Garlo Heritage Nature Preserve
Bloomville, Ohio

P2# 486325
Section 22: Planning Assistance to States (PAS)

Technical Assistance Report

January 2022

US Army Corps of Engineers
Buffalo District
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Executive Summary

This report presents the analysis and findings from a Planning Assistance to States (PAS) study, conducted on behalf of the Seneca County Parks District (SCPD), to evaluate the hydrologic and ecological conditions of the Garlo Heritage Nature Preserve. The preserve is located in Bloomville, OH and managed by SCPD. Olgierd Lake, a 39-acre manmade waterbody, is located centrally on the preserve. Waterbodies within the preserve have experienced increasing eutrophication and overall habitat degradation. Excessive algal productivity and nutrient loadings are degrading habitat quality and limiting the uses of Olgierd Lake.

Section 22 of the 1974 Water Resources Development Act, as amended (42. U.S.C. 1962d-16 authorizes the U.S. Army Corps of Engineers (USACE) to provide technical assistance related to the management of state water resources. This study was needed to assist in the evaluation of waterbodies within Garlo Heritage Nature Preserve. The study consisted of the following components:

1. An ecological evaluation
2. A water chemistry analysis
3. A hydrologic assessment of Olgierd Lake and surrounding waterbodies
4. The development of conceptual measures to reduce algal blooms and improve ecological condition

The analysis of water chemistry suggested that Olgierd Lake is hypereutrophic with high nutrient concentrations (phosphorus and nitrogen), high algal biomass, and low dissolved oxygen. The source of the nutrients appears to be the tributaries that feed the lake. The algal blooms in June 2021 consisted primarily of the blue-green algae Microcystis spp. that can produce a toxin (microcystin) that is harmful to humans. The low dissolved oxygen levels are a stressor to aquatic wildlife and further exacerbate eutrophication when ortho-phosphate from the sediment is released into the water column.

The ecological assessment indicated that the general water quality within Olgierd Lake is poor, characterized by high turbidity, high nutrients, frequent algal blooms, and low dissolved oxygen. Despite these conditions, some evidence of fish presence was observed. No evidence of floating or submerged aquatic vegetation beds were observed during the evaluation. The lake is surrounded by forests, as well as several emergent and forested wetlands.

The hydrologic analysis indicated that Olgierd Lake was historically (i.e., prior to the 1970s) a wetland that received runoff from nearby fields. The primary inflow location is a culvert on the east side of the lake; the main outflow is a spillway along a berm on the west side of the lake. A flow frequency analysis estimated the mean annual flow into Olgierd Lake to be 1.62 cfs. The annual hydraulic retention time was estimated to be ~32 days, with a monthly high of 246 days in September. This suggests that the lake is very stagnant, especially during the summer. Two regional models were utilized to estimate annual nutrient loadings. These correspond to a mean annual total phosphorous concentration of 0.271 to 0.343 mg/L. Based on these concentrations, a partial wetland conversion or upstream treatment wetland would be inadequate at reducing nutrient loading enough to significantly improve conditions in the lake.

A total of nine conceptual measures are described and evaluated. Full wetland restoration (i.e., converting the entirety of Olgierd Lake into a wetland) is most likely to mitigate algal blooms; this is especially true if it is combined with upstream nutrient management. If a full conversion of Olgierd Lake is not an option, other measures, such as hydraulic separation, could potentially mitigate algal blooms; however, the effectiveness of these approaches are less certain and likely would require a combination of several different measures.

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1 Introduction

1.1 Project Location and Background

Garlo Heritage Nature Preserve is located at 6777 S. State Route 19, in Bloomville, Seneca County, OH (Figure 1). The preserve contains 292 acres of fields, wetlands, and hardwood forest. It is managed by the Seneca County Park District (SCPD). The property was a family farm that was gifted to SCPD in 1997. Olgierd Lake (Ollie Pond), a 39-acre manmade waterbody, is located centrally on the preserve. It is fed from the east by two small tributaries and drains over a berm on the west side of the lake. It has a relatively shallow depth (< 3 feet) and provides limited habitat due to the low oxygen levels. Several smaller, surrounding water bodies are also located within the preserve.

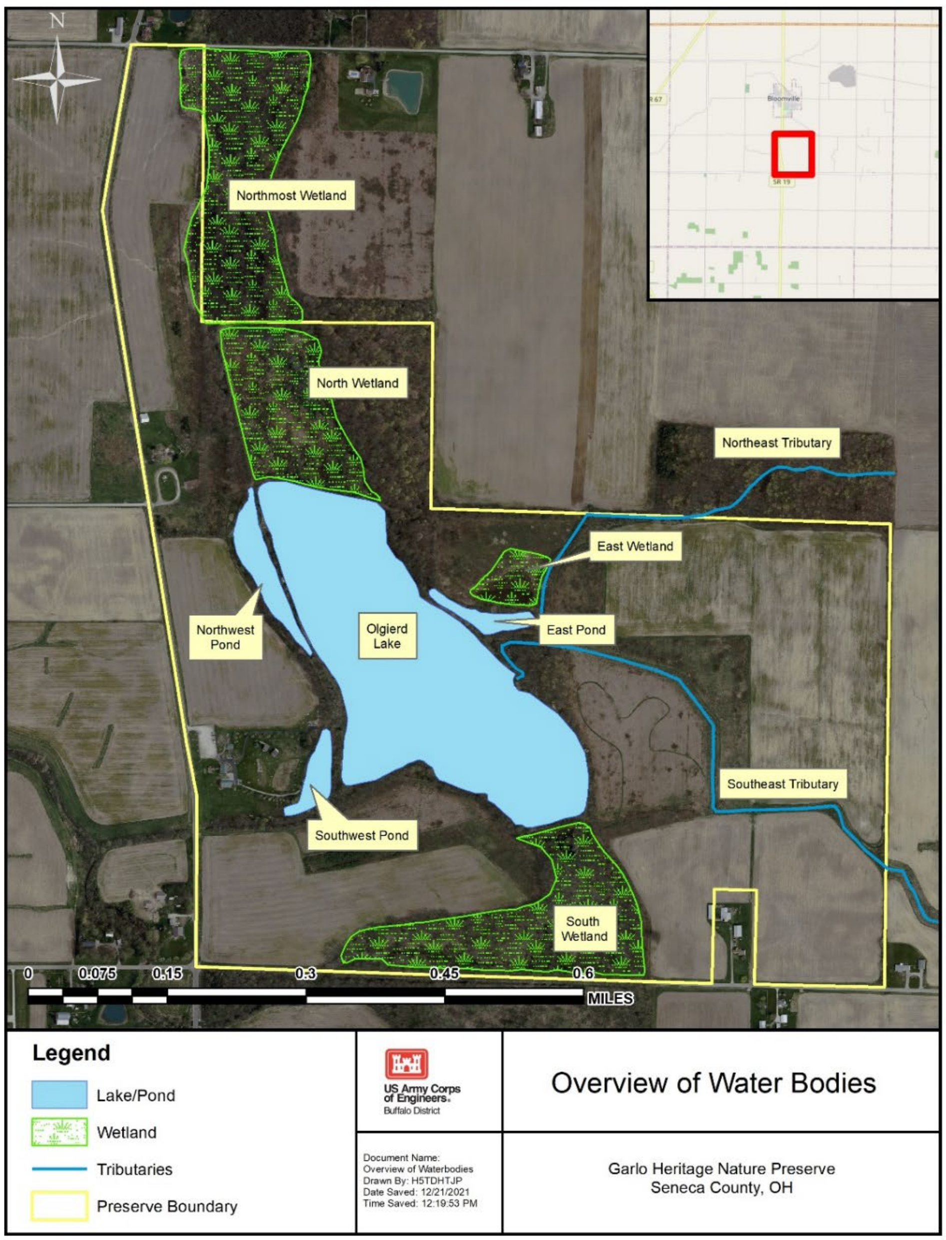

Figure 1: Map of waterbodies within Garlo Historic Nature Preserve.

1.2 Study Authority – Planning Assistance to States (PAS)

Section 22 of the Water Resources Development Act of 1974, as amended (42. U.S.C. 1962d-16) authorizes the U.S. Army Corps of Engineers (USACE) to provide technical assistance related to the management of state ware resources to a state or non-federal interest working with a state. The technical assistance component of this program is used to deliver hydrologic, economic, and environmental data and analysis. Technical assistance activities through the PAS program are cost shared fifty percent with the study partner. Federal appropriations vary from year to year; there is a maximum of $5,000,000 per state per year to work on Planning and Assistance to States (PAS) studies.

1.3 Project Need

This project was needed to assist in the evaluation of hydrologic and ecological issues associated with several waterbodies that are part of the Garlo Heritage Nature Preserve. In June of 2019, SCPD requested planning assistance for issues related to the preserve's man-made water bodies, including Olgierd Lake and the smaller surrounding ponds. These waterbodies were created before the property became part of SCPD's holdings and have experienced increasing eutrophication and overall habitat degradation. Excessive algal productivity (Figure 2) and nutrient loadings are degrading habitat quality and limiting the uses of Olgierd Lake and the adjacent waterbodies. These algal blooms include species of blue-green algae that can produce toxins harmful to humans. The occurrence and intensity of these algal blooms has increased to the point that recreational boating/paddling is no longer permitted in Olgierd Lake.

Figure 2: Images of algal blooms occurring within Garlo Heritage Nature Preserve; taken on July 3rd, 2018 by SCPD.

1.4 Scope of this PAS Study

To address the problems identified by SCPD, USACE completed an evaluation of the hydrologic and ecological conditions of the Garlo Heritage Nature Preserve. The scope focused on Olgierd Lake, but also considered other smaller waterbodies within the preserve. The study consisted of the following components:

1. An ecological evaluation:
    a. Characterization of habitat types and plant communities in the vicinity of Olgierd Lake
2. A water chemistry assessment:
    a. An evaluation of water chemistry parameters that affect habitat quality of Olgierd Lake
3. A hydrologic analysis of Olgierd Lake and surrounding waterbodies:
    a. Compilation of historical maps and aerial imagery to assess historic conditions
    b. Assessment of current hydrologic conditions
    c. Delineation of hydrologic boundaries (i.e., watersheds) and flow paths
    d. Estimations of nutrient loads
4. The development of conceptual measures to reduce algal blooms
    a. General description measures that can be used to support future planning considerations
    b. Discussion of follow-up analyses and design considerations
    c. Qualitative comparison of the advantages, disadvantages, and likelihood of success

2 Ecological Assessment

Garlo Nature Preserve consists of a variety of habitat types including deciduous woods, riparian corridors, forested wetlands, emergent wetlands, and lakes. USACE conducted a site evaluation of the preserve on June 2nd and 3rd, 2021. Vegetation and wildlife surveys were not conducted as part of this field effort, however, a brief description of the habitats observed is included below.

2.1 Olgierd Lake

Olgierd Lake is located centrally within the park, fed by the inflow of two tributaries on its east side, and bordered to the north and south by forested wetlands. This 39-acre manmade lake is shallow with nearly uniform bottom depths averaging 3 feet (Appendix A). General water quality in the lake is poor, characterized by high turbidity, high nutrients, frequent algal blooms, and low dissolved oxygen (see section 3, Figure 3). Despite these conditions, some evidence of fish presence was observed. No evidence of floating or submerged aquatic vegetation beds were observed during the evaluation. The lake is surrounded by deciduous forest consisting of a mixture of trees, including cottonwood, willow, green ash, red oak, basswood, and silver maple. These adjacent forested areas provide overhanging structure and other habitat for a variety of birds and other wildlife including wood duck, green heron, great blue heron, and belted kingfisher (eBirds.org, accessed 12/7/2021).

Figure 3. Left) Olgierd Lake, looking east from dock on west shore. Right) Small marsh located north of east pond. 3 June 2021.

2.2 Adjacent Wetlands

A small depressional wetland is located east of Olgierd Lake, just north of the east pond. This wetland is predominantly open water but supports a wide band of emergent vegetation on its northern side (Figure 3). This wetland appeared to support both open water, emergent, and wet meadow vegetation communities. It also appeared to have better water quality (lower turbidity, algal growth) than the other waterbodies observed at the preserve.

Forested wetlands are located to the north and south of Olgierd Lake. The forested wetland to the north is part of the Silver Creek Wildlife Management Area. This wetland is formed in a lowland area between upland areas to the east and west and extends to the north. It appears to be fed by runoff from the east and overflow from Olgierd Lake. A ditch runs perpendicular to this wetland in a north to south direction on its west side. The vegetation within this wetland consists of a somewhat sparce canopy of silver maple and black willow and an herbaceous layer that is heavily dominated by reed canary grass and phragmites, with some interspersed emergent vegetation and shrubs (Figure 4). Despite the dominance of the invasive reed canary grass and phragmites, this area has a variety of canopy layers and vegetation communities.

The wetlands to the south of Olgierd Lake are geomorphically similar to those north of the lake, formed in a narrow lowland between adjacent sloping areas to the east and west. This area is also a forested wetland; however, it maintains a denser canopy of more mature trees (oak and silver maple, Figure 4). Its hydrology is driven by surface runoff from the surrounding higher landscape. These wetlands to the north and south may provide a reference for what the Olgierd Lake may have been like prior hydrologic modification and conversion to open water.

Figure 4. Left) Forested wetland to the north of Olgierd Lake. Right) Forested wetland to the south of Olgierd Lake. June 3 2021.

2.3 Other Waterbodies

Olgierd lake is adjacent to several other smaller waterbodies. A small pond is located immediately east of Olgierd Lake. This small pond appeared very turbid and did not appear to support any emergent vegetation. It was bordered by a community of shrubs and hardwood trees including dogwood, red oak, silver maple and willow (Figure 5).

A large ditch runs parallel to the west edge of Olgierd Lake and extends in a north and south direction beyond the boundaries of the preserve. Minimal flow was observed in the ditch during the site visit; however, some parts of the ditch were wide and pond-like, while other parts where narrow (Figure 5). Minimal aquatic life was observed within the ditches.

Figure 5. Left) East pond, adjacent to the east pond of Olgierd Lake. Right) Ditch west Olgierd Lake. 3 June 2021.

The tributaries feeding Olgierd Lake were narrow, low-slope, and low velocity. The southeast tributary appeared to have greater volume and flowed through an open field and meadow before joining with the other tributary and flowing into Olgierd Lake. This tributary appeared to have a two-stage channel morphology with a narrow central channel adjacent to wider flat vegetated terraces. Despite the dense vegetation (reed canary grass), this creek had high nutrient content and high turbidity (see section 3). The northeast tributary was smaller than the southeast tributary and flowed through low-lying forested areas before joining the southeast tributary and entering Olgierd Lake (Figure 6). It had minimal channel development and low diversity of flow conditions. This tributary also had high nutrient concentrations and turbidity (see section 3). Due to their uniform conditions and poor water quality, these tributaries likely provide minimal habitat for aquatic organisms.

Figure 6. A) Southeast tributary to Olgierd Lake. B) Northeast tributary to Olgierd Lake, 3 June 2021.

3 Water Chemistry Data Collection and Analysis

3.1 Water Chemistry Data Collection

USACE measured in-situ water chemistry parameters at 16 locations (13 from the lake and one each from the northeast tributary, southwest tributary, and southwest pond) on 3 June 2021 (Figure 7). This was accomplished using a multi-meter. At each location, field staff recorded the following parameters:

- Temperature
- pH
- Conductivity
- Dissolved Oxygen (DO)
- Turbidity
- Depth

Water samples were also collected for laboratory analysis at five locations (three from the lake and one from the northeast and southeast tributary). The samples were analyzed for the following:

- Total Phosphorous (TP)
- Total Kjeldahl Nitrogen (TKN)
- Nitrate/Nitrate (NO_2/NO_3)
- Total Suspended Solids (TSS)
- Chlorophyl a

All water chemistry data collected by USACE is included in Appendix A

Additionally, researchers from Heidelberg University shared data collected from Garlo between 13 July 2021 and 7 October 2021. Samples were collected from 8 locations within the pond and adjacent ditches. Samples were collected on five dates during the summer and early fall of 2021 (July 13th, July 29th, August 13th, September 2nd, and October 10th) at eight locations (Figure 8). The samples were analyzed for the following parameters:

- Ammonia
- Chloride
- Sulfate
- Nitrite
- Nitrate
- Silica
- Soluble Reactive Phosphorus
- Total Phosphorus
- Total Kjeldahl Nitrogen
- Suspended Sediments
- Flouride
- Algae
- Temperature
- Dissolved Oxygen
- pH
- Specific conductivity
- Turbidity

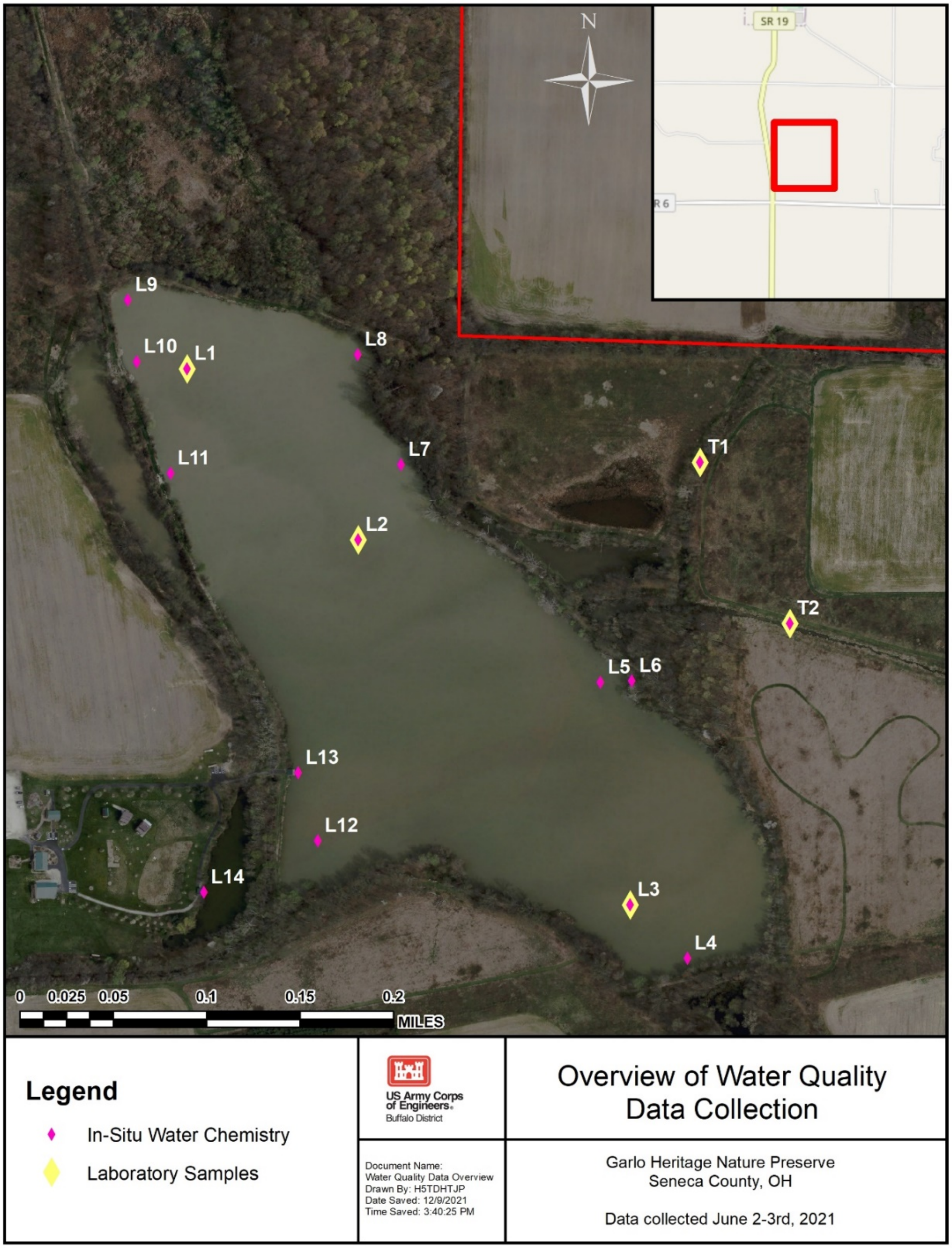

Figure 7: Overview of water quality data collected during the June 2021 site visit.

