11/12/20 0900	515.4	1.92	542.6	1.40	568.1	12.1
E8822D	111	Baynham Br. u/s dam site 1	11/5/20 1330	11/12/20 0900	514.9	2.31	541.2	2.10	568.5	14.6
E8942	111	Baynham Br. u/s dam site 1	11/12/20 1330	11/19/20 1108	515.4	1.93	541.2	4.72	567.8	19.0
E8942D	111	Baynham Br. u/s dam site 1	11/12/20 1330	11/19/20 1108	514.4	1.09	541.7	2.25	567.5	11.7
E9141	111	Baynham Br. u/s dam site 1	11/19/20 1108	12/1/20 1116	516.4	0.923	541.1	3.01	567.1	5.95
E9483	111	Baynham Br. u/s dam site 1	12/1/20 1116	12/21/20 0908	515.8	0.677	541.0	4.06	566.2	9.74

OUL	Station	Station Name	Date/Time	Date/Time	Fluorescein		Eosine		RWT	
Number	Number		Placed	Collected	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)
E7726	**112**	**Baynham Branch u/s dam site 3**	**10/1/20 0930**	**10/6/20 1127**	**ND**		**ND**		**ND**	
E7951	112	Baynham Branch u/s dam site 3	10/6/20 1127	10/8/20 1050	ND		ND		ND	
E7951D	112	Baynham Branch u/s dam site 3	10/6/20 1127	10/8/20 1050	ND		ND		ND	
E7962	112	Baynham Branch u/s dam site 3	10/8/20 1050	10/14/20 0927	ND		542.6	90.7	568.4	1,140
E7962D	112	Baynham Branch u/s dam site 3	10/8/20 1050	10/14/20 0927	ND		543.4	64.0	568.0	821
E8277	112	Baynham Branch u/s dam site 3	10/14/20 0927	10/22/20 1045	ND		543.8	46.9	567.4	449
E8277D	112	Baynham Branch u/s dam site 3	10/14/20 0927	10/22/20 1045	ND		543.2	42.8	567.9	406
E8502	112	Baynham Branch u/s dam site 3	10/22/20 1045	10/29/20 1031	515.3	76.1	541.6	16.1	567.7	82.0
E8502D	112	Baynham Branch u/s dam site 3	10/22/20 1045	10/29/20 1031	515.8	53.5	540.8	12.0	567.2	48.5
E8655	112	Baynham Branch u/s dam site 3	10/29/20 1031	11/5/20 1352	515.9	23.3	541.0	20.7	567.3	97.1
E8655D	112	Baynham Branch u/s dam site 3	10/29/20 1031	11/5/20 1352	515.7	22.1	540.7	13.6	567.6	77.6
E8823	112	Baynham Branch u/s dam site 3	11/5/20 1352	11/12/20 0913	515.7	9.00	542.6	8.09	568.7	86.8
E8823D	112	Baynham Branch u/s dam site 3	11/5/20 1352	11/12/20 0913	515.6	9.18	542.8	8.73	568.6	90.1
E8943	112	Baynham Branch u/s dam site 3	11/12/20 1352	11/19/20 1119	516.2	3.62	542.5	8.45	568.2	54.9
E8943D	112	Baynham Branch u/s dam site 3	11/12/20 1352	11/19/20 1119	516.3	2.49	542.9	6.43	567.7	39.4
E9143	112	Baynham Branch u/s dam site 3	11/19/20 1119	12/1/20 1125	516.4	2.38	541.4	11.9	568.0	38.5
E9485	112	Baynham Branch u/s dam site 3	12/1/20 1125	12/21/20 0917	515.2	1.15	541.6	8.54	566.4	21.2
E7727	**113**	**Baynham Br. @ RR Bridge**	**10/1/20 1020**	**10/6/20 1230**	**ND**		**ND**		**ND**	
E7952	113	Baynham Br. @ RR Bridge	10/6/20 1230	10/8/20 1140	ND		ND		ND	
E7952D	113	Baynham Br. @ RR Bridge	10/6/20 1230	10/8/20 1140	ND		ND		ND	
E7963	113	Baynham Br. @ RR Bridge	10/8/20 1140	10/14/20 0953	ND		ND		ND	
E7963D	113	Baynham Br. @ RR Bridge	10/8/20 1140	10/14/20 0953	ND		ND		567.6	3.03
E8279	113	Baynham Br. @ RR Bridge	10/14/20 0953	10/22/20 1059	ND		ND		566.4 *	3.40
E8279D	113	Baynham Br. @ RR Bridge	10/14/20 0953	10/22/20 1059	ND		ND		567.6 *	1.57
E8503	113	Baynham Br. @ RR Bridge	10/22/20 1059	10/29/20 1110	515.1	6.99	ND		ND	
E8503D	113	Baynham Br. @ RR Bridge	10/22/20 1059	10/29/20 1110	515.8	7.52	ND		568.0 *	1.48
E8656	113	Baynham Br. @ RR Bridge	10/29/20 1110	11/5/20 1207	514.8	2.10	ND		ND	
E8656D	113	Baynham Br. @ RR Bridge	10/29/20 1110	11/5/20 1207	514.2	1.56	ND		ND	
E8825	113	Baynham Br. @ RR Bridge	11/5/20 1207	11/12/20 0927	513.8 *	0.648	ND		ND	
E8825D	113	Baynham Br. @ RR Bridge	11/5/20 1207	11/12/20 0927	513.8 *	0.689	ND		567.0	1.48
E8945	113	Baynham Br. @ RR Bridge	11/12/20 1207	11/19/20 1139	512.4 *	0.570	ND		568.2 *	1.26
E8945D	113	Baynham Br. @ RR Bridge	11/12/20 1207	11/19/20 1139	ND		ND		ND	

OUL	Station	Station Name	Date/Time	Date/Time	Fluorescein		Eosine		RWT	
Number	Number		Placed	Collected	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)
E9144	113	Baynham Br. @ RR Bridge	11/19/20 1139	12/1/20 1150	515.8	0.736	541.0	2.38	565.6	5.99
E9486	113	Baynham Br. @ RR Bridge	12/1/20 1150	12/21/20 0936	ND		540.8	1.44	565.8	4.13
E7728	**114**	**Hunley spring br. @ RR Bridge**	**10/1/20 1045**	**10/6/20 1330**	**ND**		**ND**		**ND**	
E7964	114	Hunley spring br. @ RR Bridge	10/6/20 1330	10/14/20 1049	ND		542.8	2.62	568.0	39.8
E7964D	114	Hunley spring br. @ RR Bridge	10/6/20 1330	10/14/20 1049	ND		541.0	2.47	567.2	33.5
E8285	114	Hunley spring br. @ RR Bridge	10/14/20 1053	10/22/20 1230	ND		542.4	14.2	568.2	271
E8285D	114	Hunley spring br. @ RR Bridge	10/14/20 1053	10/22/20 1230	ND		543.4	9.52	567.6	210
E8508	114	Hunley spring br. @ RR Bridge	10/22/20 1230	10/29/20 1220	515.1	55.2	ND		567.9	320
E8508D	114	Hunley spring br. @ RR Bridge	10/22/20 1230	10/29/20 1220	515.4	31.5	ND		567.4	193
E8657	114	Hunley spring br. @ RR Bridge	10/29/20 1220	11/5/20 1005	515.2	48.8	ND		567.6	179
E8657D	114	Hunley spring br. @ RR Bridge	10/29/20 1220	11/5/20 1005	515.4	38.6	ND		567.4	110
E8826	114	Hunley spring br. @ RR Bridge	11/5/20 1005	11/12/20 1010	517.1	1.41	ND		567.9	110
E8826D	114	Hunley spring br. @ RR Bridge	11/5/20 1005	11/12/20 1010	516.2	1.43	ND		567.7	103
E8946	114	Hunley spring br. @ RR Bridge	11/12/20 1005	11/19/20 0844	516.8	0.943	ND		567.2	64.1
E8946D	114	Hunley spring br. @ RR Bridge	11/12/20 1005	11/19/20 0844	516.8	1.10	ND		567.0	77.2
E9147	114	Hunley spring br @ RR Bridge	11/19/20 0844	12/1/20 0937	516.2	0.732	542.4	2.14	567.4	55.6
E9488	114	Hunley spring br @ RR Bridge	12/1/20 0937	12/21/20 1048	ND		ND		567.8	30.6
E7729	**115**	**Spring Flow U/G Hunley spring lake**	**10/1/20 1125**	**10/6/20 1340**	**ND**		**ND**		**ND**	
E7965	115	Spring Flow U/G Hunley spring lake	10/6/20 1340	10/14/20 1037	ND		540.8	0.800	568.0	8.33
E7965D	115	Spring Flow U/G Hunley spring lake	10/6/20 1340	10/14/20 1037	ND		542.2	11.6	567.6	163
E8282	115	Spring Flow U/G Hunley spring lake	10/14/20 1037	10/22/20 1140	ND		542.4	7.30	566.6	64.5
E8282D	115	Spring Flow U/G Hunley spring lake	10/14/20 1037	10/22/20 1140	ND		543.1	18.1	567.4	147
E8505	115	Spring Flow U/G Hunley spring lake	10/22/20 1140	10/29/20 1202	516.2	511	ND		566.6	93.7
E8505D	115	Spring Flow U/G Hunley spring lake	10/22/20 1140	10/29/20 1202	516.2	499	ND		566.6	65.8
E8658	115	Spring Flow U/G Hunley spring lake	10/29/20 1202	11/5/20 0937	515.8	181	ND		566.0	41.1
E8658D	115	Spring Flow U/G Hunley spring lake	10/29/20 1202	11/5/20 0937	515.4	18.2	ND		567.2	4.34
E8827	115	Spring Flow U/G Hunley spring lake	11/5/20 0937	11/12/20 0959	515.0	71.9	542.8 **	8.69	565.8	35.8
E8827D	115	Spring Flow U/G Hunley spring lake	11/5/20 0937	11/12/20 0959	515.2	82.1	542.4 **	9.62	566.6	37.9
E8947	115	Spring Flow U/G Hunley spring lake	11/12/20 0937	11/19/20 0824	515.6	43.1	541.6 **	6.32	565.4	22.1
E8947D	115	Spring Flow U/G Hunley spring lake	11/12/20 0937	11/19/20 0824	515.0	60.8	541.6 **	8.85	566.6	30.0
E9146	115	Spring Flow U/G Hunley spring lake	11/19/20 0824	12/1/20 0842	515.4	31.4	541.4	6.71	565.2	20.2
E9487	115	Spring Flow U/G Hunley spring lake	12/1/20 0842	12/21/20 1008	515.8	15.1	542.0	11.1	566.0	27.2

OUL	Station	Station Name	Date/Time	Date/Time	Fluorescein		Eosine		RWT	
Number	Number		Placed	Collected	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)
E7730	**116**	**Hunley spring lake outflow**	**9/23/20 1300**	**10/6/20 1334**	**ND**		**ND**		**ND**	
E7966	116	Hunley spring lake outflow	10/6/20 1334	10/14/20 1040	ND		543.8	6.25	569.0	120
E7966D	116	Hunley spring lake outflow	10/6/20 1334	10/14/20 1040	ND		543.4	10.8	568.4	208
E8283	116	Hunley spring lake outflow	10/14/20 1040	10/22/20 1204	ND		543.0	27.5	567.4	419
E8283D	116	Hunley spring lake outflow	10/14/20 1040	10/22/20 1204	ND		544.6	22.2	568.0	378
E8506	116	Hunley spring lake outflow	10/22/20 1204	10/29/20 1212	515.1	38.0	ND		567.5	72.1
E8506D	116	Hunley spring lake outflow	10/22/20 1204	10/29/20 1212	515.4	46.1	ND		567.5	80.1
E8659	116	Hunley spring lake outflow	10/29/20 1212	11/5/20 0959	515.4	46.7	ND		567.4	187
E8659D	116	Hunley spring lake outflow	10/29/20 1212	11/5/20 0959	515.3	21.6	ND		567.6	70.9
E8828	116	Hunley spring lake outflow	11/5/20 0959	11/12/20 1005	513.2 *	0.648	ND		567.6	11.3
E8828D	116	Hunley spring lake outflow	11/5/20 0959	11/12/20 1005	516.5	0.808	ND		567.8	44.6
E8948	116	Hunley spring lake outflow	11/12/20 0959	11/19/20 0841	514.2 *	0.519	ND		567.4	24.5
E8948D	116	Hunley spring lake outflow	11/12/20 0959	11/19/20 0841	514.6	0.551	ND		566.8	29.3
E9148	116	Hunley spring lake outflow	11/19/20 0841	12/1/20 0928	515.6	0.913	541.8	1.92	567.6	44.9
E9489	116	Hunley spring lake outflow	12/1/20 0928	12/21/20 1023	ND		ND		567.4	21.7
E8490	**117**	**Gary well overflow**	**10/6/20 1415**	**10/29/20 0828**	**ND**		**ND**		**ND**	
E7731	**118**	**Shoal Creek u/s Baynham Br.**	**10/1/20 1030**	**10/6/20 1250**	**ND**		**ND**		**ND**	
E7967	118	Shoal Creek u/s Baynham Br.	10/6/20 1250	10/14/20 1002	ND		ND		ND	
E7967D	118	Shoal Creek u/s Baynham Br.	10/6/20 1250	10/14/20 1002	ND		ND		ND	
E8281	118	Shoal Creek u/s Baynham Br.	10/14/20 1002	10/22/20 1107	ND		ND		ND	
E8281D	118	Shoal Creek u/s Baynham Br.	10/14/20 1002	10/22/20 1107	ND		ND		ND	
E8504	118	Shoal Creek u/s Baynham Br.	10/22/20 1107	10/29/20 1130	ND		ND		ND	
E8504D	118	Shoal Creek u/s Baynham Br.	10/22/20 1107	10/29/20 1130	ND		ND		ND	
E8661	118	Shoal Creek u/s Baynham Br.	10/29/20 1130	11/5/20 1200	ND		ND		ND	
E8661D	118	Shoal Creek u/s Baynham Br.	10/29/20 1130	11/5/20 1200	ND		ND		ND	
E8829	118	Shoal Creek u/s Baynham Br.	11/5/20 1200	11/12/20 0935	ND		ND		ND	
E8829D	118	Shoal Creek u/s Baynham Br.	11/5/20 1200	11/12/20 0935	ND		ND		ND	
E8949	118	Shoal Creek u/s Baynham Br.	11/12/20 1200	11/19/20 1156	ND		ND		ND	
E8949D	118	Shoal Creek u/s Baynham Br.	11/12/20 1200	11/19/20 1156	ND		ND		ND	
E9149	118	Shoal Creek u/s Baynham Br.	11/19/20 1156	12/1/20 1202	ND		ND		ND	
E9490	118	Shoal Creek u/s Baynham Br.	12/1/20 1202	12/21/20 0943	ND		ND		ND	
E7732	**120**	**Shoal Cr. d/s Hunley spring branch**	**10/1/20 1059**	**10/6/20 1325**	**ND**		**ND**		**ND**	