Figure 8: Location of water quality samples collected by the National Center for Water Quality Research at Heidelberg University.

The water chemistry data was collected by USACE during a single day and so provides a snapshot of the conditions within Olgierd Lake. Although the data is supplemented by the information shared by Hedielberg University, the combined data set only cover several months of a single year and, therefore, likely does not capture the full range of conditions that may exist within Olgierd Lake. A much more intensive sampling and analysis program would need to be initiated to fully characterize the dynamics of water chemistry within Olgierd Lake and its surrounding water bodies; such a study was beyond the scope of this evaluation. Nonetheless, the limited data collected is used to characterize the chemical conditions within the lake and surrounding waterbodies within the context of water quality and ecological condition. The following discussion will focus on a subset of the measured parameters in order to discuss how they may be contributing to the poor aesthetic and ecological conditions within Olgierd Lake as discussed in section 1.0. Water chemistry parameters including temperature, pH, specific conductivity, suspended solids, chlorophyll a, total phosphorus (TP), total kjedal nitrogen (TKN), ammonia, nitrate/nitrate, and dissolved oxygen are discussed below; additional water chemistry data is included in Appendix A. All samples were collected mid-water column. This should reflect the entire water column as the lake is shallow (<3 feet).

3.2.1 Temperature, pH, Specific Conductivity, and Total Suspended Solids

Temperatures in Olgierd Lake during the June 3rd field sampling ranged from 18.9 to 20.4 degrees Celsius (°C). Conditions within the tributaries upstream of the lake were colder ranging from 16.0 to 16.4 °C. The Heidelberg dataset indicates temperature peaked in Olgierd Lake at 29.2 °C on 29 July 2021 and gradually cooled to 20.3 °C by 7 October 2021. Consistent with the USACE data, this dataset also showed that the upstream tributaries were generally several degrees cooler than the lake ranging from 25.4 °C in July to 17.9 °C in October. The peak temperature of 29.2 °C is quite high. As warmer water holds less dissolved oxygen, the high-water temperatures are likely contributing to the anoxic conditions (discussed more in section 3.2.2)

The measure of pH represents how acidic or basic a water body is. Understanding pH is important for determining how chemical compounds are likely to react in an environment. Generally, pH ranged from neutral (7.07) to weakly alkaline (9.60) within Olgierd Lake and the tributaries feeding it. During USACE's sampling, pH was similar in Olgierd Lake and its tributaries. The supplemental data provided by Heidelberg University suggested a slightly more variable range of pH, with Olgierd Lake being somewhat more alkaline than the ditches that feed it.

Specific conductivity, measured in units uS/cm, was also measured for the lake and tributaries. Specific conductivity is a measurement of the ability of water to conduct electricity and can be used as an indicator of different water inflows (i.e., ground water vs. surface water). The lake was mostly uniform with the majority of measurements ranging from 307.8 to 308.8 µS/cm (Figure 9). Two measurements taken from the lake near the inflow culvert had higher measurements of 320.5 and 473.9 µS/cm. Measurements taken upstream of the lake in tributary ditches also had elevated measurements of 444.2 and 579.0 µS/cm. The uniformity of specific conductance in the lake, and the elevated readings measured at the inflow and tributaries, suggests that the lake is primarily fed by the inflow culvert and does not receive much sub-surface inflow from ground water at other parts of the lake.

Table 1. TSS, pH, DO, and Turbidity; Olgierd Lake, June 2021.

Sample ID	Collection Date	TSS	pH	DO	Spec. Conductivity	Turbidity
		mg/L		mg/L	uS/cm	NTU
T1	20210603	20.8	7.71	6.49	579.0	24.04
T2	20210603	21.6	7.45	6.34	444.2	27.62
L1	20210603	73.2	7.78	5.96	308.4	158.90
L2	20210603	66.8	7.80	5.13	308.7	121.70
L3	20210603	70.0	7.72	5.40	307.8	169.60
L4	20210603	-	7.82	6.28	308.3	163.60
L5	20210603	-	7.89	6.75	320.5	111.10
L6	20210603	-	7.61	5.56	473.9	62.06
L7	20210603	-	7.83	7.14	308.5	97.85
L8	20210603	-	7.96	7.16	308.7	151.00
L9	20210603	-	7.8	6.02	308.5	132.40
L10	20210603	-	7.81	7.02	308	108.00
L11	20210603	-	7.86	5.55	308.8	124.00
L12	20210603	-	7.61	4.83	308.8	164.90
L13	20210603	-	7.73	5.7	308.1	82.09
L14	20210603	-	7.86	5.37	353.1	13.10

Water clarity is generally poor in the lake with turbidity, measured in nephelometric turbidity units (NTUs), averaging 118.59 NTUs and total suspended solid (TSS) concentrations ranging from 66.8 to 73.2 mg/L. During the June 3rd sampling, the water was a greyish brown color, and the lake bottom was not visible, despite depths being only around 3 feet.

All water chemistry data and interpolated heat are included in Appendix A.

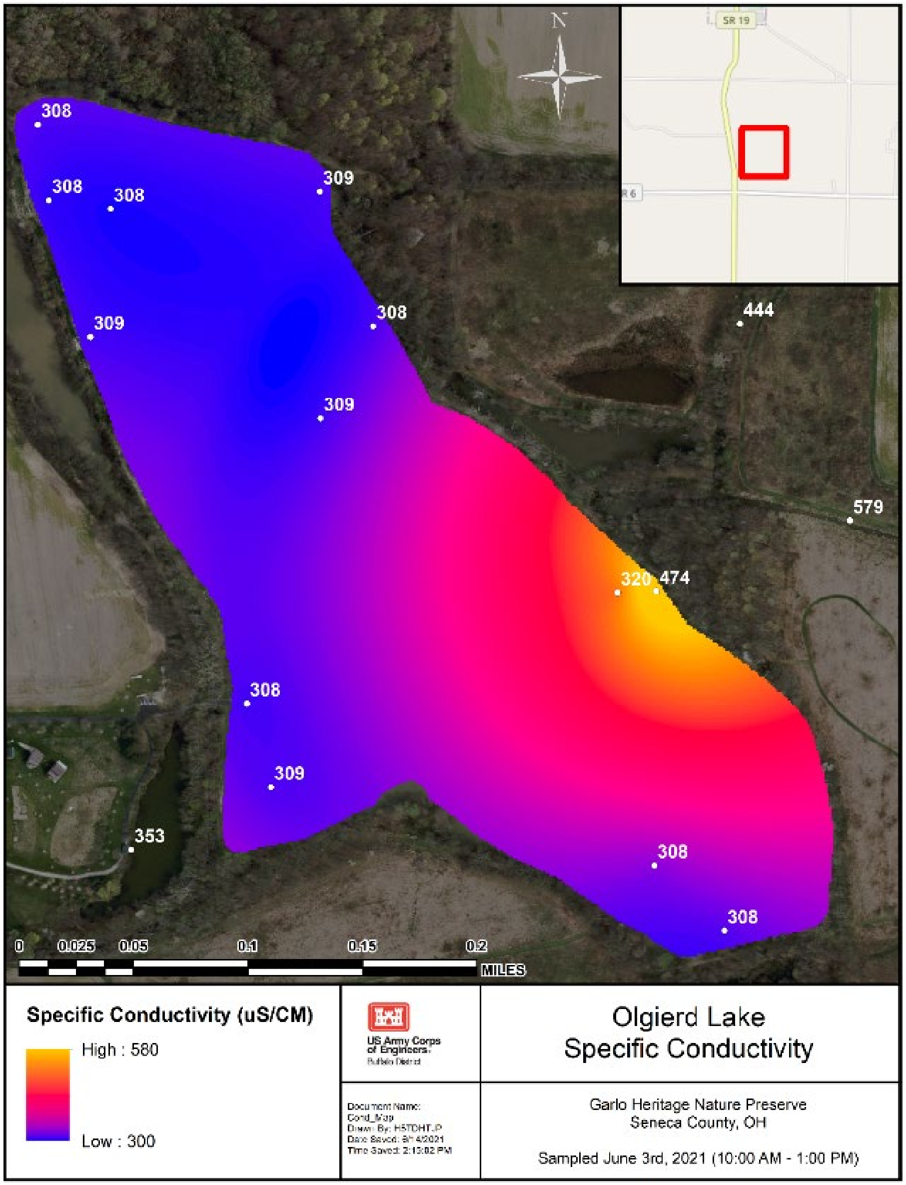

Figure 9: Olgierd Lake: Specific Conductivity; 3 June 2021.

3.2.2 Dissolved Oxygen

Dissolved oxygen (DO) is a measure of the oxygen dissolved in a given volume of water. Periods of hypoxia, low dissolved oxygen, and anoxia, absence of oxygen, can stress or cause direct mortality to fish and other aquatic organisms. The presence of oxygen in the water column also influences the cycling of chemical compounds. For instance, ortho-phosphate, the dissolved inorganic form of phosphate that is usable by plants, can be released from sediments under anoxic conditions and become mobilized in the water column, thereby resulting in increased algal growth. Both of these processes are relevant to the analysis of the conditions in Olgierd Lake.

Dissolved oxygen in Olgierd Lake was variable, ranging from 1.07 - 10.89 mg/L across the sampling period of June 2021 to October 2021 (USACE and Heidelberg University data). The lowest average DO in Olgierd Lake was 3.84 mg/L and occurred during the August 13th sampling event. However, individual measurements of DO from parts of the lake were less than 3.0 mg/L in July, August, September and August sampling (Table 2).

Dissolved oxygen less than 5 ppm (mg/L) is considered stressful for fish while DO less than 3 ppm is often associated with fish mortalities. Based on these observations, dissolved oxygen in Olgierd lake is at a level that likely stresses or causes direct mortality to fish. Although, DO measurements were not taken at night, it is likely that DO levels reach their lowest, and the water column becomes anoxic, during evening hours when plants and algae are not photosynthesizing.

Table 2. Average Dissolved Oxygen in Olgierd Lake; June to October 2021.

	Dissolved Oxygen mg/L				
Sampling Date	20210602	20210729	20210813	20210902	20211007
Lake (Average)	5.99	6.91	3.84	7.69	5.6
Lake (Low)	5.13	1.07	1.41	2.28	1.12
Tributaries	6.45	4.35	2.46	3.11	1.39
* units mg/L					

3.2.3 Chlorophyll a

Chlorophyll *a* is a measure of algal biomass growing in a waterbody. It is often used to characterize the trophic condition of a given water body. Although algae are a natural part of freshwater ecosystems, overabundance can cause aesthetic problems such as surface scums and bad odors, and can result in decreased dissolved oxygen. Some algae can also produce toxins that can be toxic to humans. Waterbodies that receive excessive nutrients (nitrogen and phosphorus) from fertilizers, septic systems, sewage treatment plants, and urban runoff will typically have high chlorophyll *a* and algal biomass. These conditions are common in waterbodies downstream of intensive agricultural operations.

Table 3. Chlorophyll-a Concentrations from Olgierd Lake; 3 June 2021.

Sample ID	Collection Date	Chlorophyll a
		ug/L
T1	20210603	10.86
T2	20210603	2.53
L1	20210603	15.54
L2	20210603	19.20
L3	20210603	25.19

Samples analyzed for Chlorophyll *a* were collected by USACE during the June 3rd sampling event. Samples taken within Olgierd Lake ranged from 15.54 to 25.19 ug/L. Samples taken from the inflow tributary ditches had lower concentrations of 10.86 (northeast tributary) and 2.53 ug/L (southeast tributary).

Heidelberg University shared data collected from Olgierd Lake from 13 July 2021 to 7 October 2021 using a fluoroprobe. This data suggested that algal concentrations averaged 324.89 ug/L, but were highly variable at different locations within the lake, ranging from 36.76 to 1029.24 ug/L. This sampling captured an algal bloom that appeared to peak in mid-august (Figure 10). The highest average algal concentration of the sampling period was 569.14 ug/L and was observed during the 18 August 2021 sampling event. This algal concentration was primarily associated with a bloom of blue-green algae that was dominated by the species *Microcystis spp*.

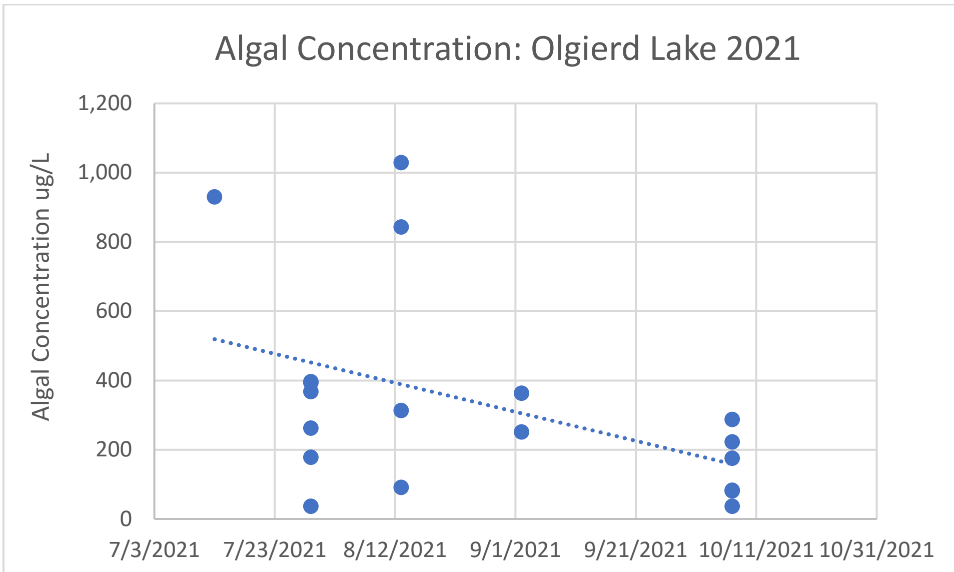

Figure 10. Algal biomass concentration, Olgierd Lake, July to October 2021. Courtesy of Heidelberg University.

The state of Ohio does not have a water quality standard established for chlorophyll *a*. When considering trophic status, concentrations of chlorophyll *a* greater than 20 ug/L and 55 ug/L are considered "eutrophic" and "hypereutrophic", respectively (Carlson, 1976 and 2007). The chlorophyll *a* and algal biomass data collected during the growing season of 2021 suggest that trophic state of Olgierd lake ranges from eutrophic to hypereutrophic. The bloom of blue-green algae captured in the Heidelberg data set is indicative of excessive nutrient load. This is aligned with descriptions of the visual characteristics of Olgierd Lake and surround waterbodies, which are described as excessive algae and green color during the summer (personal communication, Figure 11). This excessive algal growth negatively affects the aesthetics of the lake, its quality as ecological habitat, and may also present a public health risk due to the occurrence of blue-green algae blooms dominated by *Microcystis spp*., which produces a toxin (mycrosytin) that can be harmful to humans.

Figure 11. Picture of Algal bloom in Olgierd Lake taken 8 June 2020. Provided by Seneca County Parks District

3.2.4 Nutrients

Phosphorus is generally considered the limiting nutrient in in freshwater ecosystems (Correll, 1998), because the ratio of phosphorus in plant content to its availability in water is larger than for any other nutrient (Wetzel, 1983). Therefore, under typical freshwater conditions, where physical factors are conducive to the growth of algae, additions of phosphorus to the system are more likely to lead to accelerated growth, than are additions of other nutrients (Litke, 1999). Nitrogen is the other most important nutrient associated with eutrophication and can also be a limiting nutrient in freshwater systems.

During the June 3rd sampling event, total phosphorous (TP) averaged 0.64 mg/L in Olgierd Lake and was consistent across the lake (Table 4). Total phosphorus was higher in the northeast tributary (T1; 0.60 mg/L) compared to the southeast tributary (T2; 0.13 mg/L). Nitrogen, measured as TKN, averaged 2.0 mg/L in the lake, and was significantly higher than the measurements for the northeast tributary (T1, 0.70 mg/L) and the southeast tributary (T2, 0.85 mg/L).

Table 4. Nutrient Measurements in Olgierd Lake, 3 June 2021.

Sample ID	Collection Date	Ammonia	TKN	NO2/NO3	Total P
		mg/L	mg/L	mg/L	mg/L
T1	20210603	0.014	0.70	3.10	0.60
T2	20210603	0.027	0.85	0.76	0.13
L1	20210603	0.830	2.10	0.82	0.72
L2	20210603	0.860	2.00	0.79	0.59
L3	20210603	0.830	1.90	0.79	0.61

The data shared by Heidelberg University, collected between July 13th and October 7th 2021, was similar to the data collected by USACE with TP concentrations averaging 0.71 mg/L. However, this data had a greater variability ranging from 0.25 to 1.8 mg/L. The data from the lake suggests a decreasing trend of TP from July to October (Figure 12). Soluble Reactive Phosphorus (SRP) averaged 0.12 mg/L. Concentrations of TP in tributaries averaged 0.68 mg/L and ranged from 0.09 to 2.2 mg/L. No apparent trend was present in the data, but the northeast tributary was associated with the greater concentrations of TP. Nitrogen in the lake, measured as TKN, was higher than what was observed earlier in the season by USACE averaging 5.3 mg/L, and ranged from 2.0 to 18.7. This data show less of a temporal trend (Figure 13). Nitrite, nitrate, and ammonia in the lake averaged 0.014, 0.094, and 0.081 mg/L respectively.

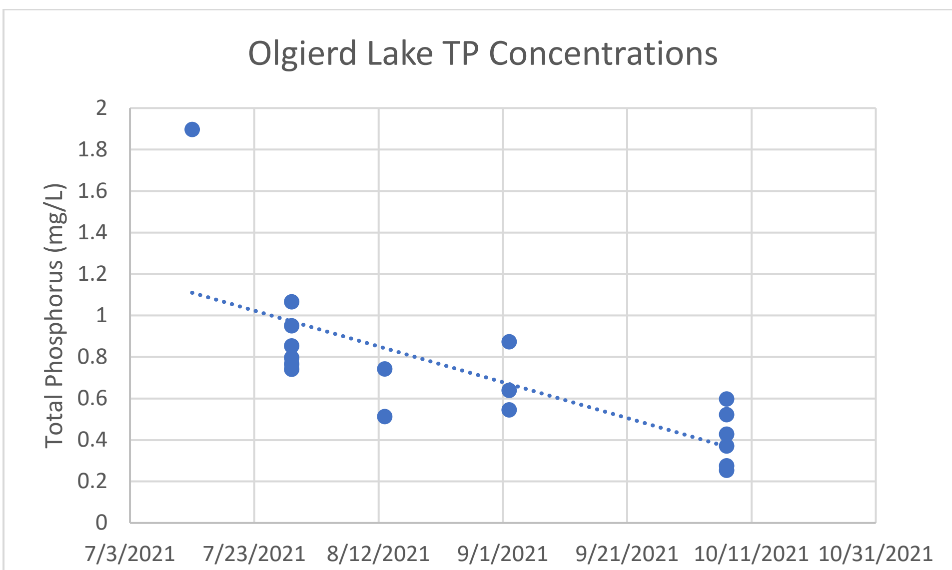

Figure 12. Concentrations of Total Phosphorus in Olgierd Lake, July to October 2021. Courtesy of Heidelberg University.

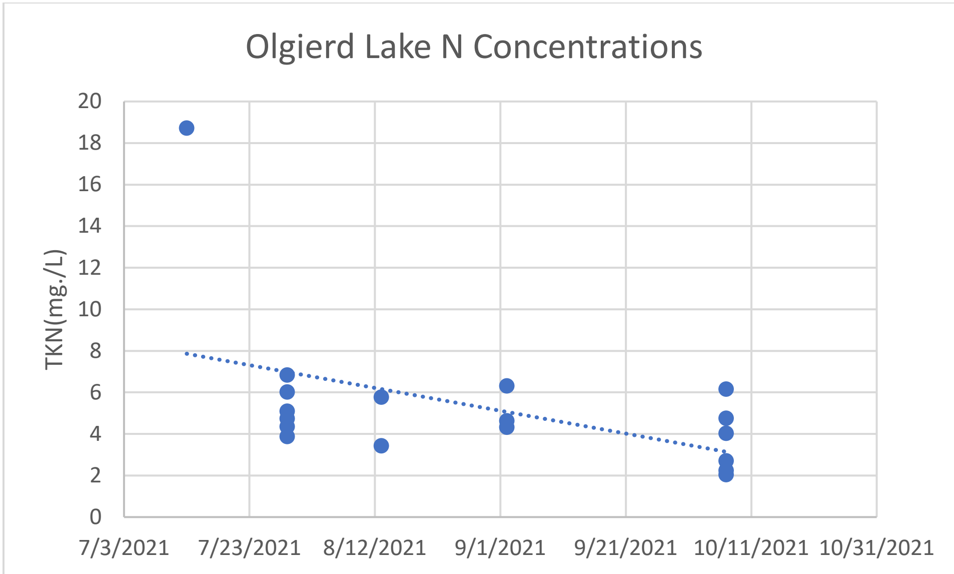

Figure 13. Concentrations of TKN in Olgierd Lake, July to October 2021. Courtesy of Heidelberg University.

Ohio has not established water quality standards for nitrogen or phosphorus so there is not a specific water quality standard to compare this data too. However, the state of Ohio has developed a "Trophic Index Criterion" (https://epa.ohio.gov/Portals/35/rules/TIC_rationaleandscoring.pdf) that evaluates the condition of a water body relative to nutrient enrichment. According to this criterion a waterbody with total phosphorus scores of greater than 0.40 mg/L would be considered impaired. Based on data collected by USACE, and the data shared by Heidelberg University, Olgierd Lake would be considered impaired according to this index.

The trophic state index (Wetzel, 2001) can also be used to characterize the trophic condition based on the concentration of TP. According to this index, freshwater systems with TP concentrations greater than 0.03 mg/L or greater than 0.10 mg/L are considered eutrophic and hypereutrophic, respectively. Based on data collected by USACE, and the data shared by Heidelberg University, Olgierd Lake would be characterized as hypereutrophic with respect to TP.

3.2.5 Conclusion

Overall, the analysis of water chemistry indicates Olgierd Lake is hypereutrophic with high nutrient concentrations (phosphorus and nitrogen), high algal biomass, and low dissolved oxygen. The source of the nutrients appears to be the tributaries that feed Olgierd Lake from its east side, as these tributaries also have elevated nutrient concentrations and are the main source of inflow into the lake. Internal cycling may also contribute to the magnification of phosphorus within the lake. The elevated concentrations of nitrogen and phosphorus drive the high algal productivity and bloom that peaked in August. According to analysis by Heidelberg University, this algal bloom consisted primarily of the blue-green algae *Microcystis spp*. that is capable of producing a toxin (microcystin) that can be harmful to humans. Decomposition of this algal biomass, as well as respiration during times when the algae is not photosynthesizing, likely consume available oxygen resulting in the low dissolved oxygen observed. This depletion of dissolved oxygen is a stress to any aquatic life (i.e., fish) with potential to cause direct mortality. In addition, there is also potential for the release of ortho-phosphate from sediments back into the water column during periods of anoxia, further exacerbating eutrophication and algal productivity.

4 Hydrologic Analysis

4.1 Hydrologic Data Collection: June 2021

On June 2nd-3rd, 2021, USACE performed a site visit to Garlo Heritage Nature Preserve to collect data for this study. A map summarizing the collected hydrologic data is shown in Figure 14. To determine the inflow and outflow paths of Olgierd Lake and surrounding water bodies, hydraulic structures, such as culverts, berms, and pipes, were identified. Their locations were determined, and in some cases, their dimensions were measured.

To evaluate if Olgierd Lake is perched (water level is raised higher than the surrounding bodies of water), measurements of the Lake's water surface height were compared to the height of surrounding wetlands and ponds. This was done at each of the four berms using a Bosch GOL32 auto-level.

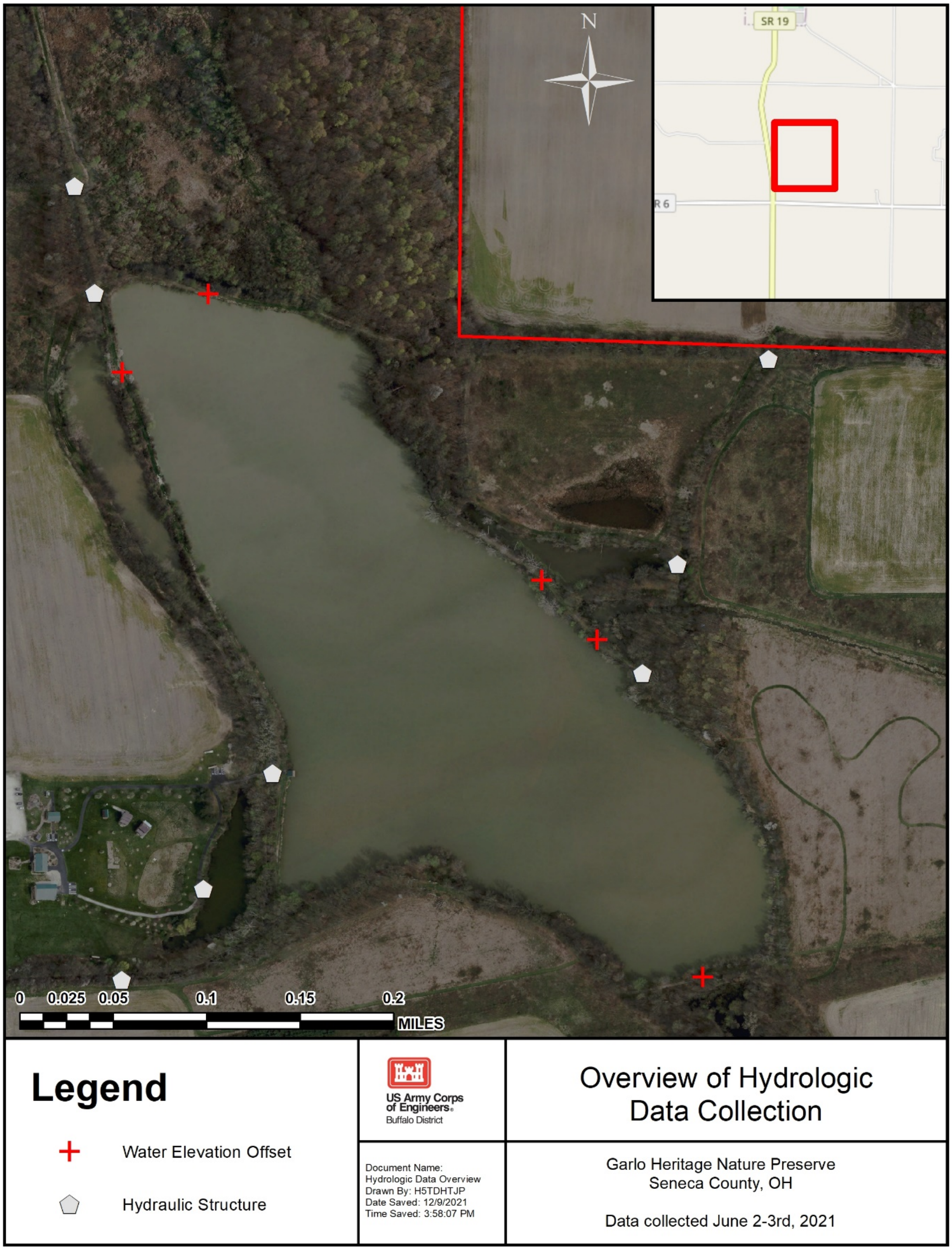

Figure 14: Overview of hydrologic data collected during the June 2021 site visit.

4.2 Historical Conditions

The Garlo Heritage Nature Preserve and the surrounding area was historically wetlands. In 1838, James Fisher created a ditch to drain portions of the cranberry bog into Silver Creek. This allowed nearby fields to be established for grazing (Figure 15).

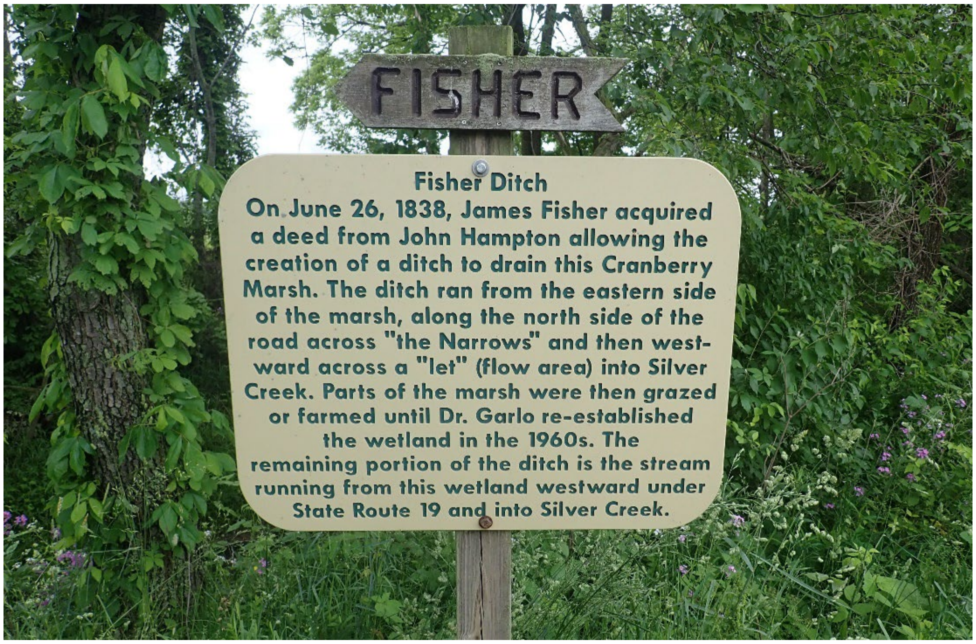

Figure 15: Sign within the preserve discussing the history of Fisher Ditch.

A historical map of Bloomville, OH from 1896 shows conditions after the drainage ditch was created (Figure 16). The area just beyond the preserve is mostly fields. Much of the preserve, including what is now Olgierd Lake, was historically wetlands. Conditions remained relatively unchanged until at least 1959, as indicated by aerial imagery (USDA, 1959) (Figure 17). The wetlands appear to be comprised mostly of woody growth (i.e., forested wetlands).

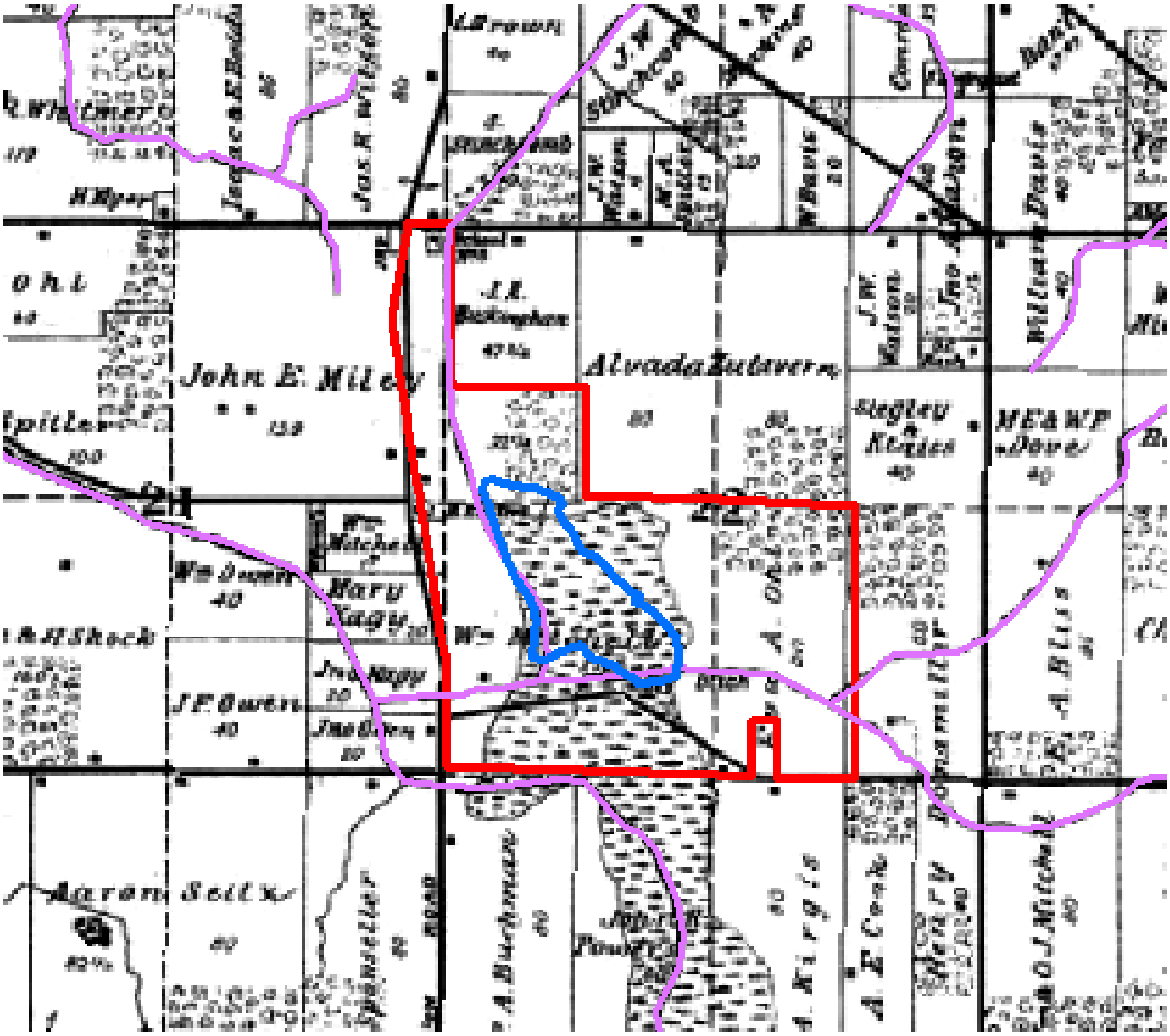

Figure 16: Map of Bloomville, OH from 1896, overlaid with the historical flow paths (in purple), Preserve boundary (in red), and current location of Olgierd Lake (in blue).

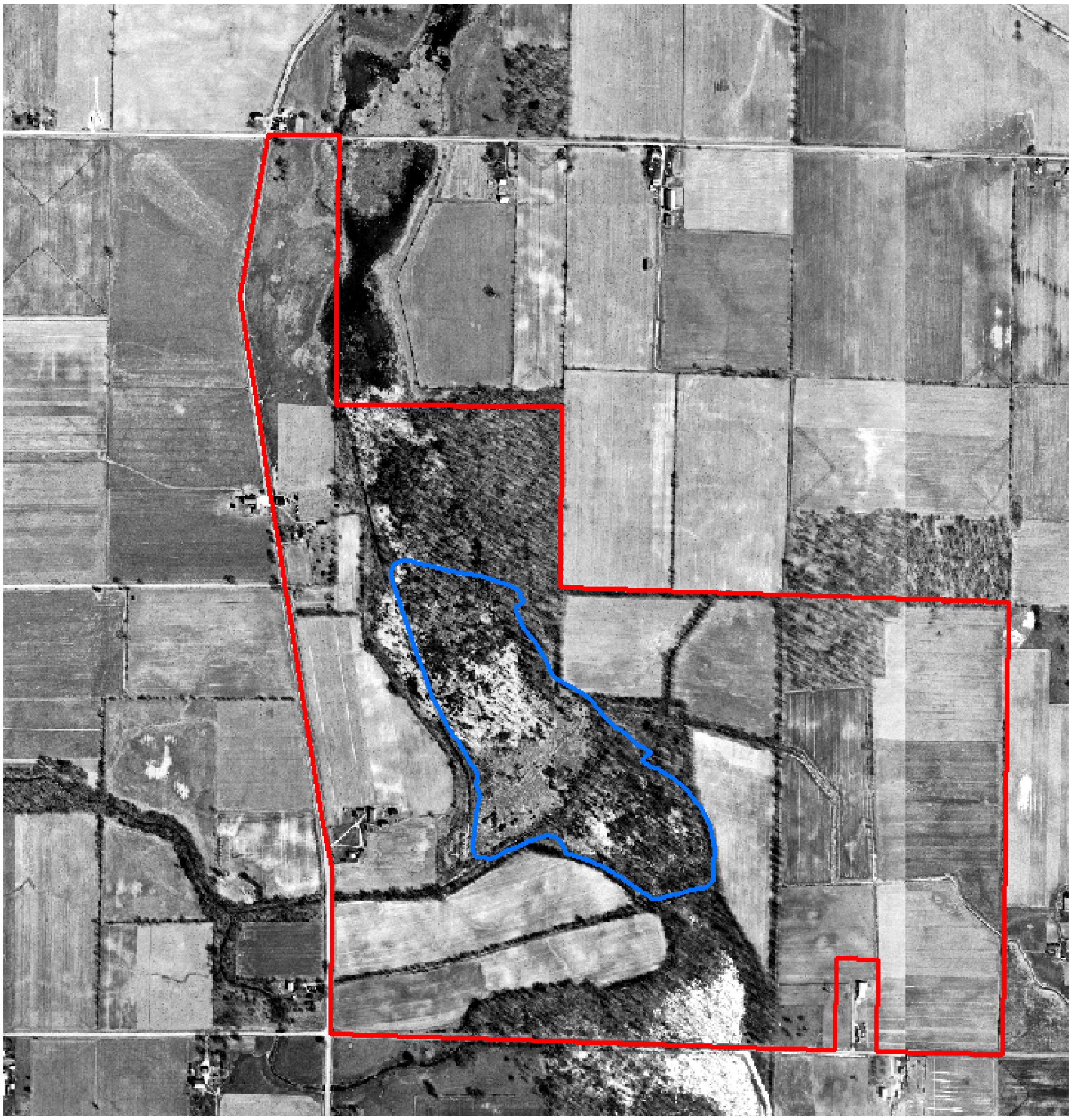

Figure 17: Historical aerial image of Garlo Heritage Nature Preserve from 1959, overlaid with the Preserve boundary (in red) and current location of Olgierd Lake (in blue).

Dr. Olgierd Garlo created Olgierd Lake in the 1970s by building berms (i.e., dikes) to store water. Based on the 1959 imagery, the northeast and southeast tributaries were not altered when the lake was created. A "spillway" was placed along the north berm that allowed water from the lake to flow into the north wetland. There is also an abandoned weir on the southwest side of the lake (Figure 30). This is likely the original outflow location and was installed when the lake was first constructed but abandoned at some point when the north spillway was created.

In 1996, Dr. Garlo's children donated the land to SCPD, thereby establishing Garlo Historic Nature Preserve. Around that time, the spillway was moved to the west berm due to the structural deterioration of the north berm. Material was taken from the west berm and used to shore up the north berm. The depression caused by the removed material resulted in the spillway shifting to the west berm. Since the new spillway was set higher, it raised the lake's water level by ~1 foot.

4.3 Depth Variability of Olgierd Lake

Based on measurements taken during the June 2021 site visit, the depth of Olgierd Lake appears to be relatively uniform, with an average of 2.6 feet (min = 2 feet, max = 3 feet). This suggests that no excavation was done to create the lake. The flat, low-grade bottom is what would be expected in an area formerly occupied by wetlands.

4.4 Olgierd Lake is Perched

A LiDAR-based digital elevation model (DEM) (OSIP I, 2006) showed the water surface elevation of Olgierd Lake to be perched (i.e., raised) two to three feet above the surrounding ponds and wetlands. This was confirmed by field measurements collected during the June 2021 site visit. An auto-level was used to measure the elevation offset between the Lake's water surface and adjacent water bodies at each of the four berms (Figure 18).

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Figure 18: Map of berms around Olgierd Lake.