OUL	Station	Station Name	Date/Time	Date/Time	Fluorescein		Eosine		RWT	
Number	Number		Placed	Collected	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)
E7968	120	Shoal Cr. d/s Hunley spring branch	10/6/20 1325	10/14/20 1053	ND		539.8	0.995	570.0	6.47
E7968D	120	Shoal Cr. d/s Hunley spring branch	10/6/20 1325	10/14/20 1053	ND		539.2	0.590	569.2	4.95
E8284	120	Shoal Cr. d/s Hunley spring branch	10/14/20 1049	10/22/20 1220	ND		543.0	1.16	568.0	9.17
E8284D	120	Shoal Cr. d/s Hunley spring branch	10/14/20 1049	10/22/20 1220	ND		541.3	0.702	569.1	9.24
E8509	120	Shoal Cr. d/s Hunley spring branch	10/22/20 1220	10/29/20 1226	515.2	15.6	ND		566.6	7.93
E8509D	120	Shoal Cr. d/s Hunley spring branch	10/22/20 1220	10/29/20 1226	515.4	13.9	ND		567.6	5.63
E8662	120	Shoal Cr. d/s Hunley spring branch	10/29/20 1226	11/5/20 1030	515.4	1.47	ND		567.2 **	3.26
E8662D	120	Shoal Cr. d/s Hunley spring branch	10/29/20 1226	11/5/20 1030	514.8	1.54	ND		566.6 **	3.29
E8830	120	Shoal Cr. d/s Hunley spring branch	11/5/20 1030	11/12/20 1017	515.2 **	1.15	ND		570.6 **	6.60
E8830D	120	Shoal Cr. d/s Hunley spring branch	11/5/20 1030	11/12/20 1017	514.8 **	0.950	ND		570.6 **	3.55
E8950	120	Shoal Cr. d/s Hunley spring branch	11/12/20 1030	11/19/20 0900	515.4 **	0.720	ND		567.8 **	3.66
E8950D	120	Shoal Cr. d/s Hunley spring branch	11/12/20 1030	11/19/20 0900	512.6 **	0.725	ND		569.8	2.90
E9150	120	Shoal Cr. d/s Hunley spring branch	11/19/20 0900	12/1/20 0957	ND		ND		ND	
E9491	120	Shoal Cr. d/s Hunley spring branch	12/1/20 0957	12/21/20 1105	ND		ND		ND	
E9491D	120	Shoal Cr. d/s Hunley spring branch	12/1/20 0957	12/21/20 1105	ND		ND		ND	
E7733	**121**	**Carver Branch d/s Lime Kiln Rd**	**10/1/20 1210**	**10/6/20 1430**	**ND**		**ND**		**ND**	
E7969	121	Carver Branch d/s Lime Kiln Rd	10/6/20 1430	10/14/20 0816	ND		ND		ND	
E7969D	121	Carver Branch d/s Lime Kiln Rd	10/6/20 1430	10/14/20 0816	ND		ND		ND	
E8270	121	Carver Branch d/s Lime Kiln Rd	10/14/20 0816	10/22/20 0930	ND		ND		ND	
E8492	121	Carver Branch d/s Lime Kiln Rd	10/22/20 0844	10/29/20 0852	ND		ND		ND	
E8663	121	Carver Branch d/s Lime Kiln Rd	10/29/20 0852	11/5/20 0916	ND		ND		ND	
E8816	121	Carver Branch d/s Lime Kiln Rd	11/5/20 0916	11/12/20 0816	ND		ND		ND	
E8936	121	Carver Branch d/s Lime Kiln Rd	11/12/20 0816	11/19/20 0812	ND		ND		ND	
E9153	121	Carver Branch d/s Lime Kiln Rd	11/19/20 0812	12/1/20 0824	ND		541.4	1,170	ND	
E9494	121	Carver Branch d/s Lime Kiln Rd	12/1/20 0824	12/21/20 0818	ND		541.4	96.4	ND	
E8496	**122**	**Dockins dug well**	**10/6/20 1118**	**10/29/20 0949**	**ND**		**ND**		**ND**	
E7950	**123**	**Baynham Br. u/s dam site 2**	**10/6/20 1118**	**10/8/20 1040**	**ND**		**ND**		**ND**	
E7950D	123	Baynham Br. u/s dam site 2	10/6/20 1118	10/8/20 1040	ND		ND		ND	
E7970	123	Baynham Br. u/s dam site 2	10/8/20 1040	10/14/20 0918	ND		544.0	84.5	569.0	1,580
E7970D	123	Baynham Br. u/s dam site 2	10/8/20 1040	10/14/20 0918	ND		543.4	88.4	568.2	1,620
E8278	123	Baynham Br. u/s dam site 2	10/14/20 0918	10/22/20 1042	ND		542.6	31.5	567.6	277
E8278D	123	Baynham Br. u/s dam site 2	10/14/20 0918	10/22/20 1042	ND		542.6	23.9	567.9	191

OUL	Station	Station Name	Date/Time	Date/Time	Fluorescein		Eosine		RWT	
Number	Number		Placed	Collected	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)
E8501	123	Baynham Br. u/s dam site 2	10/22/20 1042	10/29/20 1022	515.2	15.0	543.4	3.00	567.3	21.3
E8501D	123	Baynham Br. u/s dam site 2	10/22/20 1042	10/29/20 1022	515.8	282	ND		567.6	47.7
E8664	123	Baynham Br. u/s dam site 2	10/29/20 1022	11/5/20 1358	515.9	9.33	540.9	8.75	566.9	35.1
E8664D	123	Baynham Br. u/s dam site 2	10/29/20 1022	11/5/20 1358	515.7	17.9	540.3	10.9	567.7	55.6
E8824	123	Baynham Br. u/s dam site 2	11/5/20 1358	11/12/20 0907	515.1	1.87	541.2	1.09	568.6	11.0
E8824D	123	Baynham Br. u/s dam site 2	11/5/20 1358	11/12/20 0907	515.0	2.90	541.3	1.88	568.3	17.1
E8944	123	Baynham Br. u/s dam site 2	11/12/20 1358	11/19/20 1112	513.8	0.955	541.9	1.65	567.9	8.48
E8944D	123	Baynham Br. u/s dam site 2	11/12/20 1358	11/19/20 1112	516.2	1.56	542.2	3.07	568.0	16.7
E9142	123	Baynham Br. u/s dam site 2	11/19/20 1112	12/1/20 1122	516.4	1.29	541.0	5.88	567.6	14.5
E9484	123	Baynham Br. u/s dam site 2	12/1/20 1122	12/21/20 0911	514.6	0.756	541.2	5.54	567.2	11.8
E8507	**125**	**Spring d/s Hunley lake outflow**	**10/22/20 1211**	**10/29/20 1217**	**515.1**	**67.3**	**ND**		**567.8**	**345**
E8507D	125	Spring d/s Hunley lake outflow	10/22/20 1211	10/29/20 1217	515.5	52.9	ND		567.4	227
E8665	125	Spring d/s Hunley lake outflow	10/29/20 1217	11/5/20 0946	515.3	51.5	ND		567.5	209
E8665D	125	Spring d/s Hunley lake outflow	10/29/20 1217	11/5/20 0946	515.5	44.7	ND		567.7	186
E8831	125	Spring d/s Hunley lake outflow	11/5/20 0946	11/12/20 1003	517.2	1.01	ND		567.6	119
E8831D	125	Spring d/s Hunley lake outflow	11/5/20 0946	11/12/20 1003	517.2	1.05	ND		568.0	130
E8951	125	Spring d/s Hunley lake outflow	11/12/20 1003	11/19/20 0834	516.8	0.756	ND		566.6	72.7
E8951D	125	Spring d/s Hunley lake outflow	11/12/20 1003	11/19/20 0834	517.2	0.760	ND		567.8	77.6
E9151	125	Spring d/s Hunley lake outflow	11/19/20 0834	12/1/20 0931	516.8	0.994	543.4 **	3.30	568.0	71.7
E9492	125	Spring d/s Hunley lake outflow	12/1/20 0931	12/21/20 1013	ND		ND		566.6	34.6
E8510	**126**	**Shoal Cr. b/w Baynham Br. & Hunley Spr. Br.**	**10/22/20 1250**	**10/29/20 1233**	**ND**		**ND**		**ND**	
E8510D	126	Shoal Cr. b/w Baynham Br. & Hunley Spr. Br.	10/22/20 1250	10/29/20 1233	ND		ND		ND	
E8666	126	Shoal Cr. b/w Baynham Br. & Hunley Spr. Br.	10/29/20 1233	11/5/20 1041	ND		ND		ND	
E8666D	126	Shoal Cr. b/w Baynham Br. & Hunley Spr. Br.	10/29/20 1233	11/5/20 1041	ND		ND		ND	
E8832	126	Shoal Cr. b/w Baynham Br. & Hunley Spr. Br.	11/5/20 1041	11/12/20 1025	ND		ND		ND	
E8832D	126	Shoal Cr. b/w Baynham Br. & Hunley Spr. Br.	11/5/20 1041	11/12/20 1025	ND		ND		ND	
E8952	126	Shoal Cr. b/w Baynham Br. & Hunley Spr. Br.	11/12/20 1025	11/19/20 0907	ND		ND		ND	
E8952D	126	Shoal Cr. b/w Baynham Br. & Hunley Spr. Br.	11/12/20 1025	11/19/20 0907	ND		ND		ND	
E9152	126	Shoal Cr. b/w Baynham Br. & Hunley Spr. Br.	11/19/20 0907	12/1/20 1003	ND		ND		ND	
E9493	126	Shoal Cr. b/w Baynham Br. & Hunley Spr. Br	12/1/20 1003	12/21/20 1113	ND		ND		ND	

Table 2. Results for water samples analyzed for the presence of fluorescein, eosine and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

OUL	Station	Station Name	Date/Time	Fluorescein		Eosine		RWT	
Number	Number		Collected	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)
E8048	**104**	**Baynham Br. u/s Carver Rd**	**10/14/20 1155**	**ND**		**534.5**	**0.964**	**ND**	
E8332	104	Baynham Br. u/s Carver Rd	10/22/20 0844	ND		534.2	1.01	ND	
E8571	104	Baynham Br. u/s Carver Rd	10/29/20 0808	ND		533.4	0.636	ND	
E8716	104	Baynham Br. u/s Carver Rd	11/5/20 0841	ND		534.2	0.167	ND	
E9179	**105**	**Baynham Br. d/s Marten Rd**	**12/1/20 1306**	**ND**		**ND**		**ND**	
E8049	**106**	**Baynham Br. d/s Henson Spring**	**10/14/20 0833**	**ND**		**534.8**	**1.87**	**573.9**	**1.99**
E8334	106	Baynham Br. d/s Henson Spring	10/22/20 0940	ND		534.4	0.458	574.4	0.508
E8573	106	Baynham Br. d/s Henson Spring	10/29/20 0905	ND		534.0	0.321	574.2	0.190
E8717	106	Baynham Br. d/s Henson Spring	11/5/20 1110	ND		535.0	0.042	ND	
E8962	106	Baynham Br. d/s Henson Spring	11/12/20 0828	ND		533.3	0.216	571.2 (1)	0.056
E9017	106	Baynham Br. d/s Henson Spring	11/19/20 1002	ND		533.6	0.095	ND	
E9164	106	Baynham Br. d/s Henson Spring	12/1/20 1044	ND		ND		ND	
E9495	106	Baynham Br. d/s Henson Spring	12/21/20 0829	ND		ND		ND	
E8050	**108**	**Baynham Br. u/s Lime Kiln Rd**	**10/14/20 0839**	**ND**		**534.6**	**2.07**	**573.7**	**3.19**
E8335	108	Baynham Br. u/s Lime Kiln Rd	10/22/20 0951	ND		535.4	0.460	574.4	0.732
E8574	108	Baynham Br. u/s Lime Kiln Rd	10/29/20 0926	ND		533.8	0.288	575.5	0.185
E8718	108	Baynham Br. u/s Lime Kiln Rd	11/5/20 1140	ND		535.7	0.076	572.8	0.081
E8885	108	Baynham Br. u/s Lime Kiln Rd	11/12/20 0835	ND		534.4	0.068	ND	
E9018	108	Baynham Br. u/s Lime Kiln Rd	11/19/20 1009	ND		ND		ND	
E9165	108	Baynham Br. u/s Lime Kiln Rd	12/1/20 1052	ND		ND		ND	
E9496	108	Baynham Br. u/s Lime Kiln Rd	12/21/20 0841	ND		ND		ND	
E8051	**109**	**Parks Spring #1 (upstream)**	**10/14/20 0852**	**ND**		**534.9**	**1.89**	**573.5**	**3.21**
E8336	109	Parks Spring #1 (upstream)	10/22/20 1020	ND		533.8	0.531	574.0	0.805
E8575	109	Parks Spring #1 (upstream)	10/29/20 1002	509.4	0.075	533.4	0.270	575.1	0.264
E8719	109	Parks Spring #1 (upstream)	11/5/20 1304	ND		ND		572.2	0.178
E8886	109	Parks Spring #1 (upstream)	11/12/20 0857	ND		533.4	0.104	ND	
E9019	109	Parks Spring #1 (upstream)	11/19/20 1100	ND		536.4 (1)	0.061	574.2 (1)	0.046
E9019R	109	Parks Spring #1 (upstream)	11/19/20 1100	ND		534.4 (1)	0.045	ND	
E9166	109	Parks Spring #1 (upstream)	12/1/20 1109	ND		ND		ND	
E9497	109	Parks Spring #1 (upstream)	12/21/20 0859	ND		ND		ND	
E8052	**110**	**Parks Spring #2 (downstream)**	**10/14/20 0859**	**ND**		**534.6**	**1.83**	**574.0**	**3.70**

OUL	Station	Station Name	Date/Time	Fluorescein		Eosine		RWT	
Number	Number		Collected	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)
E8337	110	Parks Spring #2 (downstream)	10/22/20 1025	ND		534.8	0.386	573.7	0.880
E8576	110	Parks Spring #2 (downstream)	10/29/20 0957	508.7	0.085	533.7	0.276	573.0	0.287
E8721	110	Parks Spring #2 (downstream)	11/5/20 1300	ND		ND		ND	
E8887	110	Parks Spring #2 (downstream)	11/12/20 0845	ND		534.6	0.089	576.2 (1)	0.068
E9021	110	Parks Spring #2 (downstream)	11/19/20 1042	ND		535.0 (1)	0.052	574.6 (1)	0.033
E9167	110	Parks Spring #2 (downstream)	12/1/20 1101	ND		ND		ND	
E9498	110	Parks Spring #2 (downstream)	12/21/20 0853	ND		ND		ND	
E8053	**111**	**Baynham Br. u/s dam site 1**	**10/14/20 0908**	**ND**		**535.0**	**1.75**	**574.1**	**4.24**
E8338	111	Baynham Br. u/s dam site 1	10/22/20 1034	ND		534.8	0.381	574.2	0.995
E8577	111	Baynham Br. u/s dam site 1	10/29/20 1015	508.7	0.106	533.6	0.278	573.5	0.302
E8722	111	Baynham Br. u/s dam site 1	11/5/20 1330	ND		ND		576.0	0.154
E8888	111	Baynham Br. u/s dam site 1	11/12/20 0900	ND		535.6	0.053	ND	
E9022	111	Baynham Br. u/s dam site 1	11/19/20 1108	ND		532.6 (1)	0.058	574.8 (1)	0.048
E9168	111	Baynham Br. u/s dam site 1	12/1/20 1116	ND		ND		ND	
E9499	111	Baynham Br. u/s dam site 1	12/21/20 0908	ND		ND		ND	
E8054	**112**	**Baynham Br. u/s dam site 3**	**10/14/20 0927**	**ND**		**535.8**	**1.26**	**573.9**	**4.09**
E8339	112	Baynham Br. u/s dam site 3	10/22/20 1045	ND		535.0	0.336	574.2	0.972
E8579	112	Baynham Br. u/s dam site 3	10/29/20 1031	508.7	0.154	532.5	0.256	574.7	0.358
E8723	112	Baynham Br. u/s dam site 3	11/5/20 1352	510.4 (1)		ND		576.3	0.180
E8889	112	Baynham Br. u/s dam site 3	11/12/20 1913	ND		ND		575.8 (1)	0.144
E9023	112	Baynham Br. u/s dam site 3	11/19/20 1119	ND		ND		573.2	0.081
E9170	112	Baynham Br. u/s dam site 3	12/1/20 1125	ND		ND		ND	
E9502	112	Baynham Br. u/s dam site 3	12/21/20 0917	ND		ND		ND	
E8342	**113**	**Baynham Br. @ RR Bridge**	**10/22/20 1059**	**ND**		**ND**		**ND**	
E8581	113	Baynham Br. @ RR Bridge	10/29/20 1110	507.0	0.046	ND		ND	
E8724	113	Baynham Br. @ RR Bridge	11/5/20 1207	ND		ND		ND	
E9025	113	Baynham Br. @ RR Bridge	11/19/20 1139	ND		ND		ND	
E9171	113	Baynham Br. @ RR Bridge	12/1/20 1150	ND		ND		ND	
E9503	113	Baynham Br. @ RR Bridge	12/21/20 0936	ND		ND		ND	
E8055	**114**	**Hunley spring br. @ RR bridge**	**10/14/20 1049**	**ND**		**ND**		**ND**	
E8346	114	Hunley spring br. @ RR bridge	10/22/20 1230	ND		ND		574.2	0.795
E8587	114	Hunley spring br. @ RR bridge	10/29/20 1220	507.6	0.495	ND		574.3	0.466
E8725	114	Hunley spring br. @ RR bridge	11/5/20 1005	ND		ND		573.5	0.177