At the time of measurement, Olgierd Lake was perched 3.7 feet above the northwest pond (at the spillway), 3.5 feet above the north wetland (at the north berm), and 2.2 feet above the south wetland (at the south berm) (Figure 19). The lake was roughly the same height as the east pond (at the East Berm), most likely since they are fed by the same tributary (as discussed in 4.5.1). Refer to Figure 1 for the location of each waterbody.

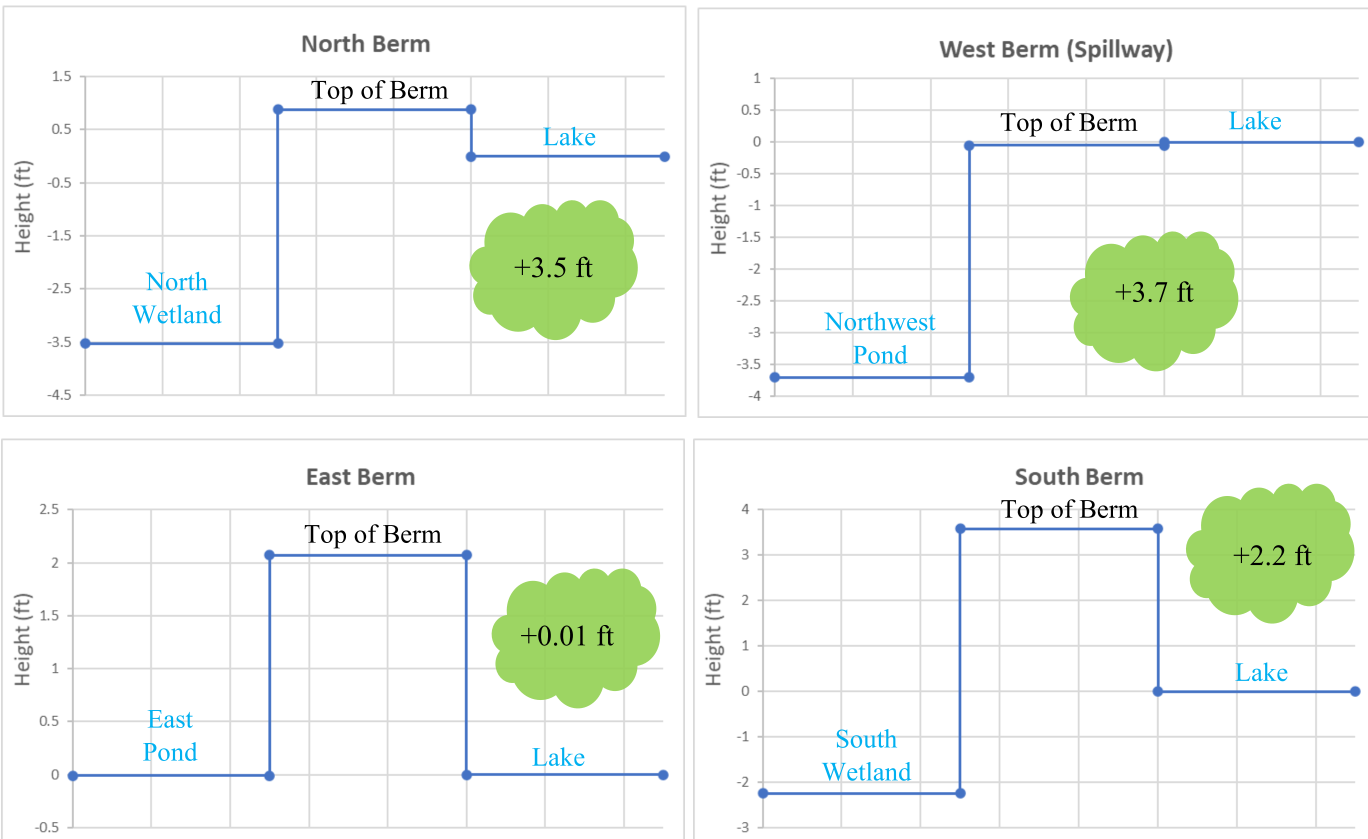

Figure 19: Water surface height offsets between Olgierd Lake and surrounding water bodies.

4.5 Flow Paths and Hydraulic Structures

The flow paths in and out of Olgierd Lake are shown in Figure 20. These were determined using a LiDAR-based digital elevation model (DEM) (OSIP I, 2006), aerial imagery (OSIP III, 2017), and field observations made during the June 2021 field visit.

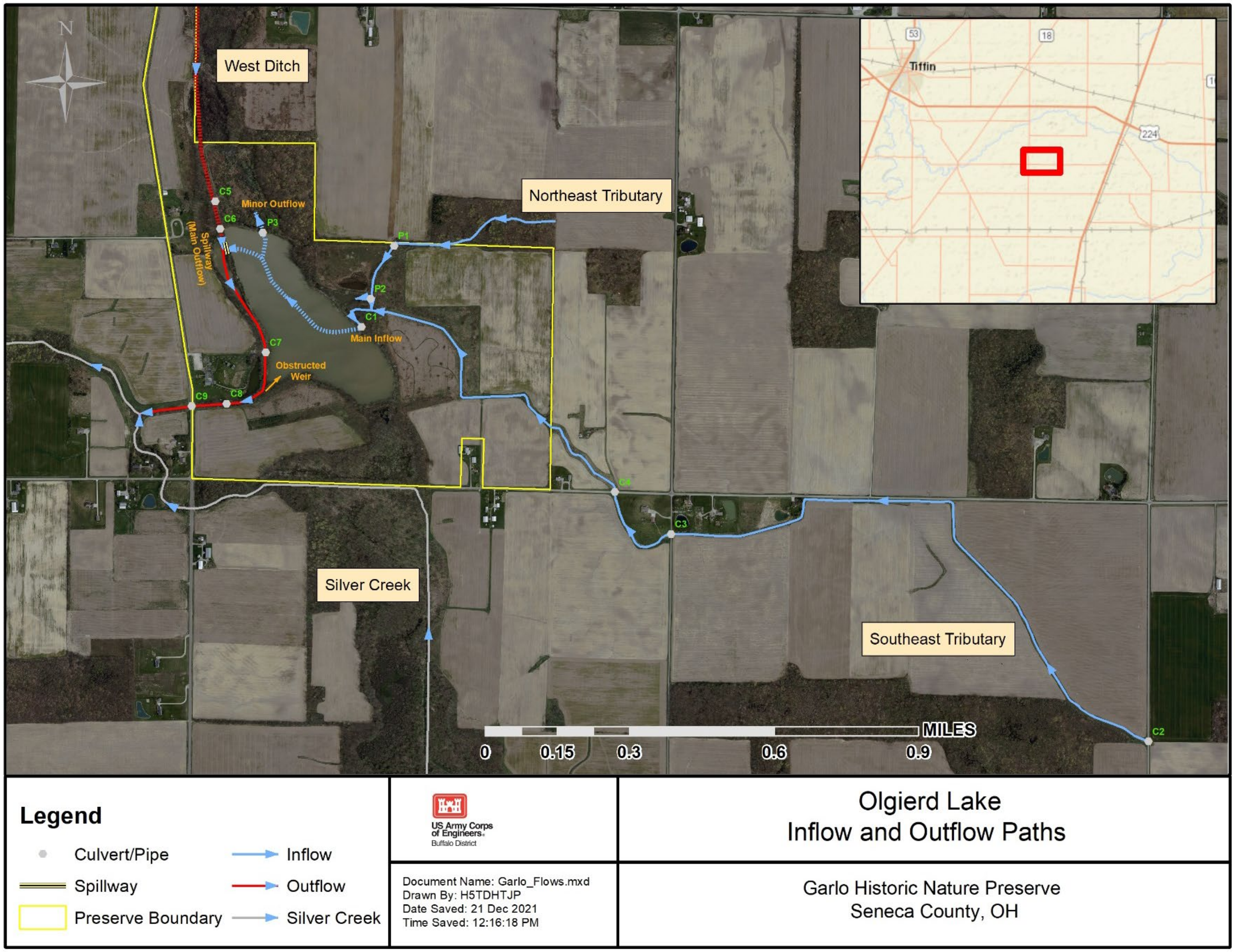

Figure 20: Overview of flow paths into and out of Olgierd Lake.

4.5.1 Inflow

The main source of inflow is a culvert on the east berm. It is approximately 20 feet long, with a diameter of 4 feet (Figure 21, location shown as C1 in Figure 20). Since the lake is perched, water cannot be flowing in from the surrounding wetlands (or else the water levels would be equalized). Conductivity measurements from the June 2021 site visit (section 3.0) also confirm that this is the only source of inflow. Samples near the culvert had a much higher conductivity than the rest of the Lake (Figure 9). If water were flowing in from another other source (i.e., through the berms, groundwater, another culvert etc.), that section of the lake would have a similarly high conductivity.

Figure 21: Culvert that is main source of inflow to Olgierd Lake; taken on upstream side of structure; location marked as C1 in Figure 20.

Two inflow tributaries (the northeast and southeast tributary) converge approximately 450 feet upstream of the culvert. They are essentially agricultural drainage ditches. Downstream of the confluence, the channel widens before passing through the culvert and converging with Olgierd Lake.

Based on a visible depression in the DEM, the headwaters of the northeast tributary are in a field just beyond the northeast corner of the Preserve. Flow eventually passes through two parallel pipes, one foot in diameter (Figure 22, marked as P1 in Figure 20), before converging with the southeast tributary. The headwaters of the southeast tributary pass through a culvert under Rt 77 (Shaffer Road) (marked as C2 in Figure 20); runoff from nearby fields drains into the culvert. Water flows through two additional culverts under Detwiler-Lenter Road (marked as C3 in Figure 20) and East County Rd 6 (Figure 23, marked as C4 in Figure 20) before converging with the northeast tributary.

Figure 22: Parallel pipes that convey flow from the Northeast Tributary seen from the side (left) and top (right); location marked as P1 in Figure 20.

Figure 23: Culvert East County Rd 6 that conveys flow from the Southwest Tributary seen from the top (left) and side (right); location marked as C4 in Figure 20.

The tributaries also feed the east pond via a small pipe (~0.75 feet diameter) (marked as P2 in Figure 20). Only the northeast tributary appears to feed the pond, since the pipe is upstream of the confluence. The similar water levels observed in Olgierd Lake and the east pond (Figure 19) suggests that there is a backwater effect from the lake and the two bodies of water are hydraulically connected (both connect to the northeast tributary). There was evidence of erosion along the east berm, suggesting that it is overtopped during periods of heavy rainfall. Thus, the east pond may occasionally serve as a source of inflow to the Lake.

4.5.2 *Outflow*

The main outflow of the lake is a spillway located along the west berm (Figure 24). While we refer to it as a spillway, it is just a depression in the berm. Water flows over the spillway, into the west ditch, and eventually into Silver Creek. From Silver Creek, it flows into Honey Creek and then the Sandusky River, which is a tributary of Lake Erie. Therefore, water from Olgierd Lake eventually makes its way to Lake Erie. Another minor outflow location is as a tile pipe (four-to-six-inch diameter) through the north berm, which conveys a small amount of flow into the north wetland (marked as P3 in Figure 20). The inlet of the pipe is not visible on the lake side of the berm. We did not identify this structure during the June 2021 site visit and did not realize that there was a second outflow location until it was brought to our attention by SCPD.


Figure 24: Spillway located along the West Berm looking toward the Lake on top of the West Berm (left) and on the West Ditch side of the berm (right).

Upstream of the spillway, the west ditch flows under two culverts (Figure 25, Figure 26, marked as C5 and C6 in Figure 20). Before converging with Silver Creek, the west ditch flows through a culvert under the path to the dock (Figure 27, C7 in Figure 20), a double culvert under a pedestrian trail (Figure 28, marked as C8 in Figure 20), and a culvert under Rout 19 (Figure 29, marked as C9 in Figure 20).

Figure 25: West Ditch culvert (looking upstream); location marked C5 in Figure 20.

Figure 26: Top of West Ditch Culvert looking upstream (left) and downstream (right); location marked C6 in Figure 20.

Figure 27: Top of West Ditch Culvert under the pedestrian path to the bridge, looking upstream (left) and downstream (right); location marked as C7 in Figure 20.

Figure 28: West ditch culvert under pedestrian path from the side (left) and top, looking downstream; marked as C8 in Figure 20.

Figure 29: West ditch culvert under Rt 19 seen from the side (left) and top, looking downstream; location marked as C9 in Figure 20.

On the southwest side of the lake, there is what appears to be a low-head weir, obstructed by steel beams and debris, and a culvert (Figure 30). This is likely the original outflow location, installed when the lake was constructed, and was abandoned when the north spillway was created. The 1959 aerial imagery shows a low flow channel through the wetland that travels through this approximate location (Figure 17).

Figure 30: Obstructed weir (left) and culvert (right).

4.6 Surrounding Water Bodies

Olgierd Lake is surrounded by several ponds and wetlands (Figure 1). According to SCPD staff, algal blooms occur in all the smaller ponds as frequently and severe (in terms of approximate portion of area coverage), if not more, than Olgierd Lake. Algal blooms have also been reported to occur in some of the surrounding wetlands.

The east pond (or Alex Pond) has an area of approximately 1.2 acres and is fed by the northeast tributary (Figure 31). A pipe (approximately 0.75 feet in diameter) connects the tributary to the pond (as discussed in section 4.5.1). Algal blooms most likely occur in the east pond since it receives inflow from the phosphorous-rich tributaries.

Figure 31: Image of East Pond.

The southwest pond (or Alma Pond) is slightly larger (approximately 1.4 acres) and most likely fed via precipitation/runoff, as it did not appear to be hydraulically connected to any surrounding ditches (Figure 32). A corrugated pipe (approximately six inches in diameter) carries runoff from the parking lot to the pond. Since this pond is not fed by any of the surrounding ditches, runoff from nearby fields is likely triggering the algal blooms.

Figure 32: Image of Southwest Pond taken from the dock (left) and corrugated pipe that feeds the Pond runoff (right).

The northwest pond (or Dolly Pond) (2.5 acres in size) is a widened section of the west ditch (Figure 33). It is fed from both the west ditch (which flows through it) and outflow from Olgierd Lake. The phosphorous-rich outflow from Olgierd Lake is certainly one cause of algal blooms occurring in the pond. The west ditch may be another, as it receives runoff from fields north of the Preserve.

Figure 33: View of Northwest Pond from the spillway (left) and further south along the West Berm (right).

The forested wetland located just north of Olgierd Lake is the North Wetland (Figure 34). It is fed from Olgierd Lake via a tile pipe and runoff/precipitation. According to SCPD staff, conditions in the North Wetland have been drier since the spillway was moved to the west berm (especially in the southern end of the wetland), since it is receiving less inflow; this is confirmed by the presence of reed canary grass observed during the June 2021 field visit (Figure 35). Algal blooms have been observed in this wetland, likely induced by the phosphorous-rich inflow from the lake.

Figure 34: Images of the North Wetland.

Figure 35: Reed Canary grass observed in the North Wetland.

We refer to the forested wetland, just north of the North Wetland, as the Northmost Wetland. Based on the LiDAR-DEM, the West Ditch appears to flow through the Northmost Wetland. Visual observations made during the June 2021 site visit confirmed that water levels were deeper in the Northmost Wetland than the North Wetland. The woody growth also appeared to be somewhat denser (Figure 36).

Figure 36: Images of the Northmost Wetland.

A third forested wetland, the South Wetland, is located just south of the lake. It appears to be fed primarily through precipitation/runoff. The embankment of East County Rd 6 separates the wetland from Silver Creek. While driving along East County Rd 6, we did not see any culverts under the embankment. Conditions did appear to be drier than the Northmost Wetland. Many mature trees were visible from the path on top of the South Berm (Figure 37).

Figure 37: Images of the South Wetland.

There is an emergent wetland, which we refer to as the East Wetland, located just north of the east pond. Based on historic aerial imagery in Google Earth, the wetland was constructed sometime between 1995 and 2004. Since it has only been around for 15-25 years, little to no woody vegetation has established (Figure 38). It is likely precipitation/runoff fed, as no hydraulic connections to the northeast tributary were observed during the June 2021 site visit.

Figure 38: Images of the East Wetland.

4.7 Floodplain Boundary: Zone A (Approximate)

No detailed Flood Insurance Study (FIS) has been completed for Bloomville, most likely since it is sparsely populated. However, an approximate floodplain (Zone A) encompasses Olgierd Lake and much of the preserve (Figure 39).

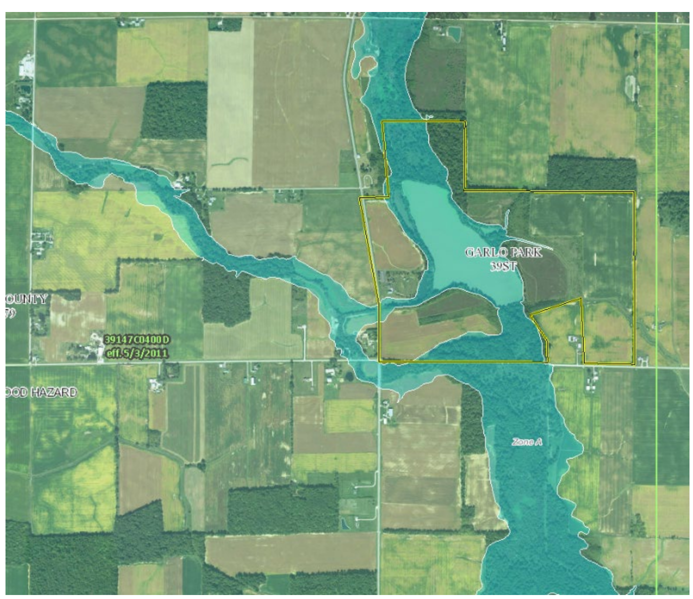

Figure 39: Boundary of Zone A (approximate) floodplain (shown in Blue); taken from the National Flood Hazard Layer (NFHL).

4.8 Watershed Delineation

The Olgierd Lake watershed (i.e., the area that drains into the Lake) was delineated via StreamStats (v4.6.2) (USGS, 2016). The pour point was placed just upstream of the inlet to determine the extent of the full watershed (41.02826, -83.00984). This was done to reflect water flowing in from the tributaries and assumes that there is no other runoff, which is reasonable given that the lake is surrounded by berms. Two additional pour points were placed just upstream of the confluence (41.02856, -83.00850 and 41.02829, -83.00825) to delineate individual watersheds for the Northeast and Southeast Tributaries. The Olgierd Lake watershed is depicted in Figure 40 and has a drainage area of 1.68 mi^2. The northeast and southeast tributary sub-watersheds have a drainage are of 0.41 mi^2 and 1.27 mi^2, respectively.