OUL	Station	Station Name	Date/Time	Fluorescein		Eosine		RWT	
Number	Number		Collected	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)
E8891	114	Hunley spring br. @ RR bridge	11/12/20 1010	ND		ND		574.5	0.114
E9026	114	Hunley spring br. @ RR bridge	11/19/20 0844	ND		ND		572.4	0.070
E9174	114	Hunley spring br @ RR Bridge	12/1/20 0937	ND		ND		ND	
E9506	114	Hunley spring br @ RR Bridge	12/21/20 1048	ND		ND		ND	
E8056	**115**	**Spring Flow u/g of Hunley spr lake**	**10/14/20 1037**	**ND**		**535.5**	**0.182**	**574.0**	**0.631**
E8343	115	Spring Flow u/g of Hunley spr lake	10/22/20 1140	ND		536.4	0.085	574.6	0.212
E8584	115	Spring Flow u/g of Hunley spr lake	10/29/20 1202	507.5	0.859	ND		572.2	0.066
E8726	115	Spring Flow u/g of Hunley spr lake	11/5/20 0937	507.5	0.387	ND		ND	
E8892	115	Spring Flow u/g of Hunley spr lake	11/12/20 0959	507.6	0.212	ND		ND	
E9027	115	Spring Flow u/g of Hunley spr lake	11/19/20 0824	507.8	0.117	ND		ND	
E9173	115	Spring Flow u/g of Hunley spr lake	12/1/20 0842	508.9	0.043	ND		ND	
E9505	115	Spring Flow u/g of Hunley spr lake	12/21/20 1008	507.0	0.016	ND		ND	
E8057	**116**	**Hunley spring lake outflow**	**10/14/20 1040**	**ND**		**537.0**	**0.539**	**573.8**	**3.38**
E8344	116	Hunley spring lake outflow	10/22/20 1204	ND		ND		573.2	0.781
E8585	116	Hunley spring lake outflow	10/29/20 1212	507.4	0.508	ND		574.0	0.514
E8727	116	Hunley spring lake outflow	11/5/20 0959	ND		ND		573.8	0.252
E8893	116	Hunley spring lake outflow	11/12/20 1005	ND		ND		573.8	0.199
E9028	116	Hunley spring lake outflow	11/19/20 0841	ND		ND		574.8	0.087
E9175	116	Hunley spring lake outflow	12/1/20 0928	ND		ND		ND	
E9507	116	Hunley spring lake outflow	12/21/20 1023	ND		ND		ND	
E8058	**118**	**Shoal Cr. u/s Baynham Br.**	**10/14/20 1002**	**ND**		**ND**		**ND**	
E9176	118	Shoal Cr. u/s Baynham Br.	12/1/20 1202	ND		ND		ND	
E8059	**120**	**Shoal Cr. d/s Hunley Spring Branch**	**10/14/20 1053**	**ND**		**ND**		**ND**	
E8345	120	Shoal Cr. d/s Hunley Spring Branch	10/22/20 1220	ND		ND		ND	
E8588	120	Shoal Cr. d/s Hunley Spring Branch	10/29/20 1226	506.6	0.020	ND		ND	
E8728	120	Shoal Cr. d/s Hunley Spring Branch	11/5/20 1030	ND		ND		ND	
E9029	120	Shoal Cr. d/s Hunley Spring Branch	11/19/20 0900	ND		ND		ND	
E9178	**121**	**Carver Br. d/s Lime Kiln Rd**	**12/1/20 0824**	**ND**		**534.4**	**0.836**	**ND**	
E9509	121	Carver Br. d/s Lime Kiln Rd	12/21/20 0818	ND		535.0	0.292	ND	
E8061	**123**	**Baynham Br. u/s dam site 2**	**10/14/20 0918**	**ND**		**534.8**	**1.27**	**574.2**	**4.36**
E8341	123	Baynham Br. u/s dam site 2	10/22/20 1042	ND		534.0	0.294	574.2	1.05
E8578	123	Baynham Br. u/s dam site 2	10/29/20 1022	508.9	0.143	533.3	0.255	572.6	0.316
E8729	123	Baynham Br. u/s dam site 2	11/5/20 1358	509.4	0.022	ND		575.0	0.173

OUL Number	Station Number	Station Name	Date/Time Collected	Fluorescein		Eosine		RWT	
				Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)	Peak (nm)	Conc (ppb)
E8890	123	Baynham Br. u/s dam site 2	11/12/20 0907	ND		534.7	0.053	574.0	0.116
E9024	123	Baynham Br. u/s dam site 2	11/19/20 1112	ND		533.2	0.046	574.2 (1)	0.051
E9169	123	Baynham Br. u/s dam site 2	12/1/20 1122	ND		ND		ND	
E9501	123	Baynham Br. u/s dam site 2	12/21/20 0911	ND		ND		ND	
E8062	**124**	**Gary Dug Well**	**10/14/20 1140**	**ND**		**ND**		**574.6**	**16,700**
E8333	124	Gary Dug Well	10/22/20 0905	ND		ND		574.5	1,530
E8572	124	Gary Dug Well	10/29/20 0830	ND		ND		574.2	1,080
E8730	124	Gary Dug Well	11/5/20 0857	ND		ND		574.1	46.4
E8348	**125**	**Spring d/s Hunley lake outflow**	**10/22/20 1211**	**ND**		**ND**		**573.8**	**0.781**
E8586	125	Spring d/s Hunley lake outflow	10/29/20 1217	507.5	0.507	ND		573.6	0.525
E8731	125	Spring d/s Hunley lake outflow	11/5/20 0946	ND		ND		573.6	0.221
E8894	125	Spring d/s Hunley lake outflow	11/12/20 1003	ND		ND		572.5	0.151
E9030	125	Spring d/s Hunley lake outflow	11/19/20 0834	ND		ND		572.6	0.084
E9177	125	Spring d/s Hunley lake outflow	12/1/20 0931	ND		ND		ND	
E9508	125	Spring d/s Hunley lake outflow	12/21/20 1013	ND		ND		ND	
E8347	**126**	**Shoal Cr. b/w Baynham Br. & Hunley Spr. Br.**	**10/22/20 1250**	**ND**		**ND**		**ND**	
E8582	**127**	**Spring u/s RR on Baynham Br**	**10/29/20 1112**	**ND**		**ND**		**ND**	
E8732	127	Spring u/s RR on Baynham Br	11/5/20 1223	ND		ND		ND	
E8963	127	Spring u/s RR on Baynham Br	11/12/20 0929	ND		ND		ND	
E9031	127	Spring u/s RR on Baynham Br	11/19/20 1135	ND		ND		ND	
E8583	**128**	**Powerline Spring**	**10/29/20 1153**	**ND**		**ND**		**ND**	
E8733	128	Powerline Spring	11/5/20 0930	ND		ND		ND	
E9172	128	Powerline Spring	12/1/20 0838	ND		ND		ND	
E9504	128	Powerline Spring	12/21/20 1002	ND		ND		ND	

Footnotes:

ND = No dye detected

NT = No time given

NDT = No date or time given

* = A fluorescence peak is present that does not meet all the criteria for a positive dye result. However, it has been calculated as though it was the tracer dye.

** = A fluorescence peak is present that does not meet all the criteria for this dye. However, it has been calculated as a positive dye result.

(1) = A fluorescence peak is present that does not meet all the criteria for this dye. However, it has been calculated as a positive dye result because dye

is present in the corresponding charcoal sampler.

Appendix C.

Ozark Underground Laboratory, Inc.

Procedures and Criteria Analysis of Fluorescent Dyes in Water and Charcoal Samplers:

Fluorescein, Eosine, Rhodamine WT and Sulphorhodamine B Dyes

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PROCEDURES AND CRITERIA

ANALYSIS OF FLUORESCENT

DYES

IN WATER AND CHARCOAL SAMPLERS:

FLUORESCEIN, EOSINE, RHODAMINE WT, AND SULFORHODAMINE B DYES

Revision Dates:
March 3, 2015
Pages A-14 to A-18 corrected to match Table 4 on **December 27, 2018**

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INTRODUCTION

This document describes standard procedures and criteria currently in use at the Ozark Underground Laboratory (OUL) as of the date shown on the title page. Some samples may be subjected to different procedures and criteria because of unique conditions; such non-standard procedures and criteria are identified in reports for those samples. Standard procedures and criteria change as knowledge and experience increases and as equipment is improved or up-graded. The OUL maintains a summary of changes in standard procedures and criteria.

TRACER DYES AND SAMPLE TYPES

Dye Nomenclature

Dye manufacturers and retailers use a myriad of names for the dyes. This causes confusion among dye users and report readers. The primary dyes used at the OUL and described in this document are included in Table 1 below.

Table 1. Primary OUL Dye Nomenclature.

OUL Common Name	Color Index Number	Color Index Name	Other Names
Fluorescein	45350	Acid Yellow 73	uranine, uranine C, sodium fluorescein, fluorescein LT and fluorescent yellow/green
Eosine	45380	Acid Red 87	eosin, eosine OJ, and D&C Red 22
Rhodamine WT	None assigned	Acid Red 388	fluorescent red (but not the same as rhodamine B)
Sulforhodamine B	45100	Acid Red 52	pontacyl brilliant pink B, lissamine red 4B, and fluoro brilliant pink

The OUL routinely provides dye for tracing projects. Dyes purchased for groundwater tracing are always mixtures that contain both dye and an associated diluent. Diluents enable the manufacturer to standardize the dye mixture so that there are minimal differences among batches. Additionally, diluents are often designed to make it easier to dissolve the dye mixture in water, or to produce a product which meets a particular market need (groundwater tracing is only a tiny fraction of the dye market). The percent of dye in “as-sold” dye mixtures often varies dramatically among manufacturers and retailers, and retailers are sometimes incorrect about the percent of dye in their products. The OUL subjects all of its dyes to strict quality control (QC) testing. Table 2 summarizes the as-sold dye mixtures used by the OUL.

Table 2. As-Sold Dye Mixtures at the OUL.

OUL Common Name	Form	Dye Equivalent
Fluorescein	Powder	75% dye equivalent, 25% diluent
Eosine	Powder	75% dye equivalent, 25% diluent
Rhodamine WT	Liquid	20% dye equivalent, 80% diluent
Sulforhodamine B	Powder	75% dye equivalent, 25% diluent

Analytical results are based on the as-sold weights of the dyes provided by the OUL. The use of dyes from other sources is discouraged due to the wide variability of dye equivalents within the market. However, if alternate source dyes are used, a sample should be provided to the OUL for quality control and to determine if a correction factor is necessary for the analytical results.

Types of Samples

Typical samples that are collected for fluorescent tracer dye analysis include charcoal samplers (also called activated carbon or charcoal packets) and water samples.

The charcoal samplers are packets of fiberglass screening partially filled with 4.25 grams of activated coconut charcoal. The charcoal used by the OUL is Calgon 207C coconut shell carbon, 6 to 12 mesh, or equivalent. The most commonly used charcoal samplers are about 4 inches long by 2 inches wide. A cigar-shaped sampler is made for use in very small diameter wells (such as 1-inch diameter piezometers); this is a special order item and should be specifically requested in advance when needed. All of the samplers are closed by heat sealing.

In specialized projects, soil samples have been collected from soil cores and analyzed for fluorescent tracer dyes. Project-specific procedures have been developed for projects such as these. For additional information, please contact the OUL.

FIELD PROCEDURES

Field procedures included in this section are intended as guidance, and not firm requirements. Placement of samplers and other field procedures require adjustment to field conditions. Personnel at the OUL are available to provide additional assistance for implementation of field procedures specific to specialized field conditions.

Placement of Samplers

Charcoal samplers are placed so as to be exposed to as much water as possible. Water should flow through the packet. In springs and streams they are typically attached to a rock or other anchor in a riffle area. Attachment of the packets often uses plastic tie wires. In swifter water galvanized wire (such as electric fence wire) is often used. Other types of anchoring wire can be used. Electrical wire with plastic insulation is also good. Packets are attached so that they extend outward from the anchor rather than laying flat against it. Two or more separately anchored packets are typically used for sampling springs and streams. The placement of multiple packets is recommended in order to minimize the chance of loss during the sampling period. The use of fewer packets is discouraged except when the spring or stream is so small that there is not appropriate space for placing multiple packets.

When pumping wells are being sampled, the samplers are typically placed in sample holders made of plastic pipe fittings. Brass hose fittings can be at the end of the sample holders so that the sample holders can be installed on outside hose bibs and water which has run through the samplers can be directed to waste through a connected garden hose. The samplers can be unscrewed in the middle so that charcoal packets can be changed. The middle portions of the samplers consist of 1.5 inch diameter pipe and pipe fitting.

Charcoal packets can be lowered into monitoring wells for sampling purposes. In general, if the well is screened, samplers should be placed approximately in the middle of the screened interval. Due to the typically lower volume of water that flows through a well, only one charcoal sampler should be used per well. However, multiple packets can be placed in a single well at depths to test different depth horizons when desirable. A weight should be added near the charcoal packet to ensure that it will not float. The weight should be of such a nature that it will not affect water quality. One common approach is to anchor the packets with a white or uncolored plastic cable tie to the top of a dedicated weighted disposable bailer. We typically run nylon cord from the top of the well to the charcoal packet and its weight. ***Do not use colored cord*** since some of them are colored with fluorescent dyes. Nylon fishing line should not be used since it can be readily cut by a sharp projection in the well.

In some cases, especially with small diameter wells and appreciable well depths, the weighted disposable bailers sink very slowly or may even fail to sink because of friction and floating of the anchoring cord. In such cases a weight may be added to the top of the disposable bailer. Stainless steel weights are ideal, but are not needed in all cases. All weights should be cleaned prior to use; the cleaning approach should comply with decontamination procedures in use at the project site.

Optional Preparation of Charcoal Samplers

Charcoal packets routinely contain some fine powder that washes off rapidly when they are placed in water. While not usually necessary, the following optional preparation step is suggested if the fine charcoal powder is problematic.

Charcoal packets can be triple rinsed with distilled, demineralized, or reagent water known to be free of tracer dyes. This rinsing is typically done by soaking. With this approach, approximately 25 packets are placed in one gallon of water and soaked for at least 10 minutes. The packets are then removed from the water and excess water is shaken off the packets. The packets are then placed in a second gallon of water and again soaked for at least 10 minutes. After this soaking they are removed from the water and excess water is shaken off the packets. The packets are then placed in a third gallon of water and the procedure is again repeated. Rinsed packets are placed in plastic bags and are placed at sampling stations within three days. Packets can also be rinsed in jets of water for about one minute; this requires more water and is typically difficult to do in the field with water known to be free of tracer dyes.

Collection and Replacement of Samplers

Samplers are routinely collected and replaced at each of the sampling stations. The frequency of sampler collection and replacement is determined by the nature of the study. Collections at one week intervals are common, but shorter or longer collection frequencies are acceptable and sometimes more appropriate. Shorter sampling frequencies are often used in the early phases of a study to better characterize time of travel. As an illustration, we often collect and change charcoal packets 1, 2, 4, and 7 days after dye injection. Subsequent sampling is then weekly.

The sampling interval in wells at hazardous wastes sites should generally be no longer than about a week. Contaminants in the water can sometimes use up sorption sites on the charcoal that would otherwise adsorb the dye. This is especially important if the dye might pass in a relatively short duration pulse.

Where convenient, the collected samplers should be briefly rinsed in the water being sampled to remove dirt and accumulated organic material. This is not necessary with well samples. The packets are shaken to remove excess water. Next, the packet (or packets) are placed in a plastic bag (Whirl-Pak® bags are ideal). The bag is labeled on the outside with a black permanent type felt marker pen, such as a Sharpie®. ***Use only pens that have black ink***; colored inks may contain fluorescent dyes. The notations include station name or number and the date and time of collection. Labels must not be inserted inside the sample bags.

Collected samplers are kept in the dark to minimize algal growth on the charcoal prior to analysis work. New charcoal samplers are routinely placed when used charcoal packets are collected. The last set of samplers placed at a stream or spring is commonly not collected.

Water Samples

Water samples are often collected. They should be collected in either glass or plastic; the OUL routinely uses 50 milliliter (mL) research-grade polypropylene copolymer Perfector Scientific vials (Catalog Number 2650) for such water samples. No more than 30 mL of water is required for analysis. The sides of the vials should be labeled with the project name, sample ID, sample date and time with a black permanent felt tip pen. ***Do not label the lid only***. The vials should be placed in the dark and refrigerated immediately after collection, and maintained under refrigeration until shipment. The OUL supplies vials for the collection of water samples.

Sample Shipment

When water or charcoal samplers are collected for shipment to the OUL they should be shipped promptly. We prefer (and in some studies require) that samples be refrigerated with frozen re-usable ice packs upon collection and that they be shipped refrigerated with frozen ice packs by overnight express. ***Do not ship samplers packed in wet ice*** since this can create a potential for cross contamination when the ice melts. Our experience indicates that it is not essential for samplers to be maintained under refrigeration; yet maintaining them under refrigeration clearly minimizes some potential problems. A product known as "green ice" should not be used for maintaining the samples in a refrigerated condition since this product contains a dye which could contaminate samples if the "green ice" container were to break or leak.

We receive good overnight and second day air service from both UPS and FedEx. The U.S. Postal Service does not typically provide next day service to us. DHL does not provide overnight service to us. FedEx is recommended for international shipments. The OUL does not receive Saturday delivery.

Each shipment of charcoal samplers or water samples ***must be accompanied by a sample custody document***. The OUL provides a sheet (which bears the title "Samples for Fluorescence Analysis") that can be used if desired. These sheets can be augmented by a client's chain-of-custody forms or any other relevant documentation. OUL's custody document works well for charcoal samplers because it allows for both the placement date and time as well as the collection date and time. Many other standard chain-of-custody documents do not allow for these types of samples. Attachment 1 includes a copy of OUL's Sample Collection Data Sheet.

Please write legibly on the custody documents and ***use black ink***. Check the accuracy of the sample sheet against the samples prior to shipment to identify and correct errors that may delay the analysis of your samples following receipt at the laboratory.

Supplies Provided by the OUL

The OUL provides supplies for the collection of fluorescent tracer dyes. Supplies provided upon request are charcoal packets, Whirl-Pak® bags (to contain the charcoal packets after collection for shipment to the laboratory), and water vials. These supplies are subjected to strict QA/QC procedures to ensure the materials are free of any potential tracer dye contaminants. The charge for these materials is included in the cost of sample analysis. Upon request, coolers and re-freezable ice packs are also provided for return shipment of samples.

The OUL also has tracer dyes available for purchase. These dyes are subject to strict QA/QC testing. All analytical work is based upon the OUL as-sold weight of the dyes.

LABORATORY PROCEDURES

The following procedures are followed upon receipt of samples at the laboratory.

Receipt of Samples

Samplers shipped to the OUL are logged in and refrigerated upon receipt. Prior to cleaning and analysis, samplers are assigned a laboratory identification number.

It sometimes occurs that there are discrepancies between the sample collection data sheet and the actual samples received. When this occurs, a "Discrepancy Sheet" form is completed and sent to the shipper of the sample for resolution. The purpose of the form is to help resolve discrepancies, even when they may be minor. Many discrepancies arise from illegible custody documents. ***Please write legibly*** on the custody documents and ***use black ink***. Check the accuracy of the sample sheet against the samples prior to shipment to identify and correct errors that may delay the analysis of your samples following receipt at the laboratory.

Cleaning of Charcoal Samplers

Samplers are cleaned by spraying them with jets of clean water from a laboratory well in a carbonate aquifer. OUL uses non-chlorinated water for the cleansing to minimize dye deterioration. We do not wash samplers in public water supplies. Effective cleansing cannot generally be accomplished simply by washing in a conventional laboratory sink even if the sink is equipped with a spray unit.

The duration of packet washing depends upon the condition of the sampler. Very clean samplers may require less than a minute of washing; dirtier samplers may require several minutes of washing.

Elution of the Charcoal

There are various eluting solutions that can be used for the recovery of tracer dyes. The solutions typically include an alcohol, water, and a strong basic solution such as aqueous ammonia and /or potassium hydroxide.

The standard elution solution used at the OUL is a mixture of 5% aqua ammonia and 95% isopropyl alcohol solution and sufficient potassium hydroxide pellets to saturate the solution.
The isopropyl alcohol solution is 70% alcohol and 30% water. The aqua ammonia solution is 29% ammonia. The potassium hydroxide is added until a super-saturated layer is visible in the bottom of the container. This super-saturated layer is not used for elution. Preparation of eluting solutions uses dedicated glassware which is never used in contact with dyes or dye solutions.

The eluting solution will elute fluorescein, eosine, rhodamine WT, and sulforhodamine B dyes. It is also suitable for separating fluorescein peaks from peaks of some naturally present materials found in samplers.

Fifteen mL of the eluting solution is poured over the washed charcoal in a disposable sample beaker. The sample beaker is capped. The sample is allowed to stand for 60 minutes. After this time, the liquid is carefully poured off the charcoal into a new disposable beaker which has been appropriately labeled with the laboratory identification number. A few grains of charcoal may inadvertently pass into the second beaker; no attempt is made to remove these from the second sample beaker. After the pouring, a small amount of the elutant will remain in the initial sample beaker. After the transfer of the elutant to the second sample beaker, the contents of the first sample beaker (the eluted charcoal) are discarded. Samples are kept refrigerated until analyzed.

pH Adjustment of Water Samples

The fluorescence intensity of several of the commonly used fluorescent tracer dyes is pH dependent. The pH of samples analyzed for fluorescein, eosine, and pyranine dyes are adjust to a target pH of greater than 9.5 in order to obtain maximum fluorescence intensities.

Adjustment of pH is achieved by placing samples in a high ammonia atmosphere for at least two hours in order to increase the pH of the sample. Reagent water standards are placed in the same atmosphere as the samples. If dye concentrations in a sample are off-scale and require dilution for quantification of the dye concentration, the diluting water used is OUL reagent water that has been pH adjusted in a high ammonia atmosphere. Samples that are only analyzed for rhodamine WT or sulforhodamine B are not required to be pH adjusted.

Analysis on the Shimadzu RF-5301

The OUL uses a Shimadzu spectrofluorophotometer model RF-5301. This instrument is capable of synchronous scanning. The OUL also owns a Shimadzu RF-540 spectrofluorometers that is occasionally used for special purposes.

A sample of the elutant or water is withdrawn from the sample container using a disposable polyethylene pipette. Approximately3 mL of the sample is then placed in disposable rectangular polystyrene cuvette. The cuvette has a maximum capacity of 3.5 mL. The cuvette is designed for fluorometric analysis; all four sides and the bottom are clear. The acceptable spectral range of these cuvettes is 340 to 800 nm. The pipettes and cuvettes are discarded after one use.

The cuvette is then placed in the RF-5301. This instrument is controlled by a programmable computer and operated by proprietary software developed for dye tracing applications.

Our instruments are operated and maintained in accordance with the manufacturer's recommendations. On-site installation of our first instrument and a training session on its use was provided by the instrument supplier. Repairs are made by a Shimadzu-authorized repairman.

Our typical analysis of an elutant sample where fluorescein, eosine, rhodamine WT, or sulforhodamine B dyes may be present includes synchronous scanning of excitation and emission spectra with a 17 nm separation between excitation and emission wavelengths. For these dyes, the excitation scan is from 443 to 613 nm; the emission scan is from 460 to 630 nm. The emission fluorescence from the scan is plotted on a graph. The typical scan speed setting is “fast” on the RF-5301. The typical sensitivity setting used is "high."

Table 3. Excitation and emission slit width settings routinely used for dye analysis.

Parameter	**Excitation Slit (nm)**	**Emission Slit (nm)**
ES, FL, RWT, and SRB in elutant	3	1.5
ES, FL, RWT, and SRB in water	5	3

Note: ES = Eosine. FL = Fluorescein. RWT = Rhodamine WT. SRB = Sulforhodamine B.

The instrument produces a plot of the synchronous scan for each sample; the plot shows emission fluorescence only. The synchronous scans are subjected to computer peak picks using proprietary software; peaks are picked to the nearest 0.1 nm. Instrument operators have the ability to manually adjust peaks as necessary based upon computer-picked peaks and experience. All samples run on the RF-5301 are stored electronically with sample information. All samples analyzed are recorded in a bound journal.

Quantification

We calculate the magnitude of fluorescence peaks for fluorescein, eosine, rhodamine WT, and sulforhodamine B dyes in both elutant and water samples. Dye quantities are expressed in microgram per liter (parts per billion; ppb). The dye concentrations are calculated by separating fluorescence peaks due to dyes from background fluorescence on the charts, and then calculating the area within the fluorescence peak. This area is proportional to areas obtained from standard solutions.

We run dye concentration standards each day the RF-5301 is used. Six standards are used; the standard or standards appropriate for the analysis work being conducted are selected. All standards are based upon the as-sold weights of the dyes. The standards are as follows:

1) 10 ppb fluorescein and 100 ppb rhodamine WT in well water from the Jefferson City-Cotter Formation
2) 10 ppb eosine in well water from the Jefferson City-Cotter Formation
3) 100 ppb sulforhodamine B in well water from the Jefferson City-Cotter Formation.
4) 10 ppb fluorescein and 100 ppb rhodamine WT in elutant.
5) 10 ppb eosine in elutant.
6) 100 ppb sulforhodamine B in elutant.

Preparation of Standards

Dye standards are prepared as follows:

Step 1. A small sample of the as-sold dye is placed in a pre-weighed sample vial and the vial is again weighed to determine the weight of the dye. We attempt to use a sample weighing between 1 and 5 grams. This sample is then diluted with well water to make a 1% dye solution by weight (based upon the as-sold weight of the dye). The resulting dye solution is allowed to sit for at least four hours to ensure that all dye is fully dissolved.

Step 2. One part of each dye solution from Step 1 is placed in a mixing container with 99 parts of well water. Separate mixtures are made for fluorescein, rhodamine WT, eosine, and sulforhodamine B. The resulting solutions contain 100 mg/L dye (100 parts per million dye mixture). The typical prepared volume of this mixture is appropriate for the sample bottles being used; we commonly prepare about 50 mL of the Step 2 solutions. The dye solution from Step 1 that is used in making the Step 2 solution is withdrawn with a digital Finnpipette which is capable of measuring volumes between 0.200 and 1.000 mL at intervals of 0.005 mL. The calibration certificate with this instrument indicates that the accuracy (in percent) is as follows:

At 0.200 mL, 0.90%

At 0.300 mL, 0.28%

At 1.000 mL, 0.30%

The Step 2 solution is called the long term standard. OUL experience indicates that Step 2 solutions, if kept refrigerated, will not deteriorate appreciably over periods of less than a year. Furthermore, these Step 2 solutions may last substantially longer than one year.

Step 3. A series of intermediate-term dye solutions are made. Approximately 45 mL. of each intermediate-term dye solution is made. All volume measurements of less than 5 mL are made with a digital Finnpipette. (see description in Step 2). All other volume measurements are made with Rheinland Kohn Geprufte Sicherheit 50 mL capacity pump dispenser which will pump within plus or minus 1% of the set value. The following solutions are made; all concentrations are based on the as-sold weight of the dyes:

1) 1 ppm fluorescein dye and 10 ppm rhodamine WT dye.

2) 1 ppm eosine.

3) 10 ppm sulforhodamine B dye.

Step 4. A series of six short-term dye standards are made from solutions in Step 3. These standards were identified earlier in this section. In the experience of the OUL these standards have a useful shelf life in excess of one week. However, in practice, Step 4 elutant standards are made weekly, and Step 4 water standards are made daily.

Dilution of Samples

Samples with peaks that have arbitrary fluorescence unit values of 500 or more are diluted a hundred fold to ensure accurate quantification.

Some water samples have high turbidity or color which interferes with accurate detection and measurement of dye concentrations. It is often possible to dilute these samples and then measure the dye concentration in the diluted sample.

The typical dilutions are either 10 fold (1:10) or 100 fold (1:100). A 1:10 dilution involves combining one part of the test sample with 9 parts of water (if the sample is water) or elutant (if the sample is elutant). A 1:100 dilution involves combining one part of the test sample is combined with 99 parts of water or elutant, based upon the sample media. Typically, 0.300 mL of the test solution is combined with 29.700 mL of water (or elutant as appropriate) to yield a new test solution.

All volume measurements of less than 5 mL are made with a digital Finnpipette. All other volume measurements are made with Rheinland Kohn Geprufte Sicherheit 50 mL capacity pump dispenser which will pump within plus or minus 1% of the set value.

The water used for dilution is from a carbonate aquifer. All dilution water is pH adjusted to greater than pH 9.5 by holding it in open containers in a high ammonia concentration chamber. This adjustment takes a minimum of two hours.

Quality Control

Laboratory blanks are run for every sample where the last two digits of the laboratory numbers are 00, 20, 40, 60, or 80. A charcoal packet is placed in a pumping well sampler and at least 25 gallons of unchlorinated water is passed through the sampler at a rate of about 2.5 gallons per minute. The sampler is then subjected to the same analytical protocol as all other samplers.

System functioning tests of the analytical instruments are conducted in accordance with the manufacturer's recommendations. Spiked samples are also analyzed when appropriate for quality control purposes.

All materials used in sampling and analysis work are routinely analyzed for the presence of any compounds that might create fluorescence peaks in or near the acceptable wavelength ranges for any of the tracer dyes. This testing includes approximately 1% of materials used.

Project specific QA/QC samples may include sample replicates and sample duplicates. A replicate sample is when a single sample is analyzed twice. A sample duplicate is where two samples are collected in a single location and both are analyzed. Sample replicates and duplicates are run for QA/QC purposes upon request of the client. These results are reported in the Certificate of Analysis.

Reports

Sample analysis results are typically reported in a Certificate of Analysis. However, specialized reports are provided in accordance with the needs of the client. Certificates of Analysis typically provide a listing of station number, sample ID, and dye concentrations if detected. Standard data format includes deliverables in MS Excel and Adobe Acrobat (.pdf) format. Hard copy of the data package, and copies of the analytical charts are available upon request.

Work at the OUL is directed by Mr. Thomas Aley. Mr. Aley has 45 years of professional experience in hydrology and hydrogeology. He is certified as a Professional Hydrogeologist (Certificate #179) by the American Institute of Hydrology and licenced as a Professional Geologist in Missouri, Arkansas, Kentucky, and Alabama. Additional details regarding laboratory qualifications are available upon request.

Waste Disposal

All laboratory wastes are disposed of according to applicable state and federal regulations. Waste elutant and water samples are collected in 15 gallon poly drums and disposed with a certified waste disposal facilityas non-hazardous waste.

In special cases, wastes for a particular project maybe segregated and returned to the client upon completion of the project. These projects may have samples that contain contaminants that the client must account for all materials generated and disposed. These situations are managed on a case-by-case basis.

CRITERIA FOR DETERMINATION OF POSITIVE DYE RECOVERIES

Normal Emission Ranges and Detection Limits

The OUL has established normal emission fluorescence wavelength ranges for each of the four dyes described in this document. The normal acceptable range equals mean values plus and minus two standard deviations. These values are derived from actual groundwater tracing studies conducted by the OUL.

The detection limits are based upon concentrations of dye necessary to produce emission fluorescence peaks where the signal to noise ratio is 3. The detection limits are realistic for most field studies since they are based upon results from actual field samples rather than being based upon values from spiked samples in a matrix of reagent water or the elutants from unused activated carbon samplers. In some cases detection limits may be smaller than reported if the water being sampled has very little fluorescent material in it. In some cases detection limits may be greater than reported; this most commonly occurs if the sample is turbid due to suspended material or a coloring agent such as tannic compounds. Turbid samples are typically allowed to settle, centrifuged, or, if these steps are not effective, diluted prior to analysis.

Table 4 provides normal emission wavelength ranges and detection limits for the four dyes when analyzed on the OUL’s RF-5301 for samples analyzed as of March 3, 2015.

Table 4. RF-5301 Spectrofluorophotometer. Normal emission wavelength ranges and detection limits for fluorescein, eosine, rhodamine WT, and sulforhodamine B dyes in water and elutant samples.

Fluorescent Dye	**Normal Acceptable Emission Wavelength Range (nm)**		**Detection Limit (ppb)**	
	Elutant	**Water**	**Elutant**	**Water**
Eosine	539.3 to 545.1	532.5 to 537.0	0.050	0.015
Fluorescein	514.1 to 519.2	505.9 to 509.7	0.025	0.002
Rhodamine WT	564.6 to 571.2	571.9 to 577.2	0.170	0.015
Sulforhodamine B	575.2 to 582.0	580.1 to 583.7	0.080	0.008

Note: Detection limits are based upon the as-sold weight of the dye mixtures normally used by the OUL. Fluorescein and eosine detection limits in water are based on samples pH adjusted to greater than 9.5.

It is important to note that the normal acceptable emission wavelength ranges are subject to change based on instrument maintenance, a change in instrumentation, or slight changes in dye formulation. Significant changes in normal acceptable emission wavelength ranges will be updated in this document as they occur.

Fluorescence Background

Due to the nature of fluorescence analysis, it is important to identify and characterize any potential background fluorescence at dye introduction and monitoring locations prior to the introduction of any tracer dyes.

There is generally little or no detectable fluorescence background in or near the general range of eosine, rhodamine WT, and sulforhodamine B dyes encountered in most groundwater tracing studies. There is often some fluorescence background in or near the range of fluorescein dye present at some of the stations used in groundwater tracing studies.

Criteria for Determining Dye Recoveries

The following sections identify normal criteria used by the OUL for determining dye recoveries. The primary instrument in use is a Shimadzu RF-5301.

EOSINE

Normal Criteria Used by the OUL for Determining Eosine Dye Recoveries in Elutants from Charcoal Samplers

Criterion 1. There must be at least one fluorescence peak in the range of 539.3 to 545.1 nm in the sample.

Criterion 2. The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. The eosine detection limit in elutant samples is 0.050 ppb, thus this dye concentration limit equals 0.150 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of eosine. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of eosine. In addition, there must be no other factors which suggest that the fluorescence peak may not be eosine dye from our groundwater tracing work.

Normal Criteria Used by the OUL for Determining Eosine Dye Recoveries in Water Samples

Criterion 1. In most cases, the associated charcoal samplers for the station should also contain eosine dye in accordance with the criteria listed above. This criterion may be waived if no charcoal sampler exists.

Criterion 2. There must be no factors which suggest that the fluorescence peak may not be eosine dye from our groundwater tracing work. The fluorescence peak should generally be in the range of 532.5 to 537.0 nm.

Criterion 3. The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our eosine detection limit in water samples is 0.015 ppb, thus this dye concentration limit equals 0.045 ppb.

Criterion 4. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

FLUORESCEIN

Normal Criteria Used by the OUL for Determining Fluorescein Dye Recoveries in Elutants from Charcoal Samplers

Criterion 1. There must be at least one fluorescence peak in the range of 514.1 to 519.2 nm in the sample.

Criterion 2. The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. The fluorescein detection limit in elutant samples is 0.025 ppb, thus this dye concentration limit equals 0.075 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of fluorescein. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of fluorescein. In addition, there must be no other factors which suggest that the fluorescence peak may not be fluorescein dye from our groundwater tracing work.

Normal Criteria Used by the OUL for Determining Fluorescein Dye Recoveries in Water Samples

Criterion 1. In most cases, the associated charcoal samplers for the station should also contain fluorescein dye in accordance with the criteria listed above. This criterion may be waived if no charcoal sampler exists.

Criterion 2. There must be no factors which suggest that the fluorescence peak may not be fluorescein dye from our groundwater tracing work. The fluorescence peak should generally be in the range of 505.9 to 509.7 nm.

Criterion 3. The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our fluorescein detection limit in water samples is 0.002 ppb, thus this dye concentration limit equals 0.006 ppb.