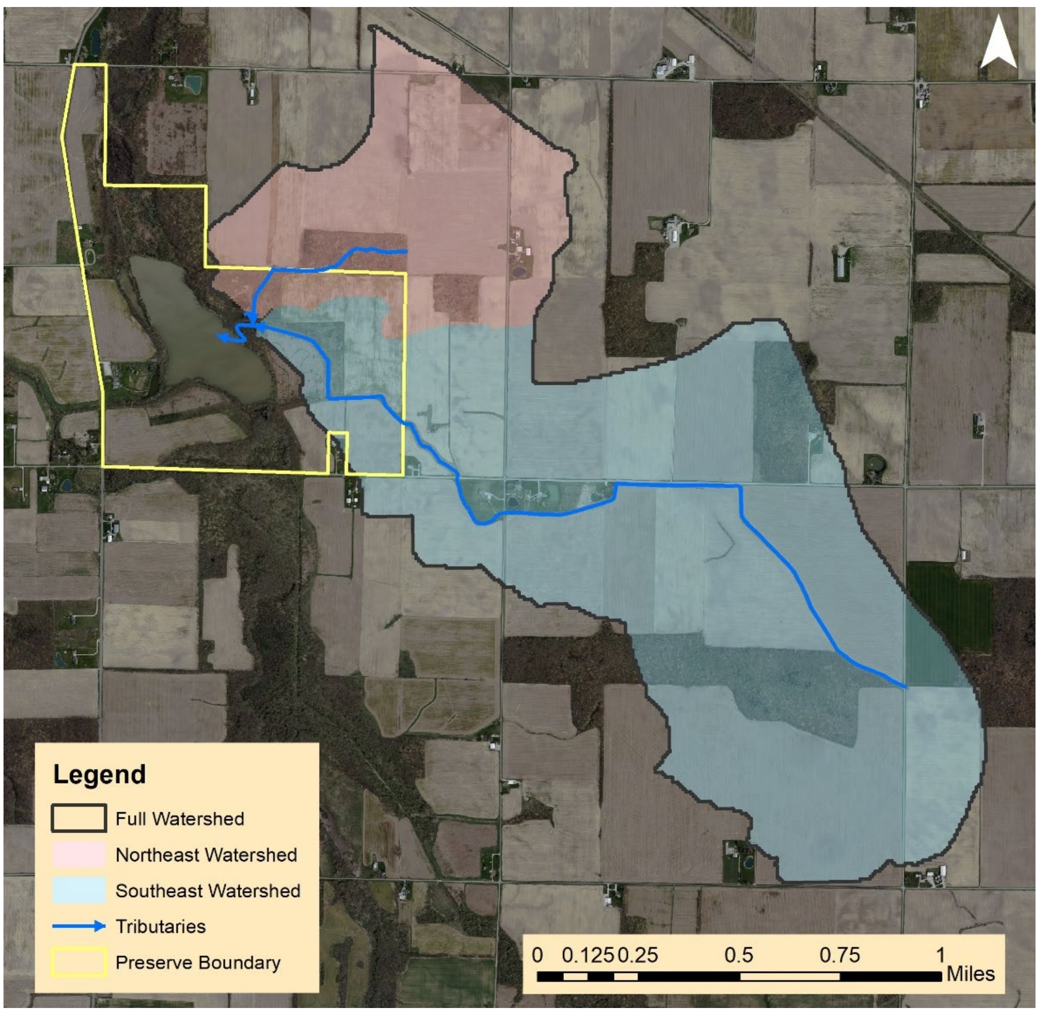

Figure 40: Olgierd Lake watershed and sub-watersheds of the Northeast and Southeast Tributaries.

4.9 Flow Frequency Analysis

A flow frequency analysis was performed using StreamStats to estimate the mean annual and monthly flows into Olgierd Lake, as well as the Annual Chance Exceedance (ACE) flows (e.g., flow corresponding to the 2-year, 100-year, 500-year storm events) (USGS, 2016). This was done for the full watershed. StreamStats estimates various flow frequencies by summarizing GIS data for the delineated watershed boundary (i.e., land cover, annual precipitation, elevation) and feeding it into regional regression equations.

The mean annual flow into Olgierd Lake is 1.62 cubic-feet per second (cfs); the mean monthly flows range from a high of 2.97 cfs in March to a low of 0.208 cfs in September (Table 5). The 50% ACE (or the flow that happens about once every 2 years) is 95.3 cfs. The 1% ACE (100-year) and 0.2% (500-year) are 339 and 450 cfs, respectively.

Table 5: Flow frequency statistics and corresponding average standard error of prediction (ASEp) for Olgierd Lake derived from SteamStats (USGS, 2016).

Flow Statistic	Flow (cfs)	ASEp (cfs)
Mean Annual Flow	1.62	11.4
Monthly Mean Flow		
January	2.24	16.6
February	2.67	11.9
March	2.97	14
April	2.78	11.2
May	1.63	19.5
June	1.06	27
July	0.628	28.2
August	0.367	36.8
September	0.208	43.6
October	0.277	50.8
November	0.738	37.5
December	1.49	21.8
Annual Chance Exceedance (ACE)		
50% (2-year event)	95.3	40.1
20% (5-year event)	152	37.2
10% (10-year event)	193	37.6
4% (25-year event)	249	38.1
2% (50-year event)	294	37.8
1% (100-year event)	339	39.6
0.2% (500-year event)	450	40.3

Note that the utilized regional regression equations have a high degree of uncertainty. It is important to consider the average standard error of prediction (ASEp) for each flow frequency provided in Table 5. For instance, the estimate for mean annual flow is 1.62 cfs, but the +/- range of the ASEp is 0.00-13.02 cfs. As there is no gauge data, these represent the best available estimates.

4.10 Olgierd Lake Water Budget

The water budget of Olgierd Lake was estimated to determine if it can be sustained solely through precipitation, which has important implications for measures that involve diverting inflow from the tributaries (i.e., hydraulic separation). It was also done to assess how long, on average, water remains in the lake (i.e., the hydraulic retention rate); warm stagnant water is a main contributor to algal blooms.

Assuming a constant water level, the annual water budget for a lake or wetland can be described as:

$$Q_0 = Q_i + A\,(P - ET - I)$$

where Q_0 is the outflow rate (measured as cubic feet per year (ft^3/yr), Q_i is the inflow rate (ft^3/yr), A is the surface area (ft^2), P is the precipitation rate (ft/yr), ET is the evapotranspiration rate (ft/yr), and I is the infiltration rate (ft/yr) (Kadlec and Wallace, 2009). Note that this is a relatively simplistic model that ignores such factors as bank loss rate, non-tributary catchment runoff, snowmelt, and groundwater inflow.

Based on the flow frequency analysis (section 4.9), Q_i is assumed to be 51 million-ft^3 (382 million-gallons), the mean annual flow accumulated over a given year (1.62 cfs X 60 sec X 60 min X 24 hr X 365 days). The area of the Lake (A) is 39.1 acres (1.7 million-ft^3). The other variables were estimated by the procedures outlined in the following sections.

4.10.1 Precipitation Rate (P)

The precipitation rate reflects the amount of water that enters the Lake through rainfall and snow. In terms of the Lake's water budget, precipitation is a source.

Thirty-year (1981-2010) climate-normals were utilized from the Parameter-Elevation on Independent Slopes Model (PRISM) to determine the average annual precipitation rate for the Lake (PRISM Climate Group, 2021). Data is provided in an 800-m^2 grid for the entire CONUS. Pixels overlapping with the Preserve boundary were averaged. This yielded an average annual precipitation rate of 970 mm/year (38.2 inches/year or 3.18 feet/year) for Olgierd Lake.

4.10.2 Evapotranspiration Rate (ET)

Evapotranspiration (ET) is the sum of all forms of evaporation plus transpiration from plants. In terms of the Lake's water budget, ET is a sink.

Reitz et al. (2017) provides gridded (800-m^2 pixels) long-term average ET rate estimates (from 2000-2013) for the entire conterminous United States (CONUS). Open water ET rates were summarized for pixels overlapping with the Preserve boundary. This yielded an average ET rate of 0.631 meters/year (24.8 inches/year or 2.1 feet/year) for the average annual ET rate of Olgierd Lake.

4.10.3 Infiltration Rate (I)

Infiltration refers to the leaching of water into soil. In terms of the Lake's water budget, it is a sink. Infiltration rates (I) depend heavily on soil type and texture (USDA NRCS, 2014a).

Based on the Soil Survey Geographic Database (SSURGO) (USDA NRCS, 2021a), Olgierd Lake is located on soil classified as Ca (Carlisle muck, Central Ohio clayey till plain, 0 to 2 percent slopes) (Figure 41). Ca is characterized as nearly level, very poorly drained soil. The Hydrologic Soils Group (HSG) is A/D. Note that A/D is a dual group, where A refers to conditions for drained soil and D refers to the conditions for wet soil. For a lakebed, the HSG would be D since the soil is saturated. Group D soils have very slow infiltration rates (USDA NRCS, 2014b).

Figure 41: Soil types within Garlo Heritage Nature Preserve; taken from USDA NRCS (2021a).

Several sources provide infiltration rates by soil texture and HSG. Rates corresponding to Clay and HSG D are summarize in Table 6. Based on this information, the infiltration rate for Olgierd Lake should be between 0.0-0.2 in/hr (or 0-1,752 inches/year). Given that this application is for infiltration through a lakebed, the rate would likely be closer to the estimates for HSG D (0-438 inches/year or 0-37 feet/year), which is still a large range. The infiltration rate could be negligible or outpace precipitation and evapotranspiration by an order of magnitude.

Table 6: Infiltration rates by soil type from different studies.

	Description	Rate (in/hr)	Rate (in/yr)
By Soil Type			
NRCC, 2010	Silty clay loams & clay soils	<0.2	<1,752
USDA NRCS, 2014a	Clayey soils	0.04-0.2	350-1,752
Brouwer et al., 1988	Clay	0.04-0.2	350-1,752
By Hydrologic Soil Group			
Endreny (2021)	Class D	0.0-0.05	0-438

4.10.4 Annual Water Budget

The estimated rates for P, I and ET (in feet/year and million-gallons per year [MGY]) are summarized in Figure 42. Based on the lake area of 1.7 million-ft^2, the volumetric rates of P, ET, and I are 41, 27, and 0-471 MGY. Since the lake is surrounded by berms, we assumed that there is no precipitation inflow from runoff (i.e., only considered precipitation falling directly onto the Lake). As the range for I is so large, it is difficult to derive a reliable estimate for outflow (Qo). In fact, the upper limit of I yields a negative outflow, which is physically impossible.

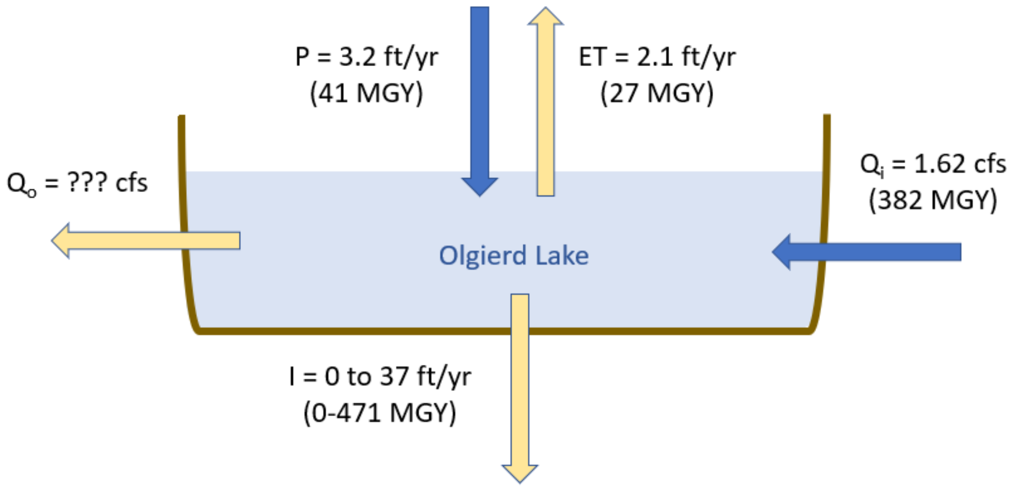

Figure 42: Annual water budget of Olgierd Lake, showing the rate of inflow rate (Q_i), outflow (Q_o), precipitation (P), evapotranspiration (ET), and infiltration (I).

As P outpaces ET by approximately 1.1 feet/year, it is possible that P – ET – I has a net positive value. In other words, if the lake were hydraulically separated from the tributaries, the water could potentially be sustained by precipitation alone. However, this would require I to be closer to the lower limit and within 0-1.1 feet/year. Better estimates of ET and I would be needed to draw this conclusion. Also note that this is a simplistic representation; the rates for Qi, P, ET, and I will vary through the year.

4.10.5 Hydraulic Retention Time (HRT)

The hydraulic retention time (HRT), or residence time, is the average amount of time that water spends in a lake or wetland. It can be estimated by dividing the total volume by the mean inflow rate (Qi) (Ellis et al., 2003).

Based on field measurements, the depth of the lake was relatively consistent, with an average of 2.6 feet (min = 2 feet, max = 3 feet). Multiplying this depth by the area (39.1 acres or 1.70 million-ft^2) yields a volume of 4.43 million-ft^3. Based on a mean annual inflow of 1.62 ft^3/s (139,968 ft^3/day), the HRT for Olgierd Lake is approximately 32 days.

Flows change over the course of a year. Based on monthly flows determined in section 4.9, the HRT over the course of a year ranges from a low of 17.4 days in March to a high of 248 days in September. (Table 7). The hottest months, July, August, and September, have a HRT of time 82, 140, and 246 days, respectively. Note that water will not actually remain in the lake this long, since flow increases as months progress. Another way to think of this is fraction of the lake that is turned over. During the months of July, August, and September, only 38%, 22%, and 12% of the lake is turned over. This suggests that there is an incredibly long residence time during the summer. Stagnant water during heat waves is a major contributing factor to algal blooms.

Table 7: Mean flow and hydraulic retention time (HRT) by month for Olgierd Lake.

Period	Mean Flow (cfs)	HRT (days)
Annual	*1.62*	*31.6*
January	2.24	22.9
February	2.67	19.2
March	2.97	17.3
April	2.78	18.4
May	1.63	31.4
June	1.06	48.3
July	0.63	81.6
August	0.37	139.6
September	0.21	246.4
October	0.28	185.0
November	0.74	69.4
December	1.49	34.4

4.11 Estimation of Annual Nutrient Loading and Concentration for Olgierd Lake

Information on annual nutrient load for the Olgierd Lake watershed was derived from two existing models:

1. SPAtially Referenced Regression on Watershed attributes (SPARROW) - Midwest, 2012 base year (Robertson and Saad, 2019)
2. Spreadsheet Tool for Estimating Pollutant Loads, version 4.4b (STEPL) (USEPA, 2020)

Both models provide nonpoint source loading estimates for the HUC-12 Silver Creek watershed, including TP and total nitrogen (TN).

Values were proportionality downscaled to the Olgierd Lake watershed based on its area. That is, since the watershed represents 6.8 percent of the Silver Creek watershed, we assumed that the corresponding annual loadings were 6.8 percent of the Silver Creek loadings. This is a reasonable assumption, given that land use/land cover within the watershed is relatively uniform and dominated by agriculture (Figure 43). Note that the Olgierd Lake watershed boundary derived from StreamStats extends beyond the HUC-12 Silver Creek boundary, likely due to minor delineation error induced by the flat terrain. The full area (including the portion beyond the Silver Creek watershed) was used to compute the area ratio. Also note that the boundary from the SPARROW model is slightly smaller than the HUC-12 Silver Creek watershed, so a different ratio was used for downscaling SPARROW estimates.

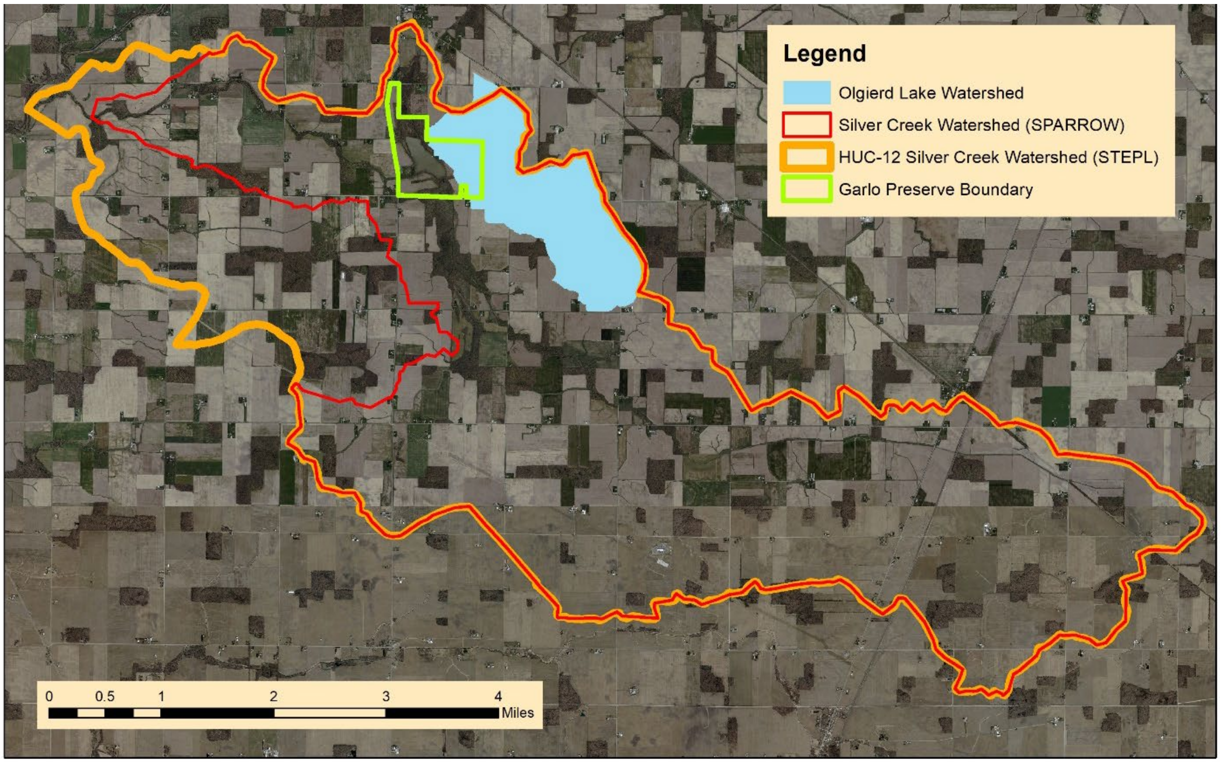

Figure 43: Map depicting the boundaries of the Garlo Heritage Nature Preserve, Olgierd Lake watershed, Silver Creek watershed (for SPARROW model), and HUC-12 Silver Creek Watershed (for STEPL model).

Once annual loadings were determined, they were converted to average annual concentrations using the mean annual flow of 1.62 cfs from StreamStats (see section 4.9) and divided by the total annual volume of inflow. Annual loadings and mean annual concentrations of TP and TN for Olgierd Lake are listed in Table 8. While the TP estimates are relatively consistent, the TN estimate from STEPL is roughly one-tenth the estimate from SPARROW.

Table 8: Annual nutrient loading and mean concentration estimates for the Olgierd Lake watershed, including total phosphorous (TP) and total nitrogen (TN).

	SPARROW	**STEPL**
Area Ratio[1]	0.0835	0.0683
Annual Loadings		
TP (kg)	497	392
TN (kg)	14,963	1,918
Mean Concentrations		
TP (mg/L)	0.343	0.271
TN (mg/L)	10.34	1.33

[1]*Area ratio is the portion of the full Silver Creek watershed boundary represented by the Olgierd Lake watershed*

Mean annual estimates of TP and TN concertation are generally within the range of values sampled from the lake and tributaries, but there is considerable variability in the sampled values (Figure 44 and Figure 45). TP samples from the lake and northeast tributary were typically higher than the SPARROW and STEPL estimates; TP concentrations from the southeast tributary were lower. As the SPARROW estimate for TN exceeded all but two samples, the STEPL TN estimate may be more applicable to the Olgierd Lake watershed.

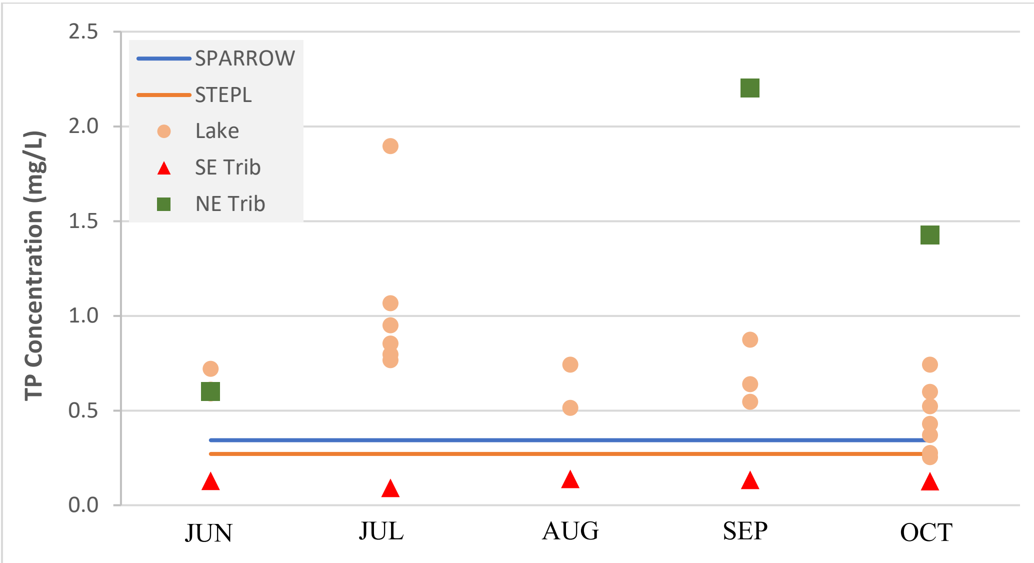

Figure 44: Comparison of SPARROW and STEPL mean annual total phosphorous (TP) concentration estimates to field samples collected in the Lake and tributaries.