Criterion 4. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

RHODAMINE WT

Normal Criteria Used by the OUL for Determining Rhodamine WT Dye Recoveries in Elutants from Charcoal Samplers

Criterion 1. There must be at least one fluorescence peak in the sample in the range of 564.6 to 571.2 nm.

Criterion 2. The dye concentration associated with the rhodamine WT peak must be at least 3 times the detection limit. The detection limit in elutant samples is 0.170 ppb, thus this dye concentration limit equals 0.510 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of rhodamine WT. In addition, there must be no other factors which suggest that the fluorescence peak may not be dye from the groundwater tracing work under investigation.

Normal Criteria Used by the OUL for Determining Rhodamine WT Dye Recoveries in Water Samples

Criterion 1. In most cases, the associated charcoal samplers for the station should also contain rhodamine WT dye in accordance with the criteria listed above. These criteria may be waived if no charcoal sampler exists.

Criterion 2. There must be no factors which suggest that the fluorescence peak may not be rhodamine WT dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 571.9 to 577.2 nm.

Criterion 3. The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our rhodamine WT detection limit in water samples is 0.015 ppb, thus this dye concentration limit is 0.045 ppb.

Criterion 4. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

SULFORHODAMINE B

Normal Criteria Used by the OUL for Determining Sulforhodamine B Dye Recoveries in Elutants from Charcoal Samplers

Criterion 1. There must be at least one fluorescence peak in the sample in the range of 575.2 to 582.0 nm.

Criterion 2. The dye concentration associated with the sulforhodamine B peak must be at least 3 times the detection limit. The detection limit in elutant samples is 0.080 ppb, thus this dye concentration limit equals 0.240 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of sulforhodamine B. In addition, there must be no other factors which suggest that the fluorescence peak may not be dye from the groundwater tracing work under investigation.

Normal Criteria Used by the OUL for Determining Sulforhodamine B dye Recoveries in Water Samples

Criterion 1. In most cases, the associated charcoal samplers for the station should also contain sulforhodamine B dye in accordance with the criteria listed earlier. This criterion may be waived if no charcoal sampler exists.

Criterion 2. There must be no factors which suggest that the fluorescence peak may not be sulforhodamine B dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 580.1 to 583.7 nm.

Criterion 3. The dye concentration associated with the fluorescence peak must be at least three times the detection limit. The detection limit in water is 0.008 ppb, thus this dye concentration limit equals 0.024 ppb.

Criterion 4. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Standard Footnotes

Sometimes not all the criteria are met for a straight forward determination of tracer dye in a sample. For these reasons, the emission graph is scrutinized carefully by the analytical technician and again during the QA/QC process. Sometimes the emission graphs require interpretation as to whether or not a fluorescence peak represents the tracer dye or not. Background samples from each of the sampling stations aid in the interpretation of the emission fluorescence graphs. When the results do not meet all the criteria for a positive dye detection, often the fluorescence peak is quantified and flagged with a footnote to the result as not meeting all the criteria for a positive dye detection. Standard footnotes are as follows:

> Single asterisk (*): A fluorescence peak is present that does not meet all the criteria for a positive dye recovery. However, it has been calculated as though it were the tracer dye.
>
> Double asterisk (**): A fluorescence peak is present that does not meet all the criteria for this dye. However, it has been calculated as a positive dye recovery.

Other footnotes specific to the fluorescence signature are sometimes also used. These footnotes are often developed for a specific project.

The quantification of fluorescence peaks that do not meet all the criteria for a positive dye detection can be important for interpretation of the dataset as a whole.

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ATTACHMENT 1

Sample Collection Data Sheet

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 fax (417) 785-4290 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project________________ **Week No:**____ **Samples Collected By:** ________________

Samples Shipped By: ________________ **Samples Received By:** ________________

Date Samples Shipped: ________ **Date Samples Received:** ________ **Time Samples Received:** ________ **Return Cooler? Yes** ☐ **No** ☐

Bill to:________________ **Send Results to:** ________________

Analyze for: ☐ **Fluorescein** ☐ **Eosine** ☐ **Rhodamine WT** ☐ **Other**________ **Ship cooler to:**

OUL use only		***Please indicate stations where dye was visible in the field*** *for field technician use - use black ink only*						*OUL use only*
# CHAR REC'D	LAB NUMBER	STATION NUMBER 1-4 Numbers	STATION NAME	PLACED		COLLECTED		# WATER REC'D
				DATE	TIME	DATE	TIME	

COMMENTS________________

This sheet filled out by OUL staff? Yes ☐ **No** ☐ **Charts for samples on this page proofed by OUL:**________________

OUL Project No.________ **Date Analyzed:**________ **Analyzed By:**________________

Appendix D.

Rules of the Missouri Department of Natural Resources

Dam and Reservoir Safety Council

Rules of
Department of Natural Resources
Division 22—Dam and Reservoir Safety Council
Chapter 1—Definitions

Title		Page

Title 10—DEPARTMENT OF NATURAL RESOURCES
Division 22—Dam and Reservoir Safety Council
Chapter 1—Definitions

10 CSR 22-1.010 General Organization
(Rescinded August 30, 2018)

AUTHORITY: Chapter 236, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Rescinded: Filed Dec. 29, 2017, effective Aug. 30, 2018.

10 CSR 22-1.020 Definitions

PURPOSE: The following terms when used in rules, standards and guidelines adopted by the Dam and Reservoir Safety Council pur- suant to the dam safety law shall have the meaning respectively ascribed to them by this section.

PUBLISHER'S NOTE: The secretary of state has determined that the publication of the entire text of the material which is incorporated by reference as a portion of this rule would be unduly cumbersome or expensive. This material as incorporated by reference in this rule shall be maintained by the agency at its headquarters and shall be made available to the public for inspection and copying at no more than the actual cost of reproduction. This note applies only to the reference mate- rial. The entire text of the rule is printed here.

(1) Agency engineer means an experienced engineer, not necessarily registered as a professional engineer in Missouri, who works for an engineering division of a state or federal agency regularly engaged in dam and reservoir design and construction for soil and water conservation or irrigation or relating to wildlife conservation.

(2) Agricultural dam means any dam, the primary use of which is to impound water for use in irrigation, livestock watering or commercial fish rearing and sale.

(3) Alterations, repairs, or either means alterations or repairs as affect the safety of a dam or reservoir, or public safety, life or property.

(4) Appurtenant works means the structures or materials incident to or annexed to dams which are built or maintained in connection with dams and which are used primarily in connection with their proper operation, maintenance or functioning. This includes, without limitation, structures as spillways, either in the dam or separate therefrom; the reservoir rim; low level outlet works; and water conduits such as tunnels, pipelines or penstocks, either through a dam or its abutments.

(5) Area capacity curves means graphic curves which show the relationship between reservoir surface area and the storage capacity of the reservoir at given elevations.

(6) Chief engineer means the head of the dam and reservoir safety program of the Department of Natural Resources or his/her representative.

(7) Commercial fish rearing reservoir means a reservoir which was designed specifically for fish rearing purposes and the primary use is to provide water for commercial fish rearing and sale to other parties in a for profit venture. This does not include activities such as sport fishing.

(8) Construction permit means a written authorization issued by the council giving the owner the right to construct, alter, enlarge, reduce, repair or remove a dam or reservoir or appurtenances thereto, with conditions that are necessary to adequately protect the public safety, life, property, the dam or reservoir.

(9) Conventional dam means any dam other than an industrial water retention dam.

(10) Council delegate or authorized representative means an individual, usually the chief engineer, authorized by the council to act in its behalf.

(11) Crest or dam crest means the top surface of the dam.

(12) Crest elevation or dam crest elevation means the lowest elevation of the crest exclusive of the spillway(s).

(13) Dam means any artificial or man-made barrier which does or may impound water and which impoundment has or may have a surface area of fifteen (15) or more acres of water at the water storage elevation or which is thirty-five feet (35') or more in height from the natural bed of the stream or watercourse or lowest point on the toe of the dam (whichever is lower) up to the crest elevation, together with appurtenant works. Sections 236.400 to 236.500, RSMo shall not apply to any dam which is not or will not be thirty-five feet (35') or in excess of thirty-five feet (35') in height or to any dam or reservoir licensed and operated under the Federal Power Act.

(14) Dam and Reservoir Safety Council referred to as the council means seven (7) members appointed by the governor for purposes of implementing the dam safety law.

(15) Dangerous dam or reservoir is a dam or reservoir which is in an advanced state of deterioration so that if deterioration continues, the threat of dam failure and flooding would be substantial.

(16) Department means the Department of Natural Resources.

(17) Downstream environment zone means the area downstream from a dam that would be affected by inundation in the event the dam failed when filled to the emergency spillway crest elevation or to the dam crest elevation, in the absence of an emergency spillway.

(18) Earthquake intensity means Modified Mercalli intensity which is used to describe the degree of shaking a dam will experience.

(19) Enforcement order means a written directive issued by the council or the chief engineer to the owner of a dam for correction of defects in the dam or reservoir which have been determined to make the structure a threat to public safety, life or property. The order will contain specific actions with which the owner must comply to remove the threat the dam or reservoir poses to public safety, life or property.

(20) Enlargement means any change in or addition to an existing dam or reservoir, which raises the height of the dam, increases the watershed for the reservoir or raises the water storage elevation of the water impounded by the dam or reservoir.

(21) Environmental class means a classification of the downstream environment zone based on the contents of that zone (see 10 CSR 22-2.040(1)). Class I represents the most severe threat to public safety, life or property and Class III represents the least threat.

(22) Factor of safety means the resultant of the summation of the forces resisting failure divided by the summation of the driving forces tending to cause failure.

(23) Freeboard means the difference in elevation between the dam crest elevation and the

water storage elevation in the reservoir.

(1) Height or height of dam means the difference in the elevation of either the natural bed of the stream or watercourse or the lowest point on the toe of the dam (whichever is lower) and the dam crest elevation.

(2) Industrial building means a permanent, enclosed structure used by groups of workers usually involved in some type of manufacturing, processing or industrial related process.

(3) Industrial water retention dam means a dam used to retain the solids transported as water-borne industrial byproducts and the associated water. This includes, but is not limited to, tailings dams, slime impoundments and settling ponds.

(4) Inundation means water, two feet (2') or more deep, over the general level of the submerged ground affected outside the stream channel.

(5) Inspection means scheduled and unscheduled examinations of a dam and reservoir with the primary objective of making safety observations and recording them in a written description.

(6) Irrigation reservoir means a reservoir whose primary use is to provide water for the irrigation of agricultural lands for the production of grains, hay, pasture, fruits, vegetables and animal feeds which are for sale or to be used by the owner.

(7) Law means the dam and reservoir safety law, as contained in Chapter 236, RSMo and all rules, standards and guidelines adopted thereto.

(8) Liquefaction is a condition where a soil will undergo continued deformation at a constant low residual stress or with low residual resistance, due to the build-up and maintenance of high pore water pressures, which reduce the effective confining pressure to a very low value.

(9) Livestock watering reservoir means a reservoir whose primary use is to provide water for livestock which are raised for breeding or marketing purposes.

(10) Maintenance means the proper keeping of all aspects of a dam or reservoir and appurtenances thereto, that pertain to safety, in a state of repair and working order as necessary to comply with the law and any permit issued thereunder and to protect public safety, life or property.

(11) Modification(s) means changes or revisions to the design, construction, maintenance, operation or repair or the alteration, enlargement, reduction, removal or natural physical changes that may occur to a dam or reservoir that were not included in the approved plans for the construction permit, or changes or revisions to a dam or reservoir where a registration or safety permit is in effect or required hereunder, if the changes or revisions would endanger public safety, life or property as a result of creating a potential failure in the dam or reservoir; except that modification(s) do not mean or include approved anticipated enlargements, outlined by design plans and specifications submitted and approved with the original application for a construction, safety or registration permit for industrial water retention dams and reservoirs.

(12) Observable defects are those defects which would be detectable by an experienced professional engineer making an on-site visual inspection of the dam in accordance with current engineering, geologic and construction practices.

(13) Owner or dam owner means a person who owns, controls, operates, maintains, manages or proposes to construct a dam or reservoir including: the state and its departments, institutions, agencies and political subdivisions, but not the United States government; a municipal or quasi-municipal corporation; a district; a public utility; a natural person, firm, partnership, association, corporation, political subdivision or legal entity; the duly authorized agents or leasees, or trustees of any of the foregoing; or receivers or trustees appointed by any court for any of the foregoing.

(14) Permanent dwelling means a dwelling occupied at least ninety (90) days a year.

(15) Permit means construction, safety or registration permit.

(16) Permit applicant or applicant means an owner who applies for a construction, safety or registration permit.

(17) Probable maximum acceleration means the horizontal acceleration developed at a dam as a result of an earthquake with a probability of occurrence similar to the probable maximum precipitation. The probable maximum acceleration is readily available from a Corps of Engineers Report entitled Earthquake Potential of the St. Louis District—Ground Motion Supplement which is on file with the chief engineer of the Dam and Reservoir Safety Program.

(18) Probable maximum precipitation or PMP means the precipitation that may be expected from the most severe combination of critical meteorologic conditions that are reasonably possible in an area. The PMP is readily available from the National Weather Service in Hydrometeorological Report 51, Probable Maximum Precipitation Estimates, United States East of the 105th Meridian.

(19) Public building means a permanent, enclosed structure used by groups of the general public but not necessarily owned by the public.

(20) Registration permit means a permit issued for a period not to exceed five (5) years by the council to the owner of a dam or reservoir in existence or in the progress of construction on August 13, 1981 or which becomes subject to the law for the dams and reservoirs by a change in factors or circumstances subsequent to that date.

(21) Reservoir means any basin, including the water, which contains or will contain the maximum amount of water impounded by a dam.

(22) Safety permit means a permit issued to the owner of a dam for a period of five (5) years, or less if safety considerations so require, by the council indicating that the dam meets the requirements of the law, and containing conditions as to operations, maintenance and repair as are necessary to adequately protect public safety, life and the dam or reservoir.

(23) Seepage means the migration of water through a dam or foundation.

(24) Significant modification means changes, alteration or modifications to an existing dam or changes to the construction documents for a new dam. Those include, but are not limited to: changes in the location of the dam or reservoir, changes in the storage capacity or drainage area, changes in the capacity of the spillway system, modification of the embankment slopes, changes in the height of the dam or structure, or the use of different construction methods or procedures than those submitted with the permit application.

(25) Spillway means any passageway, channel or structure, open or closed or both, designated expressly or primarily to discharge excess water from a reservoir after the water storage elevation has been reached.

(1) Spillway design flood or SDF means the specified flood discharge that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in an area and for which the dam and reservoir are designed. The SDF is derived from the rainfall values given in Table 5.

(Editor's Note: For Table 5 see 10 CSR 22-3.020)

(2) Stability means the properties of a dam or reservoir that cause it when disturbed from a condition of equilibrium to develop forces or moments that restore the original condition.

(3) Starter dam means a pervious or impervious dam constructed as the first phase in the building of an industrial water retention dam and reservoir.

(4) Storage means the volumetric capacity of the reservoir below the water storage elevation or other selected reference on the dam.

(5) Stream means any river, creek or channel, having well-defined banks, in which water flows for substantial periods of the year to drain a given area.

(6) Tailings means the material generated by a mining/milling operation which is deposited in slurry form in an impoundment for storage, disposal, or both.

(7) Tailings dam means an existing dam or reservoir used for the impoundment or retention of tailings or a proposed, existing or newly constructed dam and reservoir for which the anticipated or contemplated use is the impoundment or retention of tailings.

(8) Toe or toe of slope means the line of the fill (dam embankment) slope where it intersects the natural ground.

(9) Water means water, other liquids or tailings.

(10) Watercourse means a valley, swale, depression or other low place in the topography occupied by flowing water during conditions of runoff.

(11) Water storage elevation means that elevation of water surface at the principal spillway which could be obtained by the dam or reservoir were there no outflow and were the reservoir full of water.

(12) Watershed means the area that contributes or may contribute surface water to a reservoir.

AUTHORITY: sections 236.405 and 236.415, RSMo 2016. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed Sept. 1, 1993, effective May 9, 1994. Amended: Filed June 27, 2018, effective Feb. 28, 2019.*

**Original authority: 236.405, RSMo 1979, amended 1933 and 236.415, RSMo 1979.*

10 CSR 22-1.030 Immunity of Officers
(Rescinded August 30, 2018)

AUTHORITY: section 236.475, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Rescinded: Filed Dec. 29, 2017, effective Aug. 30, 2018.

Rules of
Department of Natural Resources
Division 22—Dam and Reservoir Safety Council
Chapter 2—Permits

Title 10—DEPARTMENT OF NATURAL RESOURCES
Division 22—Dam and Reservoir Safety Council
Chapter 2—Permits

10 CSR 22-2.010 Who Needs a Permit

PURPOSE: This rule identifies those persons who need to obtain a permit for their dam and reservoir and to identify those persons who do not need to obtain a permit for their dam and reservoir.

(1) The owner of a proposed new dam thirty-five feet (35') or more in height is required to obtain a construction permit and a safety permit for his/her dam and reservoir. The owner of an existing dam thirty-five feet (35') or more in height is required to obtain a registration permit within the time set forth in 10 CSR 22-2.020(2).