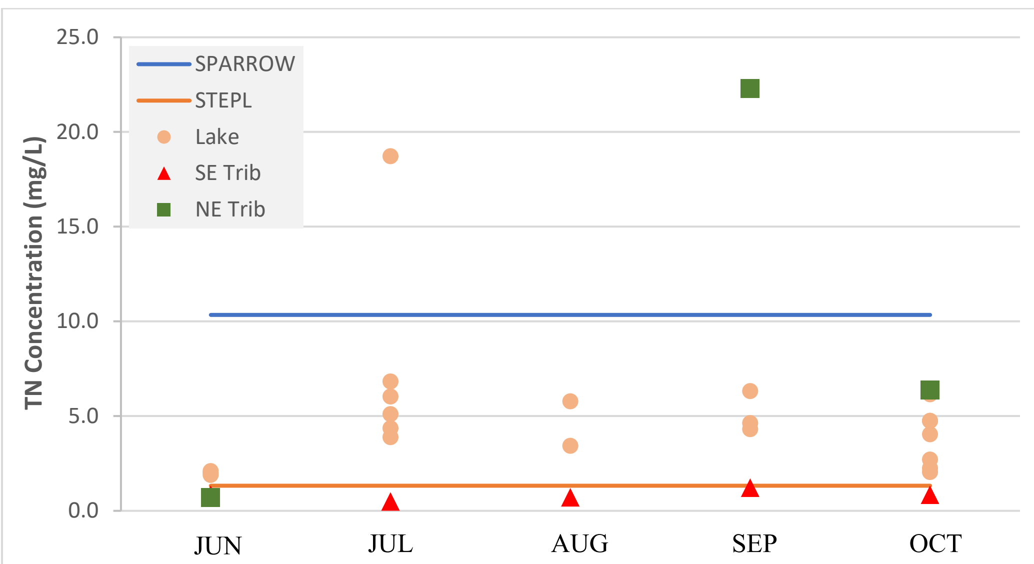

Figure 45:Comparison of SPARROW and STEPL mean annual total nitrogen (TN) concentration estimates to field samples collected in the Lake and tributaries.

Some caution should be used when comparing a limited number of static field samples to mean annual estimates, as the mean estimates represent a range of conditions that occur through the year. At the very least, field samples provide some level of ground-truthing. There is also uncertainty with the SPARROW and STEPL estimates, as they have not been calibrated with watershed specific data. However, based on the information available, we expect mean annual TP concentrations of inflow to be between 0.27-0.34 mg/L (based on SPARROW and STEPL estimates) and can range anywhere from 0.09-2.2 mg/L at a given point int time (based on tributary samples). Moreover, we can conclude that water flowing into Olgierd Lake is generally hypereutrophic, perhaps exceeding the threshold of 0.1 mg/L by 200-300%. Note that water flowing in from the tributaries is defined as eutrophic if the TP concentration is >0.03 mg/L and has potential to induce algal blooms; water is defined as hypereutrophic if the TP concentration is >0.10 mg/L and has significant potential to induce algal blooms (Wetzel, 2001).

4.12 Preliminary Wetland Sizing

This section applies three different methods to estimate the wetland area required to process the annual nutrient loading of Olgierd Lake (estimated in section 4.11). These results have important implications as to whether a partial conversion of the lake to wetlands would adequately treat the nutrient loads. Note that the current size of Olgierd Lake is 15.8 (hectares, ha) (1.7 million-ft^2 or 39 acres); if the estimated required area is greater than 15.8 ha, then a partial conversion would not be expected to fully treat the current nutrient load. As phosphorous is likely the limiting nutrient driving eutrophication, sizing requirements are based on TP; results from the three methods are listed in Table 9 and discussed below in greater detail.

Table 9: Summary of wetland sizing estimates from the three utilized methods.

Method 1	Method 2	Method 3
4.4 - 22 ha	0.6-3.0 ha	115-150 ha

4.12.1 Method 1: Rule of Thumb - 1-5% of Watershed Area

A common sizing rule of thumb is that a wetland should be 1-5% of the watershed area (Russell et al. 2021; Jones, 1997; Ellis et al., 2003; Guiesse, 2018). As per section 4.8, the estimated watershed for Olgierd Lake is 435 ha (1.68 mi^2). Thus, the wetland should be between 4.4-22 ha in order to adequately handle nutrient loading from the watershed.

Based on this method, a partial conversion may be feasible, as the lower limit of the resulting range is only 4.4 ha. However, the upper limit is greater than the total area of Olgierd Lake. Furthermore, this approach does not consider nutrient load and is more appropriate when sizing a stormwater retention wetland (Kadlec and Wallace, 2009).

4.12.2 Method 2: Aerial Loading Estimates – USEPA (2000)

A preliminary estimate of land required for a free water surface (FWS) wetland can be obtained from typical aerial loading rates provided by USEPA (2000) (see their Table 1). Aerial loading rates refer to the amount of nutrient entering the wetland in a day (or year) per unit area. Accordingly, the areal loading rate for TP should be between 1 to 4 pounds per acre per day (lb/acre/day).

The annual TP loading for the Olgierd Lake watershed was estimated to be 392-497 kilograms per year (kg/yr; or 2.4-3.0 lbs/day). Therefore, the area required for a wetland would be 0.6-3.0 acres (0.2-1.2 ha).

This is well below the total Lake's area of 15.8 ha and suggests that a partial conversion is possible. However, it is important to consider that this guidance is for constructed wetlands that treat point-source pollution. Also, the average target effluent (i.e., outflow) concentration is 2 mg/L and more than 200X the hypereutrophic threshold of 0.1 mg/L. An effluent concentration this high be unlikely to reduce eutrophication in the lake or downstream waterbodies.

4.12.3 Method 3: First-Order Model – Kadlec and Wallace (2009)

Kadlec and Wallace (2009) provide a first-order model for pollutant removal in constructed FWS wetlands:

$$C_1 = \frac{Q_i C_{in} + (k \cdot A_1 \cdot C^*)}{Q_1 + \left((\alpha ET)A_1\right) + (I \cdot A_1) + (k \cdot A_1)}$$

Where C_1 is the outflow concentration, Q_i is the inflow, Q_1 is the outflow, C_{in} is the inflow concentration, C* is the background concentration, α is the transpiration fraction, ET is the evapotranspiration rate, I is the infiltration rate, k is the rate coefficient, and A_1 is the area of the wetland.

This approach requires a target outflow concentration; the area is iteratively changed by the user until the target outflow is met. While Kadlec and Wallace (2009) state that a common criterion for phosphorus in the United States is for monthly means to be less than 1.0 mg/L, in the context of partial wetland conversion, the target would need to be much lower so that water flowing out the wetland and into the downstream lake is non-eutrophic (<0.03 mg/L).

We utilized a target outflow TP concentration of 0.03 mg/L (C_1) and the following values to determine the required A:

- Q_1 = 3,963 m3/day (mean annual flow, 1.62 cfs, see section 4.9)
- Q_i = 3,963 m3/day (mean annual flow, 1.62 cfs, see section 4.9)
- k = 0.027 m/day (10 meters/year, see Table 10.11 in Kadlec and Wallace, 2009)
- C_{in} = 0.271-0.343 mg/L (see section 4.11)
- C* = 0.002 mg/L (see Table 10.11 in Kadlec and Wallace, 2009)
- ET = 0.0017 m/day (24.8 inches/year, see section 4.10.4)
- I = 0.0009 m/day (13.4 inches/year, P-ET so P-ET-I=0, see section 4.10.4)
- α = 0.55 (dimensionless, from Tong et al., 2009 for alpine swamp meadow)

Not that this approach assumes that $Q_i = Q_1$. In other words, the sum of precipitation, infiltration, and evapotranspiration is 0. This is a reasonable assumption for preliminary wetland design (Zhang et al., 2012). Also note that this was done for average annual concentrations. During design, these computations should be done for each month, to reflect seasonal changes (Kadlec and Wallace, 2009)

To achieve an outflow TP concentration of 0.03 mg/L, 115-150 hectares (ha) of wetland is required, which is well beyond the total area of the Lake. Even achieving outflow that is below the hypereutrophic threshold of 0.1 mg/L would require 24-34 ha. Based on this method, converting the entire Lake to a wetland would likely result in outflow that is eutrophic (and potentially hypereutrophic). Therefore, a partial conversion would result in algal blooms in the downstream lake.

4.12.4 Conclusion

The results from this sizing analysis are mixed. Methods 1 and 2 suggest that a partial wetland conversion may be adequate to treat the nutrient load; Method 3 indicates that converting the entire lake to a wetland would still result in eutrophic outflow. Methods 1 and 2 are simplistic and may not be applicable. While Method 3 is intended for sizing point-source treatment wetlands, it is more conservative and better reflects the physical processes of nutrient uptake.

Achieving non-eutrophic outflow would require a TP reduction from 0.27-0.34 mg/L to 0.03 mg/L (a removal efficiency of ~80-90%). Based on a brief literature review, achieving a removal efficiency this high is doubtful, regardless of the above sizing estimates:

- Case studies in Maryland, Illinois, and Iowa indicate wetlands can remove **43%** of phosphorous; a Minnesota case study found a **73%** reduction in phosphorous (OSU, 2021).
- A meta-analysis of 203 constructed and restored wetlands (mostly in Europe and North America) determined the median TP removal efficiency to be **46%**, with a 95% confidence interval of **37-55%** (Land et al., 2016).
- The TP removal efficiency for a constricted wetland Hangzhou City, China was determined to be **78%** (Han et al., 2017).
- Jordan et al. (2003) found a TP removal efficiency of **59%** for a 3.2 acre restored wetland in Maryland.

Considering these studies in conjunction with the findings from Method 3, a partial wetland conversion would likely be ineffective in eliminating algal blooms. Additional tributary samples or a more advanced nutrient modeling procedure may indicate that the TP concentration of inflow is lower than expected, but this outcome is unlikely, given that all but one tributary sample collected in June through October 2021 were above the hypereutrophic threshold. If a partial wetland conversion is pursued, better data on phosphorous loading would help derive a more reliable sizing estimate.

5 Conceptual Measures

This section describes several measures that could be implemented to decrease the frequency/intensity of algal blooms and improve the ecological conditions in Olgierd Lake. The following discussion includes conceptual alternatives intended to illustrate a variety of concepts. They do not represent site-specific designs and additional analysis would be needed before any of the measures can be implemented.

Some measures involve modifications to existing streams and drainage ditches. Therefore, a 404 Permit from USACE may be needed, in addition to any permits required by the Ohio EPA and local municipalities. Coordination with FEMA may also be necessary to demonstrate that there will be no rise in upstream inundation, as Olgierd Lake and much of the preserve is within a Zone A (approximate) floodplain.

5.1 Measure 1: Full Wetland Restoration

This measure involves restoring historic hydrologic and ecologic conditions by converting the entirety of Olgierd Lake into a wetland. A hydraulic structure to control outflow and maintain an ideal water level would be installed at one of the existing berms. The structure could be set at a fixed elevation or be adjustable. Wetland vegetation could either be planted or allowed to colonize naturally.

As depicted in Figure 46, there are several possible locations for the outlet structure. The simplest option is to install the structure on the west berm and send outflow directly into the west ditch. It could be placed near the current “spillway” to maintain the existing flow path (Option 1) or at the southwest corner of the Lake, near the plugged-off weir (Option 2). This would best replicate the historical wetland flow path (Figure 17).

Alternatively, multiple hydraulic structures could be used to increase water levels in the North Wetland, which have been diminished since the spillway was moved to the west berm. One option is to reroute the west ditch to flow through the North Wetland and then into the newly created wetland (Option 3). Another option is to send flow into the North Wetland and then into the west ditch (Option 4). While there is already some outflow going into the North Wetland, this would result in all outflow being diverted there. As the North Wetland is 11.8 acres, it would increase the area of wetland treating inflow by ~30%. The newly created wetland will not provide maximum nutrient reductions until vegetation has fully established. With this option, the North Wetland would provide some level of treatment while vegetation establishes. Before pursuing, however, the terrain in this area of the preserve should be surveyed to ensure that the topography supports directing flow from the lake into the North Wetland and then into the west ditch. It would also be necessary to further assess if increasing water levels or sending in more nutrient-rich flow would adversely impact sensitive vegetation communities of the North Wetland.

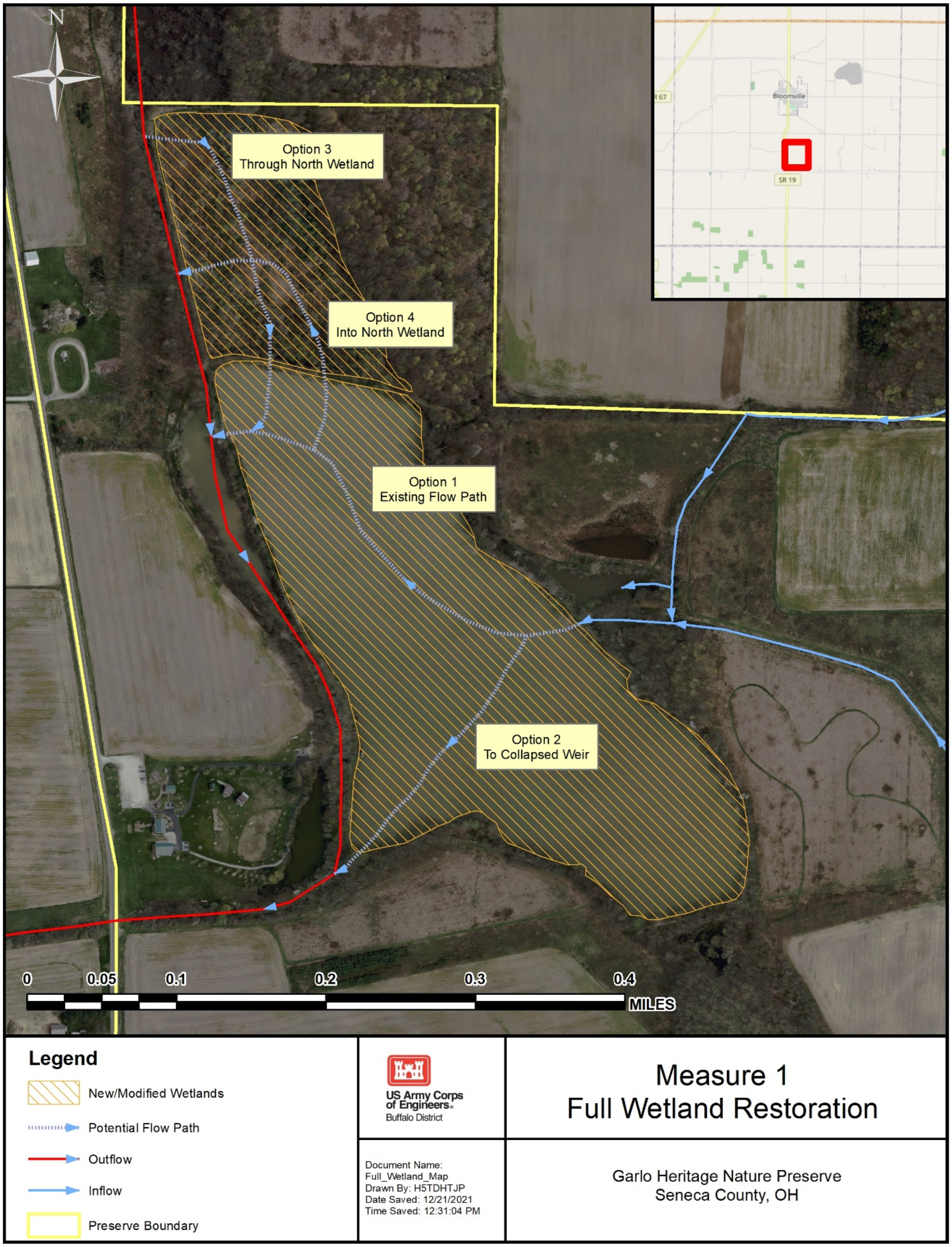

Figure 46: Depiction of Options for Measure 1: Full Wetland Restoration.

5.1.1 Advantages

In comparison to the other measures, Full Wetland Restoration is likely to have the greatest impact in mitigating (i.e., lessening of the intensity and frequency of) algal blooms and improving ecological habitat. Based on the calculations in section 4.12, converting the entire lake to a wetland would still result in eutrophic (and possibly hypereutrophic) outflow. While water within the wetland would be eutrophic, the vegetation community would be dominated by native emergent plants rather than algae. The wetland would increase water circulation and create shading, thereby eliminating conditions that are conducive to algal growth. It is possible that algal blooms will still occur, especially given that they have been observed in the North Wetland. However, Full Wetland Restoration has the greatest potential to reduce their frequency and severity.

This measure would provide the most improvement in regional habitat quality as it would reduce the export of nutrients (i.e., phosphorous removal from tributary inflow) from the lake and improve the trophic conditions of downstream waters. Furthermore, wetland creation can be a relatively inexpensive and simple process, assuming no regrading, excavation, or extensive planting is pursued.

The wetland would offer new recreational options. Since wetlands provide excellent bird habitat (Stewart, 2016), this measure would enhance bird watching and possibly attract bird enthusiasts. Boardwalk trails could offer scenic views and diversify nature trails. As wetlands are an ecologically rich and essential ecosystem, there would be significant potential for educational opportunities, especially for students of the Out and About Preschool.

Since wetland restoration would improve regional water quality, there is potential to seek external funding. The USDA provides federal funding to support wetland restoration through the Farm Bill. There may also be financial and technical assistance available through non-government organizations, such Ducks Unlimited, The Nature Conservancy, and other nonprofit organizations (Wetlands Work, 2021).

5.1.2 Disadvantages and Limitations

The main disadvantage of Full Wetland Restoration is the loss of recreational activities associated with the lake. The lake is widely utilized for fishing and boating, which may not be possible in the shallow depth and dense vegetation of a wetland.

The new wetland could also increase mosquito populations. However, given that the lake is already surrounded by wetlands, it may have a negligible impact. This measure could even reduce mosquito populations. In comparison to stagnant water, healthy wetlands do not support prolific mosquito breeding due to the strong presence of various predators, including fish, frogs, salamanders, dragonflies, and water striders (USDA NRCS, 2008a).

Depending on how the wetland is designed, operations and maintenance could be minimal (especially in comparison to other methods). However, post-construction monitoring and adaptive management will be required to ensure that the wetland is functioning properly. If an adjustable outlet structure is selected, then water levels within the wetland may need to be monitored.

5.1.3 Design Considerations and Follow-up Analyses

The design considerations discussed in this section are more detailed than those for the other measures since Full Wetland Restoration has the greatest potential to mitigate algal blooms and improve ecological conditions and was, therefore, researched the most. These are intended to serve as a preliminary resource if this measure is pursued and do not constitute a compressive list all factors that should be assessed during design.

Various sources provide guidance on the design, monitoring, and management of restored wetlands (USFWS, 1999; Hayes et al., 2000; USDA NRCS, 2003; USDA NRCS, 2008b). Kadlec and Wallace (2008) and USDA NRCS (2009) can be referenced for guidance on constructing treatment wetlands for point-source pollution (i.e., from a dairy farm or other industrial site). While creating a restored, natural wetland is an inherently different process, much of information on surface flow or free water surface (FWS) wetlands is applicable.