(2) By definition, the United States government is not considered an owner. Therefore, no federal dam and reservoir is regulated by sections 236.400—236.500, RSMo and no permits are required.

(3) Agricultural dams are exempted from all permit requirements as long as the agricultural dam and reservoir continue to be used primarily for agricultural purposes (see 10 CSR 22-1.020(2)). The owners of agricultural dams and reservoirs thirty-five feet (35') and higher in height must notify the council of their reliance on this exemption and their basis for application of this exemption to their dams. If an agricultural dam and reservoir is constructed after the effective date of the law, but subsequently becomes subject to the provisions of the law, the owner shall provide, prior to obtaining a registration permit, evidence that the dam meets the construction permit criteria in effect at the time the dam was constructed.

(4) Dams and reservoirs licensed and operated under the Federal Power Act are exempted from all permit requirements.

(5) Industrial water retention dams (see 10 CSR 22-1.020(27)) and reservoirs regulated by another state agency or federal agency are exempted from all permit requirements. For the exemption to apply, the industrial water retention dam and reservoir must be subject to safety inspections by the other state agency or federal agency and standards used must be at least as stringent as those required by the law. In addition, the owner must notify the council that another agency is regulating his/her dam and reservoir and explain the basis for the exemption to apply.

AUTHORITY: sections 236.400, 236.405, 236.415, 236.435, 236.440, and 236.465, RSMo 2016. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed Sept. 1, 1993, effective May 9, 1994. Amended: Filed June 27, 2018, effective Feb. 28, 2019.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.415, RSMo 1979, amended 1995; 236.435, RSMo 1979; 236.440, RSMo 1979; and 236.465, RSMo 1979.*

10 CSR 22-2.020 Types of Permits

PURPOSE: This rule describes the three types of permits and their uses that the Dam and Reservoir Safety Council will issue.

(1) There are three (3) types of permits—registration permits, construction permits, and safety permits and each one is intended to regulate a separate and distinct type of activity. A dam and reservoir will have only one (1) type of permit in effect at any given time although they may have more than one (1) type of permit during their existence.

(2) Registration permits (see 10 CSR 22-1.020(44)) apply to and are required for the continued operation of a dam and reservoir that was in existence or in the process of being constructed on the effective date of this section, August 13, 1981. A registration permit also applies to and is required for structures which become subject to the provisions of the dam and reservoir safety law that were in existence prior to the date that they became subject to the law. Registration permits may be issued for a time period up to five (5) years.

(3) Construction permits (see 10 CSR 22-1.020(8)) apply to the construction of a new dam and reservoir, the alteration, enlargement, reduction, repair, or removal of a new or existing dam, reservoir, or appurtenances. New dams are dams for which construction commences after the effective date of this section, August 13, 1981. A construction permit may be issued for any reasonable length time period in order to complete construction and it may contain appropriate restrictions placed on the owner for construction and operation of the dam and reservoir during that period. At the conclusion of construction, a safety or registration permit shall be obtained by the owner.

(4) Safety permits (see 10 CSR 22-1.020(48)) apply to the operation of a dam and reservoir constructed pursuant to a construction permit. The safety permit is not a guarantee of the dam and reservoir's safety and does not alter the owner's liability; it is simply an operating permit. If a dam and reservoir were not subject to the provisions of the law when they were constructed but subsequently become subject to the provisions of the law, the owner shall obtain a registration permit, not a safety permit. Safety permits may be issued for a time period up to five (5) years, and they may contain appropriate conditions for the operation and safety of the dam and reservoir.

AUTHORITY: sections 236.400, 236.405, 236.415, 236.435, 236.440, and 236.465, RSMo 2016. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed May 15, 1987, effective Sept. 15, 1987. Amended: Filed June 27, 2018, effective Feb. 28, 2019.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.415, RSMo 1979, amended 1995; 236.435, RSMo 1979; 236.440, RSMo 1979; and 236.465, RSMo 1979.*

10 CSR 22-2.030 Types of Dams and Reservoirs

PURPOSE: This rule describes the two fundamentally different types of dams and reservoirs that will be required to obtain permits from the Dam and Reservoir Safety Council.

(1) There are two (2) types of dams and reservoirs, conventional dams and reservoirs and industrial water retention dams and reservoirs. The two (2) types of dams and reservoirs are distinguished on the basis of their reservoir contents and the length of the time period during which active dam building occurs.

(2) Conventional dams and reservoirs (see 10 CSR 22-1.020(9)) are dams and reservoirs used for purposes other than tailings, slime, settling or other similar industrial water retention purposes. A conventional dam is constructed in one (1) relatively continuous operation over a short time span (compared to the design life of the reservoir). Filling and use of the reservoir occurs after construction is completed.

(3) Industrial water retention dams and reservoirs (see 10 CSR 22-1.020(27)) are dams and reservoirs used for the purpose of storing

solids and the water associated with the particular industrial process such as tailings, slime and other similar industrial materials. An industrial water retention dam may be constructed in phases and steps or continuously, over a long period of time (compared to the design life of the reservoir). Filling and use of the reservoir may occur during most phases of construction. An industrial water retention dam and reservoir in existence or under construction on the effective date of 10 CSR 22-2.020(2), August 13, 1981, shall obtain a registration permit which may include approval to make enlargements. The owner of any such dam and reservoir shall apply for and obtain new construction and/or registration permits for any modifications to that dam and reservoir other than enlargements covered by an existing permit. A construction permit is required and shall be obtained by the owner, for the initial construction phase of any new industrial water retention dam and reservoir built after the effective date of 10 CSR 22-2.020(3), August 13, 1981. Upon completion of the initial construction phase, the owner shall apply for a safety permit for the operation and enlargement of the new dam and reservoir.

AUTHORITY: sections 236.405, RSMo Supp. 1993 and 236.415, 236.435, 236.440 and 236.465, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.405, RSMo (1979), amended 1993 and 236.415, 236.435, 236.440 and 236.465, RSMo (1979).*

10 CSR 22-2.040 Classes of Downstream Environment

PURPOSE: This rule describes the three environmental classes for the downstream environmental zone that will be used by the Dam and Reservoir Safety Council when considering permits.

(1) The downstream environment zone is the area downstream from a dam that would be affected by inundation in the event the dam failed. Inundation is defined as water, two feet (2') or more deep over the general level of the submerged ground affected outside the stream channel. Based on the content of the downstream environment zone, three (3) environmental classes are defined. They are: class I, which contains ten (10) or more permanent dwellings or any public building; class II, which contains one to nine (1–9) permanent dwellings, or one (1) or more campgrounds with permanent water, sewer and electrical services or one (1) or more industrial buildings; and class III, which is everything else.

(2) Spillway design standards are based on the environmental class of the downstream environment zone of a dam and reservoir. The standards become more stringent for lower environmental class numbers. If conditions change in the downstream environment zone and it becomes necessary to change the environmental class of the dam and reservoir, the owner must then meet the standards and criteria for the new environmental class of the dam and reservoir. A dam and reservoir may be in only one (1) environmental class at a given time.

(3) Inundation, the downstream environmental zone and the associated environmental class are analyzed, assuming the dam fails with the reservoir at the emergency spillway crest elevation or the dam crest elevation in the absence of an emergency spillway. If the spillway standards for class I are used, the failure analysis does not have to be performed. If a failure analysis is made, the contents of the downstream environment zone used to determine the environmental class are only the features that would be inundated by the flooding resulting from the dam failure.

AUTHORITY: sections 236.405, RSMo Supp. 1993 and 236.415, 236.435, 236.440 and 236.465, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.405, RSMo 1979, amended 1993 and 236.415, 236.435, 236.440 and 236.465, RSMo 1979.*

10 CSR 22-2.050 Issuing First Permit

PURPOSE: This rule describes the procedure for issuing the first permit to a dam and reservoir owner for a particular dam and reservoir.

(1) A permit will be issued or a letter will be sent to the owner with comments within forty-five (45) days after the receipt of a properly prepared application or after the completion of any hearings or record period conducted by the council in connection with the application, whichever is later. The council, upon hearing the recommendations of the chief engineer, shall approve or deny the permit application.

(2) A permit will be issued if a complete and proper application has been submitted and the dam and reservoir comply with the law.

(A) A registration permit may be denied if it is determined that the owner has not complied with the experienced professional engineer's or agency engineer's inspection recommendations.

(B) A construction permit may be denied if there is insufficient information to determine that the proposed construction, alteration, enlargement, reduction or removal of a dam or reservoir would not endanger public safety, life or property or otherwise would comply with the law.

(C) A safety permit may be denied if it is determined that there are violations of the construction permit or the law.

(D) If revisions have been made which vary substantially from the provisions of the construction permit, the owner must show that the revisions do not endanger public safety, life or property before a safety permit will be issued.

(3) Conditions contained in a construction permit shall include that the construction work must be under the responsible charge of an experienced professional engineer and the records be kept and made available as required by the chief engineer including, without limitation, for the foundation excavation and inspection and placement of backfill in the core trench. It is not necessary for the engineer in responsible charge to be on-site continuously. During construction, the council or its delegate, the chief engineer, may make periodic site inspections the purpose of inspecting and securing conformity of construction with the approved plans and specifications and the owner shall permit, upon reasonable notice, the person entry upon its property to make such inspections. The owner may be required to perform, at its own expense, reasonable work or tests as are necessary to provide sufficient information to enable the council to determine that there is conformity. Usually, testing will be limited to verification of embankment compaction, concrete strengths and other similar requirements. It is expected that the tests will be required where the owner's inspection records are lacking.

(4) Any significant modifications from a construction permit or approved plans makes the permit void and requires the owner to obtain a new permit. Significant modification to the plans and specifications must be prepared by an experienced professional engineer. The council or its delegate will follow the same evaluation procedures for the modifications

as used with issuance of the original construction permit. Special attention will be given to these modification requests to provide a quick decision.

(5) The owner of a dam and reservoir that is removed under a construction permit must notify the council or its delegate when this work is completed and in conformity with the provisions of the construction permit. The council or its delegate will then issue a final approval to relieve the owner of the requirement to have a permit upon a showing that the requirements of the law for removal have been satisfied.

(6) Approval by the council for a construction permit becomes invalid within one (1) year, unless work on the construction has begun within that period, except that the owner may be excused from beginning work for a period of time that the work is prevented by flood, shortage of materials or regulation of government which cannot be met for reasons over which the owner has no control or other causes beyond the owner's control. The same applies to construction of approved modifications contained in the conditions of a registration or safety permit for industrial water retention dams unless the conditions specify a different time schedule.

AUTHORITY: sections 236.400, 236.415, 236.435, 236.440 and 236.465, RSMo 1986 and 236.405, RSMo Supp. 1993. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.400, 236.415, 236.435, 236.440 and 236.465, RSMo 1979 and 236.405, RSMo 1979, amended 1993.*

10 CSR 22-2.060 Issuing Permit Renewals
(Rescinded August 30, 2018)

AUTHORITY: sections 236.405, RSMo Supp. 1993 and 236.415, 236.440 and 236.465, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Rescinded: Filed Dec. 29, 2017, effective Aug. 30, 2018.

10 CSR 22-2.070 Modifications not Requiring Permit Changes
(Rescinded January 1, 1985)

AUTHORITY: sections 236.405, 236.415, 236.435, 236.440, and 236.465, RSMo Supp. 1980. Original rule filed April 14, 1981, effective Aug. 13, 1981. Rescinded: Filed June 14, 1984, effective Jan. 1, 1985.

10 CSR 22-2.080 Revoking Permit

PURPOSE: This rule describes the reasons for revoking a permit.

(1) Approval of the council or its delegate, the chief engineer, shall be obtained for modifications that substantially alter or adversely affect the safety or stability of the dam or reservoir. Modifications, without the approval of the council or its delegate, the chief engineer, are cause for suspension or revocation of any permit. If the chief engineer finds that the condition of the dam and reservoir has deteriorated substantially from those conditions present when the permit was issued, or that has defects which adversely affect the safety or stability of the dam and reservoir or threatens public safety, life or property, s/he shall revoke the permit. If a permit is suspended or revoked, the dam owner will be in violation of the law and may be subject to prosecution for a misdemeanor.

(2) If the chief engineer determines that a dam or reservoir constitutes a threat to public safety, life or property, s/he may order its removal or take any other actions necessary to reduce or eliminate the threat. Failure of a dam owner to alter or remove his/her dam and reservoir as directed, when it is found to be a threat to public safety, life or property, will result in revocation of the permit and, if necessary, removal of the dam or any other action necessary to reduce or eliminate the threat to public safety, life or property by the state at the owner's expense.

AUTHORITY: sections 236.405, RSMo Supp. 1993 and 236.415, 236.445, 236.495 and 236.500, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.405, RSMo 1979, amended 1993 and 236.415, 236.445, 236.495 and 236.500, RSMo 1979.*

10 CSR 22-2.090 Transferring Permit

PURPOSE: This rule describes the procedure for transferring a permit when ownership changes.

(1) Permits issued pursuant to 10 CSR 22-2.050 and 10 CSR 22-2.060 are transferable only as provided in section 236.460, RSMo. If ownership or other transfer of interest in the dam and reservoir changes, the former owner must notify the chief engineer of the sale or transfer and the permit will be transferred to the new owner after determination that the transfer will not endanger the public safety, life, property, the dam or reservoir. The permit holder of record will be held responsible for maintaining compliance with these rules and standards. If the former owner does not have the permit transferred, the new owner may submit the appropriate application and documents necessary to obtain a new permit. The new owner, in this case, must also show proof of ownership. The old owner's responsibilities of ownership under the law will not be extinguished until the permit is transferred to an eligible owner. Nothing in these regulations shall be construed to eliminate the liability of the previous owner for damages or injuries caused by a dam failure, nor a new operator who has not obtained a permit nor had an existing permit transferred to his/her name.

AUTHORITY: sections 236.405, RSMo Supp. 1993 and 236.415, and 236.460, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective, Jan. 1, 1985.*

**Original authority: 236.405, RSMo 1979, amended 1993 and 236.415 and 236.460, RSMo 1979.*

10 CSR 22-2.100 Appeal of Action on Permits

PURPOSE: This rule describes the procedure for appealing the results of any action taken with regard to a permit.

(1) Permits revoked or denied are subject to council appeal. All parties shall be afforded an opportunity for hearing before the council for review of denial or revocation decisions, if request is made within thirty (30) days after notice is served personally or by certified or registered mail upon the parties or their agents. Except for emergency action, further legal action shall not be taken until after the hearing and council decision.

(2) The record of hearing shall include all written testimony, data, records, etc., as well as all oral proceedings recorded.

(3) A final decision will be in writing, and the party or its agents will be notified personally or by registered or certified mail of the final decision. A copy of any opinion in support of this decision will be furnished upon request. Decisions are subject to judicial review pursuant to provisions of section

236.480, RSMo.

AUTHORITY: sections 236.405, 236.415, 236.425, 236.440, 236.445, 236.470, and 236.480, RSMo 2016. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed June 27, 2018, effective Feb. 28, 2019.*

**Original authority: 236.405, RSMo 1979, amended 1993, 1995; 236.415, RSMo 1979, amended 1995; 236.425, RSMo 1979; 236.440, RSMo 1979; 236.445, RSMo 1979; 236.470, RSMo 1979; and 236.480, RSMo 1979.*

Rules of

Department of Natural Resources

Division 22—Dam and Reservoir Safety Council

Chapter 3—Permit Requirements

Title 10—DEPARTMENT OF NATURAL RESOURCES
Division 22—Dam and Reservoir Safety Council
Chapter 3—Permit Requirements

10 CSR 22-3.010 General Information

PURPOSE: The purpose of this rule is to provide general information about permit requirements.

(1) Requirements for existing or proposed dams and reservoirs must allow for variations in conditions and materials from site-to-site. Therefore, this rule and 10 CSR 22-3.020—10 CSR 22-3.050 describe the minimum general requirements which are consistent with current engineering, geologic, construction, operation and maintenance practices, necessary to obtain permits from the Dam and Reservoir Safety Council.

(2) These rules are not intended to define the only requirements for a dam and reservoir to comply with the law or sound engineering, geologic and construction practices, to be used in detailed site investigation or in the specific design and construction of individual dams. The detailed and specific information that outlines current and prudent engineering, geologic and construction practices is available in technical literature. Determinations by the Dam and Reservoir Safety Council, after hearing the recommendations of the chief engineer of the acceptability of a design and adequacy of plans, specifications and construction must be made, by necessity, on a case-by-case basis. Therefore, it is recommended that applicants unfamiliar with the way these rules are applied contact the council or the chief engineer prior to commencing extensive work or plan development.

(3) Adherence to the law does not guarantee the safety of any dam or reservoir or relieve the owner of any liability in the event of dam failure.

(4) A permit application form along with a copy of the laws, rules, standards and guidelines relating to dam and reservoir safety can be obtained free from the Department of Natural Resources, Division of Geology and Land Survey, Dam Safety Program, P.O. Box 250, Rolla, MO 65401. Persons seeking this and/or other information on dams in Missouri should address their inquiry to the chief engineer.

AUTHORITY: sections 236.400, 236.405, 236.415, 236.435, 236.440 and 236.465, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981.*

**Original authority: 246.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.415, RSMo 1979, amended 1995; 236.435, RSMo 1979; 236.440, RSMo 1979; and 236.465, RSMo 1979.*

10 CSR 22-3.020 General Requirements

PURPOSE: The purpose of this rule is to itemize the basic requirements and standards that apply to all permits.

(1) The permit application must contain information required by the council and the chief engineer including, but not limited to, the following information: type of permit being applied for; name of owners; mailing address of owners; telephone number(s) of owners; name of dam; name of reservoir; coordinate location of the dam centerline at the maximum section; purpose or use of dam and reservoir; name, address and telephone number of the experienced professional engineer or agency engineer who has provided or will provide required technical assistance; and the downstream environment zone environmental class for the dam and reservoir. The owners must complete all applicable investigations required in 10 CSR 22-3.0202–10 CSR 22-3.050 before filing a permit application. All permit applications must be filed with the chief engineer at the address listed in 10 CSR 22-3.010(4).

(2) The owner must provide a determination of an environmental class for each dam and reservoir. The method, data and assumptions used by the owner to determine environmental class shall conform to practices reputable and in current use in the engineering, geologic and construction professions or the chief engineer may reject the owner's classification. If an owner chooses not to have this done by an experienced professional engineer or an agency engineer, the chief engineer will assign the dam and reservoir to environmental class I or s/he may assign the dam and reservoir to another environmental class if s/he has justification to do so.

(3) The anticipated consequences of a dam failure with respect to public safety, life and property damage are important considerations in establishing acceptable methods for specific investigations and sites. Methods used in exploration design, construction and maintenance must be in accordance with good engineering practices reputable and in current use in the engineering, geologic and construction professions.

(4) When the owner is applying for a construction permit, the design factors of safety for slope stability for earth and rock conventional dams which are given in Table 1 shall be met. The required design factors of safety for concrete conventional dams are given in Table 2. The required design factors of safety for slope stability for industrial water retention dams are given in Table 3. Owners shall meet these requirements in the design of new dams prior to the issuance of the permit. Owners shall also meet these requirements when substantial changes are proposed to the height or slope of an existing conventional dam or structure prior to the issuance of the construction permit (see the following tables).

(5) For new dams constructed wholly or partially of cohesionless materials (such as sands and silts) or having a foundation of cohesionless materials, earthquake loading may result in the build-up of pore water pressures and a loss of strength. Engineers shall take this pore pressure increase and loss of strength into account when performing their stability analysis, but the degree to which liquefaction may affect the factor of safety for slope stability shall be left up to the engineer's best judgment. Bedrock accelerations and earthquake intensities are listed in Table 4.

(6) New dams constructed wholly of cohesive materials (such as clays) and having a foundation of cohesive materials or rock, can be expected to withstand significant earthquake shaking if it can be shown that other required design factors of safety for slope stability are met. Therefore, only new dams located in Bollinger, Butler, Cape Girardeau, Dunklin, Mississippi, New Madrid, Pemiscot, Ripley, Scott, Stoddard and Wayne Counties must meet the requirements for slope stability during earthquake loading while dams located in other counties do not unless 10 CSR 22-3.030(5) applies to them. Bedrock accelerations and earthquake intensities are listed in Table 4.

Table 1—Design Factors of Safety for Slope Stability Earth and Rock Conventional Dams

Loading Condition	Factor of Safety
End of construction, full reservoir*	1.4
Steady seepage, full reservoir*	1.5
Steady seepage, maximum reservoir**	1.3
Sudden draw down, from full to empty reservoir (if applicable)	1.2
Earthquake***, steady seepage, full reservoir*	1.0

*Full reservoir means water level is at the water storage elevation.

**Maximum reservoir means water level is at maximum water level attained during the spillway design flood or at the dam crest elevation, whichever is lower.

***Earthquake loading will vary according to dam location in relation to seismic source zones and downstream environmental zones. (See Table 4).

Table 2—Design Factors of Safety Concrete Conventional Dams

Failure Mode	Loading Condition	Factor of Safety
Overturning	full reservoir*	1.5
	maximum reservoir**	1.3
Sliding	full reservoir*	1.5
	maximum reservoir**	1.3
Structural integrity	full reservoir*	1.5
	maximum reservoir**	1.3
Earthquake*** any mode	full or maximum reservoir* & **	1.0

*Full reservoir means water level is at the water storage elevation.

**Maximum reservoir means water level is at maximum level attained during the spillway design flood.

***Earthquake loading will vary according to dam location in relation to seismic source zones and downstream environmental zones. (See Table 4).

Table 3—Design Factors of Safety for Slope Stability Industrial Water Retention Dams

Loading Condition	Factor of Safety
Starter dam, end of construction, full reservoir*	1.4
Any other stage of construction, full reservoir*, steady seepage	1.3
Any other stage of construction, maximum reservoir*, steady seepage	1.0
Completed dam, full reservoir*, steady seepage	1.5
Completed dam, maximum reservoir**, steady seepage	1.3
Earthquake***, steady seepage, full reservoir*	1.0

*Full reservoir means water level is at the water storage elevation.

**Maximum reservoir means water level is at the maximum level attained during the spillway design flood or at the dam crest elevation, whichever is lower.

***Earthquake loading will vary according to dam location in relation to seismic source zones and downstream environmental zones. (See Table 4).

(7) The required spillway design flood, which shall allow for flood storage in the reservoir, is to be derived by using the precipitation values given in Table 5 and shall apply to both new and existing dams.

Table 4—Required Design Acceleration For Earthquake Design

Dam Type	Stage of Construction	Special Descriptions	Environmental Class I	II	III
Conventional or Industrial	Completed	New dams less than 50 feet in height	.75PMA*	.5PMA*	.25PMA*
		New dams greater than 50 feet in height**	.75PMA*	.5PMA*	.4PMA*
Industrial	Starter dam	New dams**	.5PMA*	.2PMA*	.1PMA*
	After starter dam is finished and before final dam is completed	New dams**	.75PMA*	.5PMA*	.2PMA*

Zone	PMA*	Intensity**
A	0.31 g	IX—X
B	0.28 g	IX
C	0.26 g	VIII—IX
D	0.23 g	VIII
E	0.20 g	VII—VIII
F	0.17 g	VII

ZONE A	ZONE B	ZONE C	ZONE D	ZONE E	ZONE E (cont.)	ZONE F
Dunklin	Bollinger	Carter	Crawford	Audrain	Lewis	Adair
Mississippi	Butler	Howell	Dent	Barry	Lincoln	Andrew
New Madrid	Cape Girardeau	Iron	Douglas	Barton	Linn	Atchison
Pemiscot	Ripley	Madison	Franklin	Bates	Livingston	Buchanan
	Scott	Oregon	Jefferson	Benton	McDonald	Clay
	Stoddard	Perry	Ozark	Boone	Macon	Clinton
	Wayne	Reynolds	Phelps	Caldwell	Maries	Davis
		St. Francois	Pulaski	Callaway	Marion	Dekalb
		Ste. Genevieve	St. Louis	Camden	Miller	Gentry
		Shannon	St. Louis City	Carroll	Moniteau	Grundy
			Taney	Cass	Monroe	Harrison
			Texas	Cedar	Montgomery	Holt
			Washington	Chariton	Morgan	Mercer
			Wright	Christian	Newton	Nodaway
				Clark	Osage	Platte
				Cole	Pettis	Putnam
				Cooper	Pike	Schuyler
				Dade	Polk	Sullivan
				Dallas	Ralls	Worth
				Gasconade	Randolph	
				Greene	Ray	
				Henry	St. Charles	
				Hickory	St. Clair	
				Howard	Saline	
				Jackson	Scotland	
				Jasper	Shelby	
				Johnson	Stone	
				Knox	Vernon	
				Laclede	Warren	
				Lafayette	Webster	
				Lawrence		

* PMA is Probable Maximum Acceleration of bedrock which is determined as a fraction of the acceleration of gravity (g = 32.2 fps2) for the six zones in Missouri (see 10 CSR 22-1.020(41)).

** See 10 CSR 22-2.020(3) for clarification.

*** Modified Mercalli Intensity.

Table 5—Spillway Design Flood Precipitation Values

Dam Type	Stage of Construction	Special Descriptions	Environmental Class I	Environmental Class II	Environmental Class III
Conventional or Industrial	Completed	Any existing dam**	.75PMP*	.5PMP*	100 Yr.****
	New dam less than 50 feet in height***		.75PMP*	.5PMP*	100 Yr.****
	New dam greater than 50 feet in height		.75PMP*	.5PMP*	100 Yr.****
Industrial	Starter dam	Any	.5PMP*	.2PMP*	.1PMP*
	After starter dam is finished and before final dam is completed	Any	.75PMP*	.5PMP*	.2PMP*

*PMP is Probable Maximum Precipitation.

**Existing dam means a dam which was completed by August 13, 1981 or which was started prior to August 13, 1981 and completed by August 13, 1987.

***See 10 CSR 22-2.020(3) for clarification.

****100 Yr. is the 100 year frequency rainfall event.

AUTHORITY: sections 236.400, 236.405, 236.415, 236.435, 236.440, and 236.465, RSMo 2016. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed Aug. 15, 1988, effective Jan. 1, 1989. Amended: Filed May 15, 1990, effective Nov. 30, 1990. Amended: Filed June 27, 2018, effective Feb. 28, 2019.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.415, RSMo 1979, amended 1995; 236.435, RSMo 1979; 236.440, RSMo 1979; and 236.465, RSMo 1979.*

10 CSR 22-3.030 Registration Permit Requirements

PURPOSE: The purpose of this rule is to itemize the requirements for a registration permit.

(1) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020(1), (2), (3), and (7), the registration permit application for a conventional dam and reservoir must include certification by an experienced professional engineer or an agency engineer that the dam and reservoir have been inspected in accordance with the law and that the owner has complied with the engineer's recommendations to correct the observed defects and an inspection report, as required by the law. The engineer must further show that the spillway can safely pass the spillway design flood derived from Table 5 and submit a report describing the correction of all observed defects and the description of an operation and maintenance program to be followed while the registration permit is in effect.

(A) The inspection of a dam and reservoir for a registration permit is intended to detect observable defects. The procedure to determine observable defects normally will be a surface examination by an experienced professional engineer or an agency engineer. The inspection must include all surface examinations necessary to determine if observable defects exist that affect the stability of the dam and reservoir or the adequacy of the spillway. Judgment of the structural stability and an evaluation of the spillway capacity must be made. Judgment shall be based upon the engineer's experience, training and knowledge of similar dams and in accordance with practices reputable and in current use in the engineering, geologic and construction professions.

1. Observed defects which may require correction, evaluated on the basis of current engineering, geologic and construction practices, include but are not limited to: slides; slopes as steep as or steeper than those on similar types of dams and constructed of similar materials which have experienced slope stability problems; piping of fines; seepage that exits in an uncontrolled fashion on the downstream slope of or from the downstream foundation of the dam; unusual zones of softness and irregular settlement; erosion on the upstream or downstream slope of the dam; spillways that are calculated to be inadequate for the design flood; spillways that are eroded or otherwise in poor condition and cracks in the embankment or structure.

2. Observed defects that are in an advanced state of deterioration must be immediately reported by the inspecting engineer to the owner and to the chief engineer.

(B) Proper maintenance and operation of a dam and reservoir are critical to the continuing safety of a dam and reservoir and to public safety, life and property. A maintenance program is required and shall include the following items: erosion control on the embankment; monitoring emergency spillway flow rates; vegetation control; spillway maintenance; emergency action plans; maintenance and monitoring of seepage observation devices, if any; and maintenance and monitoring of instruments used, if any, to observe the stability of the dam.

(C) Visits for the purpose of observation of maintenance and operation may be made by the council, the chief engineer, or a member of the chief engineer's staff. Visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life, or property, inspection may be at any time.

(D) The application need not state, nor is it necessary to show, that the dam is a safe dam. The intent of the registration permit is to show that the dam is performing adequately and that there are no observable indications that the dam is unsafe.

(2) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020(1), (2), (3), and (7), the registration permit application for an industrial water retention dam and reservoir shall include certification by an experienced professional engineer or an agency engineer that the dam and reservoir have been inspected in accordance with the law and that the owner has complied with the engineer's recommendations to correct observed defects and an inspection report, as required by the law. The engineer must further show that the spillway can safely pass the spillway design flood derived from Table 5 and submit a report describing the correction of any observed defects, the operation and maintenance program to be made a part of the registration permit and the phased, stepped, and/or continuous construction of the dam.

(A) The inspection of an industrial water retention dam and reservoir for a registration permit is intended to detect observable defects. The procedure to determine observable defects normally will be a surface examination by an experienced professional engineer or an agency engineer. The inspection must include all surface examinations necessary to determine if observable defects exist that affect the stability of the dam and reservoir or the adequacy of the spillway. Judgment of the structural stability and an evaluation of the spillway capacity must be made. Judgment shall be based upon the engineer's experience, training and knowledge of similar dams and in accordance with practices reputable and in current use in the engineering, geologic and construction professions.

1. Observed defects which may require correction, evaluated on the basis of current engineering, geologic and construction practices, include but are not limited to slides; slopes as steep as or steeper than those on similar types of dams and constructed of similar materials which have experienced slope stability problems; piping of fines; seepage that exits in an uncontrolled fashion on the downstream slope of or from the downstream foundation of the dam; unusual zones of softness and irregular settlement; erosion on upstream or downstream slope of the dam; spillways that are calculated to be inadequate for the design flood; spillways that are eroded or otherwise in poor condition and cracks in the embankment or structure.

2. Observed defects that are in an advanced state of deterioration must be immediately reported by the inspecting engineer to the owner and to the chief engineer.

(B) Proper maintenance and operation of a dam and reservoir are critical to the continuing safety of a dam and reservoir and the protection of public safety, life and property. A maintenance program is required and shall include the following items: erosion control on the embankment; monitoring of storm runoff; vegetation control; spillway maintenance; emergency action plans; maintenance and monitoring of seepage observation devices, if any; and maintenance and monitoring of instruments used, if any, to observe the stability of the dam.

(C) The council or chief engineer may require the owner to submit a report describing the phased, stepped, and/or continuous construction of an industrial water retention dam and reservoir, containing information on the materials used, method of transport, and placement of materials, the sequence and placement location of materials, spillway changes to be made, the anticipated final dimensions and configuration of the dam, and the name, address, and telephone number of the person(s) in responsible charge of this work.

(D) Visits for the purpose of inspecting during construction or enlargement or observation of maintenance and operation may be made by the council, the chief engineer, or a member of the chief engineer's staff. Visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property, inspection may be made at any time.

(E) It shall not be necessary for the owner to retain an experienced professional engineer or an agency engineer continuously during the entire permit period unless there is modification(s) in the construction method described in the permit application. However, personnel with adequate supervision and training in methods of safe construction, maintenance and operation of dams must be provided to insure that the construction maintenance and operation of the dam and reservoir are carried out as described.

(F) The registration permit will be the only permit required for an industrial water retention dam and reservoir that was in existence prior to the effective date listed in 10 CSR 22-2.020(2) unless it is to be reduced or removed. If the dam or reservoir is to be reduced or removed, a construction permit will be required. Other changes will require the owner to obtain a new registration permit.

(G) The applicant need not state, nor is it necessary to show, that the dam is a safe dam. The intent of the registration permit is to show that the dam is performing adequately and that there are no readily observable indications that the dam is unsafe and that phased, stepped, and/or continuous construction of the dam will meet the requirements of the law.

AUTHORITY: sections 236.400, 236.405, 236.415, 236.420, 236.425, 236.440, and 236.465, RSMo 2016. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed June 27, 2018, effective Feb. 28, 2019.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.415, RSMo 1979, amended 1995; 236.420, RSMo 1979; 236.425, RSMo 1979; 236.440, RSMo 1979; and 236.465, RSMo 1979.*

10 CSR 22-3.040 Construction Permit Requirements

PURPOSE: The purpose of this rule is to itemize the requirements for a construction permit.

(1) In addition to the basic requirements for all permits listed in 10 CSR 22-3.030, the construction permit application for a conventional dam and reservoir shall be prepared under the direction of and certified by an experienced professional engineer and shall be in accordance with practices reputable and appropriate in the engineering, geologic, and construction professions.