5.1.3.1 Engineering survey

As part of the design process, an engineering survey of the site should be completed and include the collection of:

- Lake bathymetry with a sufficient point density to estimate the existing volume and lakebed gradient. Another option is to collect continuous points using a kayak or canoe-mounted Sonar sensor.
- Cross sections along the northeast and southeast Tributaries, as well as the western drainage ditch (from top-of-bank to top-of-bank). Ideally, the tributaries should be surveyed from the headwaters to the confluence with the lake. However, if rights of entry cannot be obtained, surveying only within the preserve's boundary may be sufficient.
- Bathymetry of the Northern Wetland if an outlet structure is placed at the north berm. This is needed to determine if the gradient is sufficient for water to flow from the newly established wetland, into the Northern Wetland, and then into the western ditch.
- Top/bottom elevation and width of all existing culverts within the preserve along the selected flow path.
- Crest elevation of the current spillway (elevation points every 50-200 ft).
- Top elevation of the four berms (elevation points every 50-200 feet along the structure).

It may also be beneficial to establish a monument near the shoreline of the lake that can be used to relate water levels to known elevations. This can also be used to create a staff gauge to monitor post-construction hydrologic conditions of the wetland.

5.1.3.2 Continuous flow measurements

While we provide estimates of different flow frequencies, the utilized regression equations have a high degree of uncertainty. Continuous measurements of flow into Olgierd Lake would facilitate wetland design. Ideally, continuous flow measurements over the course of one or more years would be taken near the inlet culvert and/or in the tributaries. This data would be used to derive a flow hydrograph.

5.1.3.3 Additional nutrient loading data

While detailed nutrient loading data for Full Wetland Restoration is less important than other measures (and may not be necessary at all, since the maximum area is already being utilized), additional water chemistry samples would help assess potential improvements in regional water quality. A total of 10 samples have already been collected in the tributaries from June to October 2021. Continuing data collection would help understand how phosphorous concentrations fluctuate over the growing season. The goal is to sample the full range of conditions, including periods of high and low flow.

While existing regional (i.e., HUC-12) nutrient load estimates from the SPARROW and STEPL models were utilized for this study, a more complex model with localized input could be employed. USEPA (2018) provides an overview of tools available to estimate nitrogen, phosphorous, and sediment loads. To derive a more precise estimate from the STEPL model, additional watershed-specific information could be determined for Olgierd Lake, such as months manure is applied, number of livestock, and septic tank conditions. Another option is the Soil and Water Assessment Tool (SWAT). The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modeled by SWAT.

5.1.3.4 Identify reference wetland(s) to guide design and monitoring

The design process could be guided by the identification of a reference wetland (or multiple wetlands). These would provide a better understanding of suitable conditions, in terms of plant composition, hydrology (including water table fluctuations), and soil properties (US FWS, 1999). The reference wetlands could serve as a model for design and standard for post-construction monitoring (US FWS, 1999; USEPA, 2021). Wetlands located within the preserve could potentially be utilized (Figure 1). While nearby woody wetlands can be used to guide the end goal (conditions 50-100 years from now), it may be more beneficial to utilize emergent wetlands, as these conditions can be obtained in 3-10 years.

5.1.3.5 Monitoring and adaptive management

Monitoring and adaptive management can help ensure that the wetland is performing to its intended function (USDA NRCS, 2003; USEPA, 2021). Guidance on monitoring and managing restored wetlands is provided by USFWS (1999), USDA NRCS (2003), and USDA NRCS (2008b). Periodic observations of water levels, water table depth, and vegetation health are recommended (USFWS, 1999). A healthy reference wetland can be used as a baseline for comparison (EPA, 2021). Frequency of monitoring depends upon the complexity of the project, intended outcome, and potential for problems to develop (USDA NRCS, 2003).

Management actives may include manipulating water levels, planting food plots, and establishing (or reestablishing) certain vegetation types (USDA NRCS, 2008b). Invasive species, weeds, and nuisance animal populations could interfere with the operational condition of the wetland and may need to be controlled as well (Kadlec and Wallace, 2009).

5.1.3.6 Selecting an appropriate water depth and control structure

An appropriate water depth will need to be identified during design. Measuring water levels over the course of the growing season or year at a reference wetland could help identify a suitable range of depths. Recontouring could also be considered to create deeper pools and shallow/emergent areas to support a variety of wetland vegetation. Most wetland designs will incorporate some type of inlet or outlet structure, flow splitter, or diversion structure for regulating flow (Hayes et al., 2000). The water level is typically controlled by an outlet structure at the downstream end of the wetland. Common outlet structures include weirs, sills, chutes, spillways, and drop inlet pipes (Hayes et al., 2000; USDA NRCS, 2003).

The control structure could be set at a fixed elevation or be adjustable to allow for changes in water level. A fixed elevation would eliminate the potential for user error and reduce operation requirements (USDA NRCS, 2003). The downside is that adaptive management is not possible. For instance, if post-construction monitoring determines that the water level is too deep for newly planted vegetation, adjustments could not be made. If an incorrect elevation is identified during design, modifications can be logistically complicated and expensive.

While an adjustable outlet structure would allow for adaptive management, it would require regular management activities (adjusting crest elevation) to maximize benefits. One advantage is that water levels could be temporarily increased to reduce the presence of non-desirable vegetation (woody species, reed canary grass, phragmites). This would enhance the wetland's ability provide high quality habitat. Outflow could also be reduced during dry periods to ensure suitable conditions for plants. Another advantage to having an adjustable structure is that it could be used to fluctuate water-levels to promote germination of native species and manage invasive plant species. Common adjustable outlet structures for wetlands include swivel pipes and adjustable weirs, with either stoplogs or a gate (Kadlec and Wallace, 2009; USDA NRCS, 2009).

5.1.3.7 Planting and establishment of wetland vegetation

Based on the surrounding wetlands, it is likely that the lake would gradually revert to forested wetlands after the restoration of hydrology. This should be considered as a target end state for the wetland plant community, although it will transition through emergent and wet meadow stages of succession. The simplest approach is to allow vegetation to naturally colonize overtime (USDA NRCS, 2008b). Restored wetlands do not necessarily require planting, especially if the topsoil is preserved during construction (Penn State, 2017). Since the Lake is surrounded by wetlands, this method is feasible, as seeds will travel in from nearby wetlands (Hayes et al., 2000).

There are two disadvantages to natural colonization: 1.) the process can take a long time (woody wetlands can take 50-100 years to establish; emergent wetlands can take 3-10 years) and 2.) unplanted areas can become dominated by invasive or aggressive species, such as phragmites, cattail, and canary grass (USFWS, 1999; Penn State, 2017). Planting nursery stock and/or a mixture of native seeds can expedite the establishment of desired vegetative conditions. However, this will increase the cost and complexity of the project (USDA NRCS, 2008b). Furthermore, if an investment in planting is made, additional monitoring may be necessary to ensure plant survivability. Nearby reference wetlands can be used to identify a mixture of suitable species. NRCS (2003) provides a directory of wetland plant vendors for Ohio.

5.1.3.8 Climate resiliency and preparedness

It is reasonable to assume that climate change will alter hydrologic conditions within the preserve, most likely in the form of increased precipitation and tributary inflow. Therefore, it would be advantageous to design the wetland to handle greater inflows overtime. The extent to which inflow may increase could be estimated by analyzing historical trends in precipitation at nearby weather stations or peak-annual discharge at gauges in adjacent watersheds. Regional climate projections may also be available for Ohio.

5.2 Measure 2: Management of Upstream Nutrient Runoff

One of the most effective means SCPD can take to mitigate algal blooms is collaborating with local landowners (i.e., farmers) within the Olgierd Lake watershed to reduce nutrient runoff, as it would address the root cause of the problem. This can be done in conjunction with any other measure, including Full Wetland Restoration.

H2Ohio is Governor DeWine's comprehensive plan to reduce harmful algal blooms and improve watershed infrastructure. The H2Ohio website lists a set of best management practices (BMPs) for farmers (H2Ohio, 2021).

Funding and technical assistance for nutrient management may be available through the USDA NRCS's Environmental Quality Incentives Program (EQIP) (USDA NRCS, 2021b). Other incentives specific to addressing harmful algal blooms may also be available through the Ohio EPA (Ohio EPA, 2021). State and Federal assistance would help entice local landowners to cooperate and reduce phosphorous-rich runoff from their farms. Examples of nutrient load reduction methods include planting winter cover crops, eliminating fall fertilizing, implementing vegetated filter strips along agricultural streams and ditches, and implementing grassed swales to address gully erosion.

In addition, the local Soil and Water Conservation District (SWCD) can modify the questionnaires in applications for NRCS funded programs so that they better reflect local priorities. SCPD could engage with the SWCD to prioritize nutrient load reductions in areas draining to lakes and ponds with harmful algal blooms.

5.2.1 Advantages

Coordination with local landowners is advantageous since it addresses the root cause of algal blooms; all other measures are reactionary. In theory, this could fully mitigate the problem, though it would require all farmers within the watershed to effectively eliminate their nutrient runoff, which is unlikely. As there are potentially state and federal incentives available, this measure could be pursued with little to no costs to SCPD (beyond the labor associated with outreach and applying for grants). Another advantage is that it can be done in conjunction with any other measure.

5.2.2 Disadvantages and Limitations

This measure is only effective if landowners are willing to cooperate. It could significantly reduce algal blooms or have little to no impact. Given the nearly 30-year struggle to reduce nutrient runoff from farms within the Lake Erie watershed, it is seemingly unlikely that this would fully mitigate algal blooms within the lake. Unless paired with other measures, it would, as best, only reduce the severity and frequency of algal blooms.

5.2.3 Design Considerations and Follow-up Analyses

If this measure is pursued, the first step is outreach to local landowners. If it is determined upon initial outreach that landowners are unwilling to employ nutrient management practices, then this measure is unfeasible. SCPD should also seek sources of external funding, as discussed above (Ohio EPA, 2021; USDA NRCS, 2021b).

5.3 Measure 3: Aeration

As discussed in section 3.2.2, Olgierd Lake periodically becomes anoxic, resulting in fish stress/mortality and increased algal growth (from stored phosphorous re-reentering the water column). This measure would involve installing an aeration system to maintain consistent dissolved oxygen levels and prevent the lake from becoming anoxic. Lake aeration is commonly utilized to address symptoms of eutrophication and improve fish habitat in manmade ponds (VTANR, 2018; Zhang et al., 2020; Kasco, 2021).

A variety of aeration system types are available. Fountains are often used (Figure 47). Diffused aeration systems are another option and have a more natural appearance, as less water movement is visible from the surface (Figure 48). While this approach is typically applied to smaller manmade ponds, there are examples of aeration being used for large natural lakes. The Vermont Agency of Natural Resources designed a $1.6 million aeration system for Lake Carmi (1,375 acres), which continually mixes water and prevents sudden releases of phosphorous from the lakebed (Gribkoff, 2018).

Figure 47: Fountain aeration system; taken from Kasco (2021).

Figure 48: Diffused aeration system shown from the bottom of a pond/lake (left) and surface (right); taken from ProPond and Lakes (2021).

5.3.1 Advantages

The main advantage of Aeration is that it would preserve the lake and associated recreational activities (i.e., fishing and paddling). It would also reduce algal growth and improve fish habitat by preventing anoxic conditions. Finally, this measure could be a relatively simple means to reduce algal blooms and improve the aquatic habitat in some of the smaller surrounding ponds (i.e., the northwest pond, southwest pond, and east pond).

5.3.2 Disadvantages and Limitations

While aeration can decrease the frequency and severity of algal blooms, they are rarely eliminated entirely (VTANR, 2018). Aeration can also decrease the availability of still water for fish spawning and increase temperatures throughout the water column due to the mixing of warm surface water downward (VTANR, 2018). Another disadvantage of aeration is that the system would have an unnatural appearance, especially if fountains are utilized. Finally, as most of the “out of the box” aeration systems are intended for small lakes and ponds, some sort of customized system may be needed. This could be expensive to design and install.

5.3.3 Design Considerations and Follow-up Analyses

If Aeration is pursued, SCPD or a hired contractor will need to design an appropriately sized system. As Olgierd Lake is fairly large (39 acres and ~2.6 feet deep), several fountains or diffusers will likely be needed. Moreover, it may be necessary to design a customized system for the lake.

Having a better understanding of when and how often the lake becomes anoxic would help design the aeration system and derive an operation scheme. Continuous dissolved oxygen (DO) loggers could be installed at several locations to measure changes in daily and seasonal DO. If samples are manually collected, measurements during both the day and night should be collected over the course of one or more growing seasons.

5.4 Measure 4: Dredging

Given the long-term inflow of hypereutrophic water, there is likely a significant amount of phosphorous stored in the lakebed sediment. As discussed in section 3.2.2, the lake periodically becomes anoxic. Under these conditions, phosphorous reservoirs reenter the water column, resulting in increased algal growth. This measure involves dredging the lakebed sediment, thereby removing stored phosphorous from the system. The ecological improvement from dredging could be enhanced by further deepening some areas of the lake. This recontouring would create pools and shallower areas to support a greater variety of aquatic vegetation and wildlife.

5.4.1 Advantages

The main advantage of dredging is that it maintains the lake and associated recreational activities. It should also reduce the frequency and severity of algal blooms, as stored phosphorous would no longer reenter the water column under anoxic conditions. This would decrease the downstream export of nutrients as well. In addition, dredging would likely lower water temperatures during summer months, possibly increasing dissolved oxygen levels.

5.4.2 Disadvantages and Limitations

The main disadvantage of dredging is that it is unlikely to fully mitigate algal blooms; at best, it would only decrease the severity and frequency of occurrence. While phosphorous stored in the system would be removed, highly eutrophic water from the tributaries would still flow in from the tributaries and promote algal growth.

Another disadvantage is that dredging can be expensive. It is difficult to provide a cost estimate, as it depends on the utilized equipment, dewatering process, and disposal site. However, dredging could easily be so expensive that the project becomes unfeasible. Furthermore, if not paired with other measures that address inflowing nutrients, dredging will need to be done on a reoccurring basis.

5.4.3 Design Considerations and Follow-up Analyses

Sediment samples should be taken to determine the amount of phosphorous stored in the lakebed and how much material would need to be excavated. Dredging may not be necessary, but this seems unlikely given the high phosphorous concentrations in the tributaries and extensive history of algal blooms. A dewatering and disposal plan should also be created.

To estimate how often the lake needs to be dredged, a better understanding of the lake's phosphorous loading and sediment transport processes is required. The goal would be to determine how much phosphorous enters the lake and what portion settles on the bottom. This would involve taking samples in the tributaries under various flow conditions. A more detailed watershed model, such as SWAT, could also help derive a better understanding of the lake's phosphorous loading. Kalin and Hantush (2003) describe several sediment transport models for lakes and reservoirs that could potentially be applied.

5.5 Measure 5: Partial Wetland Restoration

Partial Wetland Restoration would involve converting only a portion of Olgierd Lake to a wetland (Figure 49). The goal of this measure would be to reduce nutrient concentrations to the extent that algal blooms no longer occur in the downstream section that remains a lake. However, based on the calculations in section 4.12, decreases in nutrient concentrations are likely to only be marginal.

A wetland, separated from the rest of the lake by a berm, would be created around the inflow. An outlet structure would send flow from the wetland into the downstream lake (now reduced in size). Note that Figure 49 depicts approximately two-thirds of the lake being utilized as a wetland; the actual area needed would be determined prior to developing a design. The east pond could also be converted to a wetland and used to treat flow from the tributaries.

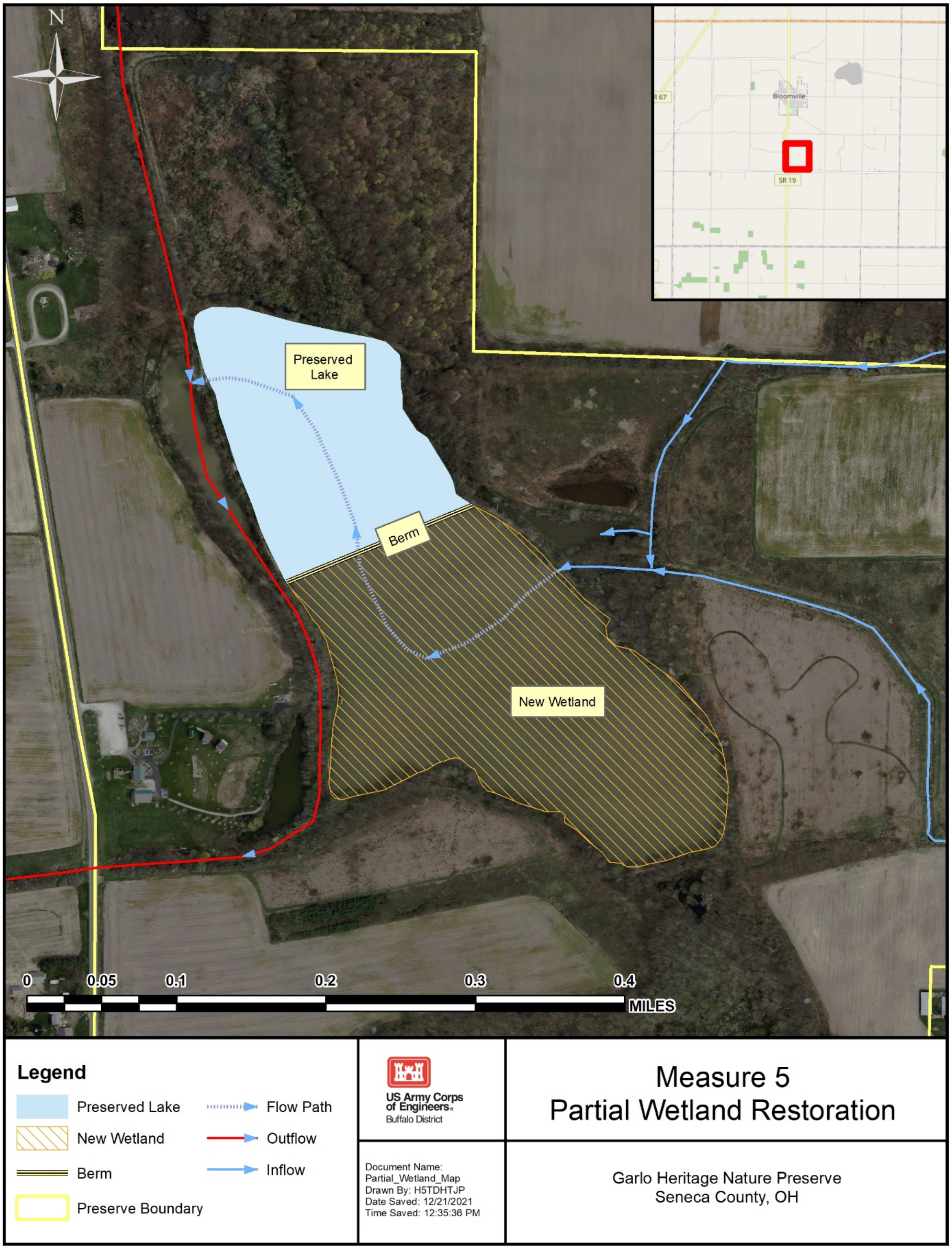

Figure 49: Depiction of the Measure 5: Partial Wetland Restoration.

5.5.1 Advantages

This measure could reduce algal productivity, improve ecological habitat, and reduce the export of nutrients to downstream waters, though to a lesser extent than Full Wetland Restoration. The lower lake volume and hydraulic retention time (HRT) would also help to control algal blooms, since there would be better circulation. However, the degree to which algal blooms would be mitigated is difficult to determine without additional information on phosphorous loading.

In terms of recreational activities, Partial Restoration allows for the maintenance of some of the lake area. Paddling and fishing would still be possible in the downstream lake. The upstream wetland would offer new recreational opportunities, such as enhanced bird watching, boardwalk hikes, and educational events.

5.5.2 Disadvantages and Limitations

The main disadvantage of this measure is that it is unlikely to fully eliminate algal blooms in the portion of the lake that is not converted to a wetland. As discussed in section 4.12; even a full conversion would result in eutrophic (and possibly hypereutrophic) outflow, so water entering the downstream lake would still be susceptible to seasonal agal blooms.