(A) The following information shall be provided by the owner:

1. Up-to-date topographic map(s) showing the location of the proposed or existing dam, the upstream watershed, the reservoir, and the downstream environment zone. An up-to-date United States Geological Survey topographic map is considered a minimum;

2. Exploration records and results including the location of all exploration, especially in the area of the core trench, the method(s) used to explore the site, a record of what was found, the method(s) used to obtain samples, and the number of samples taken;

3. Testing records and results including information on the care and treatment of samples, types of tests performed on samples or *in situ*, reference(s) to or the procedures used in testing, and the test results. Physical and mechanical properties of foundation and construction materials must include the information source for these values, especially if they are not the results of testing;

4. The geotechnical design procedure(s) or method(s) shall be identified and referenced or described so that they may be reviewed and the applicability verified. This shall include all assumptions made. The geotechnical procedure(s) or design results shall include the minimum computed factors of safety and they must meet or exceed the design factors of safety (see 10 CSR 22-3.020(4)). The geotechnical design information shall be presented for the foundation, core trench, and dam embankment. Earthquake loading must be analyzed as outlined in 10 CSR 22-3.020(5) and (6);

5. The structural design procedure(s) or method(s) shall be identified and referenced or described so that they may be reviewed and their applicability verified. Design results for concreted dams and concrete structures appurtenant to embankment dams shall provide for and show an adequate factor of safety for normal and maximum loading conditions of compression, tension, shear, torsion, buckling, sliding, and overturning;

6. Hydrologic information used to evaluate the watershed, reservoir, spillway, and downstream environment zone including the watershed area, rainfall rate and duration, antecedent moisture conditions, time of concentration, area capacity curves, description of spillway elevation(s), type(s), dimensions, locations, cross section and profiles, dam crest elevation, and the downstream valley cross sections;

7. The hydrologic/hydraulic design procedure(s) or method(s) used shall be identified and referenced or described so that they may be reviewed and their applicability verified. This includes all assumptions made. The hydrologic/hydraulic procedure(s) or design results shall include the reservoir inflow hydrograph, the reservoir outflow hydrograph, the spillway discharge capacity, the freeboard at the maximum water storage elevation, and the environmental class of the dam. The dam shall be capable of safely containing or discharging the required design flood (see 10 CSR 22-3.020(5));

8. Location and design of diversion channels or other structures to control stream flow during or after construction shall be provided if failure of these channels or other structures would affect hydrologic conditions of the dam. Stream diversion systems used during construction shall be designed to provide protection to the dam and the safety of the public;

9. Construction control and inspection procedures shall be used during the construction of a new dam and reservoir or modification of an existing dam and reservoir. Construction control and inspection procedures should include compaction testing and density testing;

10. Procedures shall be used for recordkeeping and monitoring throughout the construction or modification process to provide information about any construction progress and conditions that may cause difficulties during construction;

11. The location of and protective measures used in conjunction with all drain lines, sewer lines, utilities, or other structures that pass through or under the dam;

12. Topographic surveys showing the location of baselines, centerlines, and other horizontal and vertical control points sufficiently accurate to locate the proposed construction and to define the volume of storage in the reservoir;

13. Two (2) sets of plans and specifications including—

A. Graphic scales for all scaled drawings;

B. The title, displayed identical on the plans and the specifications, shall include: the name of the dam; the name of the owner; whether the work shows an existing dam, a proposed dam, or an enlargement, repair, or alteration of the dam, or reservoir; the county(ies) the dam and reservoir are in; the location of the dam by quarter section, section, township and range, or by geodetic coordinates; and each sheet shall have in an appropriate title block the name of the dam as well as the sheet number in relation to the total, for example, sheet one (1) of twelve (12); and

C. Certifications by the experienced professional engineer and the owner shall be provided and be similar to those presented in figures 1 and 2 (see figures 1 and 2); and

Figure 1

Certification by Experienced Professional Engineer

I hereby certify that these plans for the (insert the correct word or words choosing

from: existing; construction of the; repair of the; enlargement of the; or alteration of the

________________________________ Dam were prepared by me (or under my
Name of Dam
direct supervision) for the owners thereof.

____
Firm Name

____
Registered Engineer (Seal)

Figure 2

Certification by Owner

I, ________________________________, owner, whose Post Office Address is
Name of Owner
________________________________ , Zip ________________________ , do
Owner's Address

hereby accept and approve these plans.

____
Owner

14. If a construction permit is requested to convert a dam to a retaining or retarding structure, the procedure to be followed in making the conversion shall be described by the owner; and

15. The procedures set up for regular inspection by the owner. The owner shall develop an emergency action plan, inspect his/her dam regularly and as necessary to protect public safety, life and property. A list of items to be inspected, a time schedule for these inspections, and a form for reporting the results shall be established.

(B) The council or chief engineer may require the following action and information from the owner:

1. Procedures set up to provide regular maintenance and minor repairs to the dam and reservoir after construction and to continue or start recordkeeping and monitoring work so that the dam and reservoir are maintained in a safe condition and a complete history of its performance is available;

2. Location and types of instrumentation, drainage, and/or seepage control facilities. Monitoring equipment and drainage and seepage control facilities are recommended for all dams and reservoirs, however, depending on conditions, they may be mandatory items if necessary to accomplish the purposes of the law;

3. The downstream environment zone warning procedure to be used if dam failure is a threat. A downstream environment zone warning system is recommended for all dams and reservoirs, however, depending on conditions, it may be necessary to accomplish the purposes of the law. This would consist of the current name(s) of the dam and reservoir owners' representative(s) responsible for giving notification of a threat of failure and the current phone numbers of appropriate local police and other persons having emergency assistance authority;

4. Upstream slope protection from wave action; and

5. Additional actions or information as required to protect public safety, life and property and to accomplish the purposes of the law.

(C) Visits for the purpose of inspecting during or after construction or observation of operation and maintenance may be made by the council, the chief engineer, or a member of the chief engineer's staff. Visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property, inspection may be made at any time.

(2) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020, the construction permit application for an industrial water retention dam and reservoir shall be prepared under the direction of and certified by an experienced professional engineer and shall be in accordance with practices reputable and appropriate in the engineering, geologic, and construction professions.

(A) The engineer who plans and designs an industrial water retention dam and reservoir or its modification shall assess the sequence, timing, method of placement and stability control program during construction from the beginning of the starter dam or modification through the life of the structure and after operation ceases or until the dam and reservoir no longer need a permit.

(B) Adequate records, as required by best practices in the geologic and engineering professions, shall be kept and made available to the council or chief engineer for the construction, maintenance, and operation procedures. Adequate instrumentation and monitoring of seepage water shall be provided where necessary. Any significant settling or movement in the foundation of the dam should be measured, if possible. Trained personnel and adequate supervision shall be provided to insure the construction and operation of the dam and reservoir are carried out to specifications.

(C) The following information shall be provided by the owner:

1. A description of the system used to deposit tailings on the dam;

2. Up-to-date topographic map(s) showing the location of the proposed dam, the upstream watershed, the reservoir, and the downstream environment zone. An up-to-date United States Geological Survey topographic map is considered minimum;

3. The location(s) of surface and underground mine workings if these workings would cause, would contribute to the cause, or would be affected in the event of failure;

4. Exploration records and results including the location of all exploration, especially in the area of the core trench, the method(s) used to explore the site, a record of what was found, the method(s) used to obtain samples, and the number of samples taken;

5. Testing records and results including information on the care and treatment of samples, types of tests performed on samples or *in situ*, reference(s) to or the procedures used in testing, and the test results. Physical and mechanical properties of foundation and construction materials must include the information source for these values, especially if they are not the results of testing;

6. The geotechnical design procedure(s) or method(s) shall be identified and referenced or described so that they may be reviewed and their applicability verified. This shall include all assumptions made. The geotechnical procedure(s) or design results shall include the minimum computed factors of safety and they must meet or exceed the design factors of safety (see 10 CSR 22-3.020(4)). The geotechnical design information shall be presented for the foundation core trench and dam embankment. Earthquake loading must be analyzed as outlined in 10 CSR 22-3.020(5) and (6);

7. Type and physical properties of the liquid and solid materials to be used in construction of the dam and contained in the reservoir;

8. The changes created in the downstream environment zone as the dam and reservoir become incrementally larger;

9. The embankment changes and new factors of safety for stability as the dam and reservoir become incrementally larger;

10. If a starter dam is used, whether it will be pervious or impervious;

11. The expected crest elevation, dam configuration, spillway elevation, and the size and configuration of each successive stage of the dam shall be included;

12. Anticipated storage volume of solid or semisolid materials and of liquids at the completion of the dam;

13. The structural design procedure(s) or method(s) shall be identified and referenced or described so that they may be reviewed and their applicability verified. Design results for concrete dams and concrete structures appurtenant to embankment dams shall provide for and show an adequate factor of safety for normal and maximum loading conditions of compression, tension, shear, torsion, buckling, sliding, and overturning;

14. Hydrologic information used to evaluate the watershed, reservoir, spillway, and downstream environment zone including the watershed area, rainfall rate and duration, antecedent moisture conditions, time of concentration, area capacity curves, description of spillway elevation(s), type(s), dimensions, locations, cross sections and profiles, dam crest elevation, and the downstream valley cross sections;

15. Hydrologic/hydraulic design procedure(s) or method(s) used shall be identified and referenced or described so that they may be reviewed and their applicability verified. This shall include all assumptions made. The hydrologic/hydraulic procedure(s) or design results shall include the reservoir inflow hydrograph, the reservoir outflow hydrograph, the spillway discharge capacity, the freeboard at the maximum water storage elevation and the environmental class of the dam. The dam shall be capable of safely containing or discharging the required design

flood (see 10 CSR 22-3.020(5));

16. The hydrologic changes, the spillway alterations proposed, and the freeboard changes as the dam becomes incrementally larger;

17. Location and design of diversion channels or other structures to control stream flow during or after construction shall be provided if failure of these channels or other structures would affect the stability or hydrologic conditions of the dam. Stream diversion systems used during construction shall be designed to provide protection to the dam and to protect public safety, life and property;

18. Location and design of any diversion channels or other structures to control runoff or reclaimed water;

19. Construction control and inspection procedures shall be determined by the engineer and used during the construction of a new dam and reservoir or modification of an existing dam and reservoir. Construction control and inspection procedures shall include compaction testing and density testing and any other quality control measures used to insure compliance with the construction specifications;

20. Procedures shall be used for recordkeeping and monitoring throughout the construction, enlargement, or modification process to provide information about any construction progress and conditions that may cause difficulties during construction;

21. The location of and protective measures used in conjunction with all drain lines, sewer lines, utilities, or other structures that pass through or under the dam;

22. Topographic surveys showing the location of baselines, centerlines, and other horizontal and vertical control points sufficiently accurate to locate the proposed construction and to define the volume of storage in the reservoir at each planned stage of construction;

23. Two (2) sets of plans and specifications including:

A. Graphic scales for all scaled drawings;

B. The title, displayed identical on the plans and the specifications, shall include: the name of the dam; the name of the owner; whether the work shows an existing dam, a proposed dam or an enlargement, repair, or alteration of the dam and reservoir; the county(ies) the dam and reservoir are in; the location of the dam by quarter section, section, township, and range, or by geodetic coordinates; and each sheet shall have in an appropriate title block the name of the dam, as well as the sheet number in relation to the total, for example, sheet one (1) of twelve (12); and

C. Certification by the experienced professional engineer and the owner shall be placed near the lower right-hand corner of the title sheet (first sheet) of the drawing. The certifications shall be as presented in figures 1 and 2 (see figures 1 and 2 preceding);

24. If a construction permit is requested to convert a dam to a retaining or retarding structure, the procedure to be followed in making the conversion shall be described by the owner; and

25. The procedure set up for regular inspection by the owner. The owner shall develop an emergency action plan, inspect his/her dam and reservoir regularly and as necessary to protect public safety, life and property. A list of items to be inspected, a time schedule for these inspections, and a form for reporting the results shall be established by the council or chief engineer. Items that shall receive maintenance to and/or inspections on a daily basis during periods of active dam enlargement include: the spigots or cyclones; the decant lines; the position of the water pool in relation to the spillway, decant intake, and crest of the tailings dam; drain lines checked for quantity of water and sediment; the embankment observed for visual defects such as slides or significant seepage changes; the spillway shall be checked to verify that it has not become blocked.

(D) The council or chief engineer may require the following action and information from the owner:

1. Procedures set up to provide regular maintenance and minor repairs to the dam and reservoir during construction and enlargement so that the dam and reservoir are maintained in a safe condition and a complete history of its performance is available;

2. Location and types of instrumentation, drainage, and/or seepage control facilities. Monitoring equipment and drainage and seepage control facilities are recommended for all dams and reservoirs, however, depending on conditions, they may be mandatory items, if necessary, to accomplish the purposes of the law; a list of items to be inspected, a time schedule for these inspections, and a form for reporting the results shall be established by the council or chief engineer;

3. The downstream environment zone warning procedure to be used if dam failure is a threat. A downstream environment zone warning system is recommended for all dams and reservoirs, however, depending on conditions, it may be necessary to accomplish the purposes of the law. This would consist of the current name(s) of the dam and reservoir owners' representative(s) responsible for giving notification of a threat of failure and the current phone numbers of appropriate local police and other persons having emergency assistance authority;

4. Upstream slope protection from wave action; and

5. Additional actions or information as required to protect public safety, life and property and to accomplish the purposes of the law.

(E) Visits for the purpose of inspecting during or after construction or observation of operation and maintenance may be made by the council, the chief engineer, or member of the chief engineer's staff. Visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property, inspection may be made at any time.

(F) Drawings to show changes shall be submitted when changes are made to the original plans including, without limitation, changes in incremental dam crest heights, spillway locations, and cross sections.

AUTHORITY: sections 236.400, 236.405, 236.415, 236.420, 236.425, 236.435, 236.440, and 236.465, RSMo 2016. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed June 27, 2018, effective Feb. 28, 2019.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.415, RSMo 1979, amended 1995; 236.420, RSMo 1979; 236.425, RSMo 1979; 236.435, RSMo 1979; 236.440, RSMo 1979; and 236.465, RSMo 1979.*

10 CSR 22-3.050 Safety Permit Requirements

PURPOSE: The purpose of this rule is to itemize the requirements for a safety permit.

(1) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020, the safety permit application for a conventional dam and reservoir shall include:

(A) Notification of the completion of construction and application for the first safety permit for the dam and reservoir shall be provided by the owner. The experienced professional engineer or agency engineer who was in responsible charge of the construction work shall certify that the construction was substantially in accordance with the approved plans and specifications. If revisions have been made which vary considerably from the provisions of the construction permit, it must be shown that the revisions do not endanger public safety, life or property. This subsection shall not be construed to excuse any person from the requirement to notify the council or chief engineer of modifications or revisions prior to commencing the actions and to obtain the required permits or authorization thereof;

(B) Notification of completion shall be within two (2)-months' time after completion of construction; and

(C) As-built drawings shall be submitted.

(2) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020, the application for a safety permit for an industrial water retention dam and reservoir shall include:

(A) Notification of completion of the starter dam or the initial phase of construction shall be prepared by, or under the supervision of, an experienced professional engineer and shall indicate that construction was performed in accordance with the provisions of the construction permit;

(B) Notification of the completion of construction and application for the first safety permit for the dam and reservoir shall be provided by the owner. The experienced professional engineer who was in responsible charge of the construction work shall certify that the construction was substantially in accordance with the approved plans and specifications. If revisions have been made which vary considerably from the provisions of the construction permit, it must be shown that the revisions do not endanger public safety, life or property. This subsection shall not be construed to excuse any person from the requirement to notify the council or chief engineer of modifications or revisions prior to commencing the actions and to obtain the required permits or authorization therefore;

(C) Notification of completion shall be within two (2) months time after completion of construction; and

(D) As-built drawings shall be submitted.

(3) Visits for the purpose of observation of operation and maintenance procedures may be made by the council, the chief engineer, or a member of their staff. Visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property, inspection may be made at any time.

AUTHORITY: sections 236.400, 236.405, 236.415, 236.420, 236.425, 236.440, and 236.465, RSMo 2016. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed June 27, 2018, effective Feb. 28, 2019.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.415, RSMo 1979, amended 1995; 236.420, RSMo 1979; 236.425, RSMo 1979; 236.440, RSMo 1979; and 236.465, RSMo 1979.*

Rules of

Department of Natural Resources

Division 22—Dam and Reservoir Safety Council
Chapter 4—Action Taken by Council and Chief Engineer

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Title 10—DEPARTMENT OF NATURAL RESOURCES
Division 22—Dam and Reservoir Safety Council
Chapter 4—Action Taken by Council and Chief Engineer

10 CSR 22-4.010 Emergency Action
(Rescinded August 30, 2018)

AUTHORITY: sections 236.400, 236.405, 236.420, 236.425 and 236.455, RSMo 1986. Original rule filed June 14, 1984, effective Jan. 1, 1985. Rescinded: Filed Dec. 29, 2017, effective Aug. 30, 2018.

10 CSR 22-4.020 Enforcement Orders and Enforcement Procedures

PURPOSE: The purpose of this rule is to identify the procedure to be taken for the issuance of enforcement orders.

(1) Enforcement orders shall be prepared by the chief engineer or council in cases where a dam or reservoir contains serious defects which pose a threat to public safety, life or property. Enforcement orders shall be sent to a dam owner by certified mail or served personally.

(2) If an owner does not initiate corrective actions to his/her dam and reservoir within thirty (30) days of the issuance of an enforcement order by the chief engineer or council, the council may request the attorney general or a prosecuting attorney to apply to the circuit court having jurisdiction to enforce compliance.

AUTHORITY: sections 236.400, 236.405, 236.410, 236.415, 236.445, and 236.450, RSMo 2016. Original rule filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed June 27, 2018, effective Feb. 28, 2019.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.410, RSMo 1979, amended 1992, 2013; 236.415, RSMo 1979, amended 1995; 236.445, RSMo 1979; and 236.450, RSMo 1979.*