As discussed in 3.2.2, the lake periodically becomes anoxic. During these conditions, any phosphorous stored in the sediment would re-enter the water column. Therefore, this measure would need to be paired with Aeration (Measure 3) and/or Dredging (Measure 4), though dredged spoils could be used for the berm. Both Aeration and Dredging have their limitations (as discussed in sections 5.3.2 and 5.4.2) and would increase both the cost and complexity of the project. For maximum effectiveness, this measure should be paired with the Management of Upstream Nutrient Runoff (Measure 2). Without these additional measures implemented in parallel, Partial Wetland Restoration is unlikely to result in any significant reduction in algal blooms.

5.5.3 Design Considerations and Follow-up Analyses

To properly size the upstream treatment wetland (i.e., portion of the lake to convert), a better estimate of phosphorous loading is required. This would involve taking samples in the tributaries under various flow conditions to derive a phosphorous loading curve. Ideally, continuous samples would be taken over the course of several growing seasons, but this would be expensive. A more detailed watershed model, such as SWAT, could also help derive a better understanding of the lake's phosphorous loading.

Given that phosphorous reservoirs within the lakebed sediment could induce algal blooms in the lake portion under anoxic conditions, sediment samples should be collected to assess the amount stored. Dredging may not be necessary, but this seems unlikely given the high phosphorous concentrations in the tributaries and extensive history of algal blooms. Alternatively, if an aeration system is pursued, further analysis is needed to determine an appropriate size and operation scheme. Dissolved oxygen levels should also be assessed over the course of a year or several years to better understand when and how often the lake becomes anoxic.

In addition to these factors, design considerations from Full Wetland Restoration would be applicable as well.

5.6 Measure 6: Hydraulic Separation

The Hydraulic Separation measure involves hydraulically separating Olgierd Lake from its tributaries (

Figure 50). The goal is to eliminate the source of nutrient inflow. Depending on how this is accomplished, water levels in the lake would be maintained by precipitation and/or tributary flow during periods of low nutrient concentrations.

Option 1: Complete Separation: One option is to fully separate the lake from the tributaries. This would mean that water levels within the lake are maintained solely through precipitation. By our estimate, the average rate of precipitation (3.2 feet/year) outpaces the rate of evapotranspiration (2.1 feet/year) by approximately 1.1 feet/year. Therefore, this option would be feasible, so long as the infiltration rate is less than the difference between precipitation and evapotranspiration. However, the estimate for infiltration is 0-44 feet/year and thus very uncertain. Before this option is pursued, localized rates of evapotranspiration and infiltration are required to ensure that the Lake would not dry out.

Option 2: Partial Separation: Another option is to divert only the southeast tributary and keep the northeast tributary connected to the lake. As the watershed of the northeast tributary is much smaller (0.41 mi^2 vs. 1.27 mi^2), it would be expected to have a proportionately lower phosphorous loading. However, all samples taken from the northeast tributary from June to October of 2021 indicated that the water was hypereutrophic (TP > 0.1 mg/L) (Table 10). While this would reduce the total amount of phosphorous entering the lake, hypereutrophic water may still flow in. The condition of the east pond, which is fed solely from the northeast tributary and subject to algal blooms, suggests that this measure would likely be ineffective.

Option 3: Periodic Diversion: A third option is to keep both tributaries connected to the lake and create a diversion channel. During periods of high nutrient concentrations, such as a heavy rainfall event, water from the tributaries would be sent to the diversion channel and flow directly into Silver Creek. The tributaries would only feed the lake when nutrient levels are low. It should be noted, however, that all samples collected in both tributaries were either eutrophic or hypereutrophic (TP > 0.03 or 0.1) (Table 10). This suggests that conditions may never be low enough to fully eliminate algal blooms with this option. However, diverting tributary flow during hypereutrophic conditions would reduce nutrient concentrations within the lake to an extent.

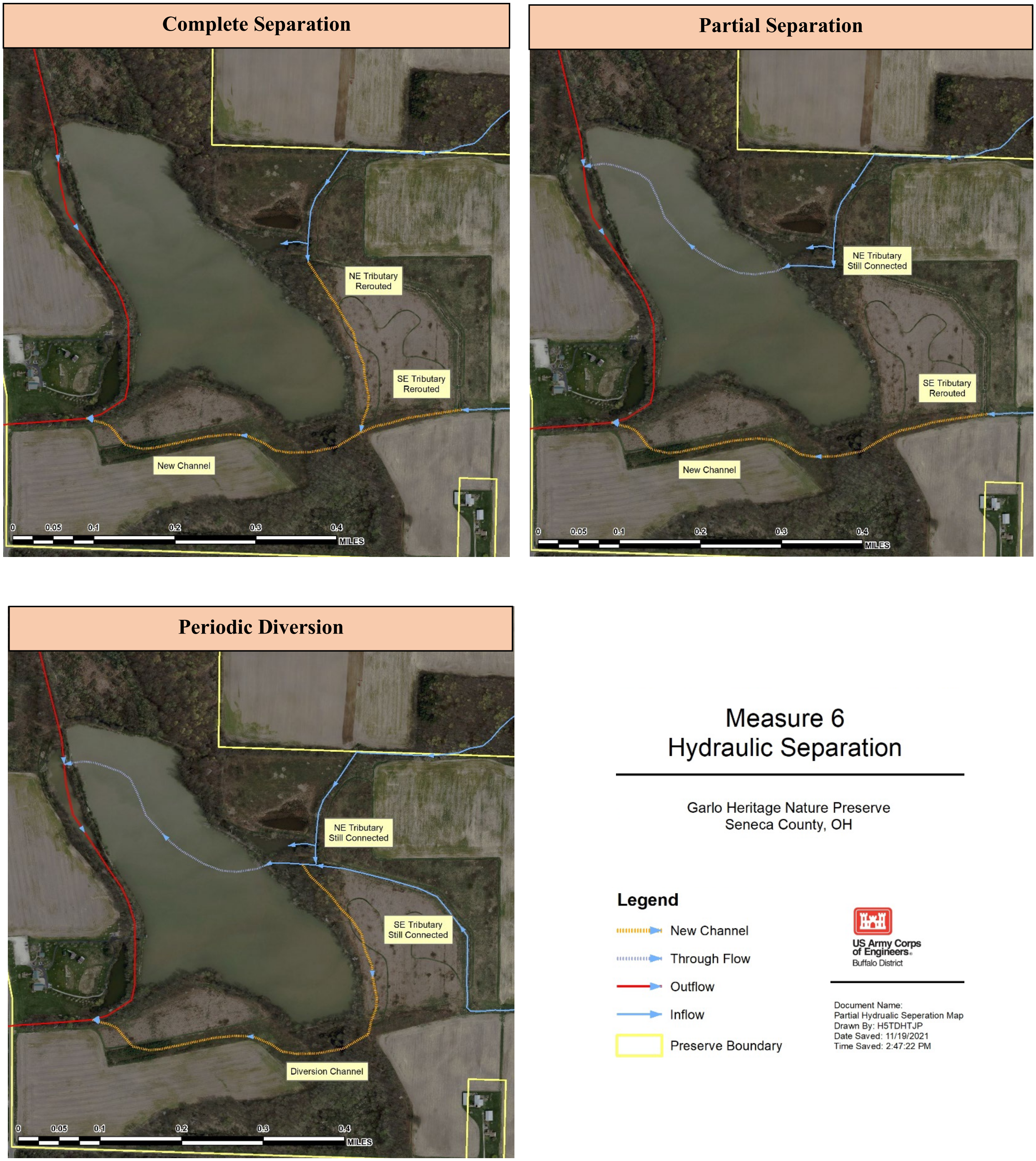

Figure 50: Depiction of Options for Measure 6: Hydraulic Separation.

Table 10: Summary to total phosphorous (TP) concentration samples from the northeast and southeast tributaries from June to October 2021

	TP Concentration (mg/L)
NE Tributary	
Jun-21	0.60
Sep-21	2.20
Oct-21	1.43
SE Tributary	
Jun-21	0.13
Jul-21	0.09
Aug-21	0.14
Sep-21	0.13
Oct-21	0.13

5.6.1 Advantages

The main advantage of Hydraulic Separation is that it would preserve the lake and related recreational activities. This measure also has some potential to reduce nutrient concentrations within the lake and the presence of algal blooms. However, the extent to which is difficult to determine based on the available information.

5.6.2 Disadvantages and Limitations

Partial Separation (Option 2) and periodic diversion (Option 3) are unlikely to fully mitigate algal blooms; at best, they would only reduce the intensity and frequency of occurrence. All phosphorous samples collected in the tributaries were either eutrophic or hypereutrophic. Partial separation (Option 2) would likely still be subject to eutrophic inflow from the northeast tributary. For periodic diversion (Option 3), there may never be conditions when nutrient concentrations in the tributaries are low enough to feed the lake. Complete separation (Option 1) has some potential to fully mitigate algal blooms, but additional study is needed to ensure that water levels can be maintained solely through precipitation.

Even if eutrophic inflow was eliminated, there would still be phosphorous reservoirs in the lakebed. Unless dredged, the stored phosphorous would reenter the water column under anoxic conditions. Therefore, in order to be effective, Hydraulic Separation would need to be paired with Aeration (Measure 3) and/or Dredging (Measure 4). Both measures have their limitations (as discussed in sections 5.3.2 and 5.4.2) and would increase the cost and complexity of the project.

Hydraulic separation could cause the lake to become too shallow or dry-out completely. This is especially true for complete separation (Option 1). Before this option can be pursued, additional analysis is needed to better understand the water budget of the lake.

While Hydraulic Separation may reduce nutrient concentrations within the lake, it would not decrease the amount of nutrients exported downstream. It could even increase the amount exported, since eutrophic water would be sent downstream without first settling in the lake. SCPD may need to coordinate downstream impacts to the Silver Creek watershed with USACE, Ohio EPA, and/or local municipalities.

Unlike measures that convert the lake or a portion of the lake to a wetland, Hydraulic Separation would not create any new habitat. It would provide little to no ecological benefit to the preserve.

5.6.3 Design Considerations and Follow-up Analyses

This measure would require a better understanding of the water budget, especially with complete separation (Option 1). To determine inflow rates, flow meters could be installed in each of the tributaries or downstream of the confluence, just before the lake. Nearby weather station data would likely be sufficient to estimate precipitation rates. However, localized evapotranspiration and infiltration rates would need to be determined. A simple way to preliminarily assess the water budget is to measure changes in depth during summer months when there is no inflow from the turbaries. If there is a significant decrease in depth, then Hydraulic Separation is likely unfeasible. Other, more complex, means of measuring infiltration (Johnson, 1993) and evapotranspiration (Jefferson, 2021) are also available.

As with Partial Wetland Restoration, a better estimate of phosphorous loading is needed. Knowing when and how frequently conditions within the tributaries become non-eutrophic is especially important for periodic diversion (Option 3). Further data may indicate that conditions are never suitable or suitable so infrequently that this measure is unfeasible.

For periodic diversion (Options 3), some form of hydraulic structure, such as a valved pipe, would be needed to regulate flow into the Lake and diversion channel. The appropriate size should be determined in a follow-up hydraulic analysis during design. The analysis would also need to identify conditions when flow should be sent to the diversion channel (i.e., an operation scheme).

If the tributaries are rerouted (for Options 1 and 2), an appropriate channel slope and invert would need to be determined. Rerouting the tributaries would also require a 404 Permit from USACE and possibly additional permits or coordination with the Ohio EPA and FEMA. This is especially pertinent if the new route extends through an existing wetland.

5.7 Measure 7: Flushing

Periodic Flushing would involve rapidly draining (i.e., flushing) the lake during and/or after heavy rainfall events when the nutrient concentration of inflowing water is high. Following the event, the lake would refill with water that is ideally non-eutrophic. This would require an adjustable weir to be installed in the western berm to create a direct flow path into the western ditch. The lake could also be flushed when algal blooms occur, to remove the highly eutrophic water from the system.

5.7.1 Advantage

The main advantage of Periodic Flushing is that it would preserve the lake and related recreational activities. This measure also has the potential to decrease nutrient concentrations within the lake and reduce algal blooms to an extent.

5.7.2 Disadvantage and Limitations

Periodic Flushing is unlikely to fully mitigate algal blooms; at best, it would only reduce the severity and frequency of occurrence. Based on tributary samples (Table 10), phosphorous concentrations may always be elevated to eutrophic or hypereutrophic levels regardless of rainfall. There may never be periods when nutrients are sufficiently low to allow the lake to refill with non-eutrophic water. Even if flushing effectively reduced phosphorous concentrations, phosphorous reservoirs stored in the lakebed could induce algal blooms under anoxic conditions unless dredged. Therefore, this measure would need to be paired with Aeration (Measure 3) and/or Dredging (Measure 4). Both have their limitations (as discussed in sections 5.3.2 and 5.4.2) and would increase the cost and complexity of the project.

Other disadvantages and limitations are similar to the ones for Hydraulic Separation. These include no reduction (and possibly an increase) in the export of downstream nutrients and limited habitat creation. SCPD may need to coordinate downstream impacts to the Silver Creek watershed with USACE, Ohio EPA, and/or local municipalities if this measure is pursued.

5.7.3 Design Considerations and Follow-up Analyses

Before this measure can be pursued, additional nutrient sampling in the tributaries is required to derive a phosphorous loading curve (a function that describes phosphorous concentration as a function of flow). This would help determine how often phosphorous concentrations are sufficiently low (i.e., non-eutrophic) to refill the lake. In addition, a hydrologic/hydraulic analysis should be performed to derive a flushing scheme. The Hydrologic Modeling System (HEC-HMS) could be used for this analysis and help assess retention time vs. outflow rates for different rainfall events (Scharffenberg, 2013).

The outlet structure would need to be properly sized and placed in a location that allows for effective flushing into the west ditch. The structure could consist of a gated weir or stoplogs. Based on a rough volume estimate of 1.7 million-ft^3, the structure would need to pass approximately 50 cfs to fully drain the lake in 24-hours.

5.8 Measure 8: Floating Wetland Islands (FWIs)

This measure involves installing manmade floating wetland islands (FWIs) that are anchored to the bottom of Olgierd Lake. FWIs are sometimes referred to as floating treatment wetlands (FTWs). The goal is to replicate water treatment processes that naturally occur with floating vegetation (Figure 51; Figure 52).

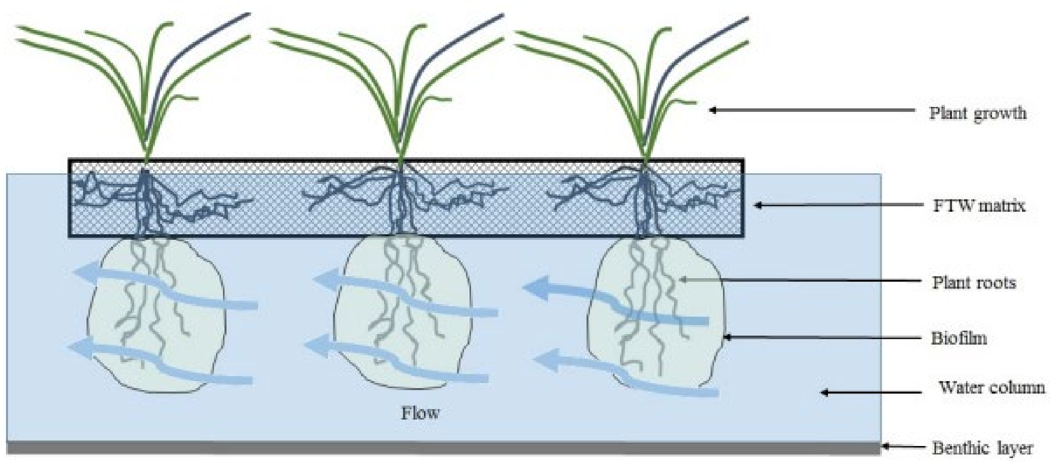

Figure 51: Schematic of a floating wetland islands (FTW); taken from Nichols et al. (2016).

Figure 52: Recently installed floating wetland islands (FWIs) (left) and established FWIs (right); taken from Hunt et al. (2012).

FWIs have several benefits over traditional wetlands, including plant roots assisting in filtering/settling processes and the ability to treat deeper water (i.e., with longer wetland retention time) (Dodkins and Mendzil, 2014). Researchers have found FWIs to achieve total phosphorous (TP) removal rates that are comparable to traditional wetlands:

- *Nichols et al. (2016)*: 53% TP removal → Bribie Island, Queensland, Australia
- *Dodkins and Mendzil (2014)*: 6-88% TP removal → various study areas (review study)
- *Hunt et al. (2012):* 29-57% TP removal → Durham, NC
- *Floating Islands International Inc. (2011)*: 42-69% TP removal → various study areas (review study)

As for the portion of a lake or pond that should be covered, Dodkins and Mendzil (2014) determined that FWIs should cover 18-50% of the surface area; any more would result in anoxic conditions and any less would result in limited nutrient reduction.

5.8.1 Advantages

FWIs would preserve the lake and related recreational activities. They would also marginally reduce algal blooms, improve ecological conditions, and lessen the downstream export of nutrients. In addition, FWIs could be used in conjunction with any other measure (besides Full Wetland Restoration).

FWIs have significant potential for research and educational opportunities. Olgierd Lake is a controlled environment with known eutrophication problems. It could serve as an ideal setting to assess the efficiency of FWIs in northern Ohio. SCPD could look to collaborate with the National Center for Water Quality Research at Heidelberg University on such a project. As part of a hands-on learning activity, students at the Out and About Preschool could participate in building FWIs or watch and learn about the process.

5.8.2 Disadvantages and Limitations

This measure is unlikely to fully mitigate algal blooms. At best, it would only decrease the severity and frequency of occurrence. Considering that the average annual total phosphorous concentration was estimated to be 0.271-0.344 mg/L (see section 4.11), even a best-case scenario of 80% removal would still result in eutrophic water within the lake. Shading from the islands may reduce water temperatures, but the water would still be stagnant, shallow, eutrophic, and ultimately conducive to algal growth.

In comparison to traditional wetland restoration, FWIs are a new technique. While we have identified several studies showing good nutrient removal rates, there is uncertainty as to how these systems would perform in northern Ohio. Moreover, limited information is available on potential costs, longevity, and operation/maintenance requirements.

5.8.3 Design Considerations and Follow-up Analyses

Dodkins and Menzil (2014) discuss design considerations for floating treatment wetlands. The flow volume, flow variation, nutrient concentration, and required outflow characteristics should all be considered when designing the system. Prebuilt FWIs could potentially be purchased.

5.9 Measure 9: Biomanipulation

Biomanipulation is the top-down alteration of an aquatic ecosystem to improve its health despite excess nutrient loads. The main goal is to increase the quantity of zooplankton to keep the phytoplankton (including harmful algae) in check. To increase the zooplankton population, it is necessary to decrease the population of planktivorous fish population. This is typically performed by the combination of two methods: 1) Removal of most of the existing population of planktivorous fish; and 2) Stocking of piscivorous fish to help keep the planktivorous fish population in check.

5.9.1 Advantages

Advantages of this approach include the ability to maintain the full size and current recreational uses of the lake. Some fishers may appreciate the addition of new sport species of piscivorous fish such as Largemouth Bass or Northern Pike.

5.9.2 Disadvantages and Limitations

The main disadvantage of Biomanipulation is that in its current state, the lake cannot support the needed trophic levels of fish. In addition, the algae population is so great that zooplankton are unlikely to provide any significant reduction. Biomanipulation has been found to have only limited success in highly eutrophic waters (Peretyatko et al., 2012). This measure may be more effective if applied to a less-eutrophic system, for instance, if combined with Management of Upstream Nutrient Runoff (Measure 2), Partial Wetland Restoration (Measure 5), or Hydraulic Separation (Measure 6), as these measures would reduce the nutrient concentration of water flowing into the lake.

This measure often requires periodic maintenance in the form of periodic harvesting of planktivorous fish and/or re-stocking the piscivorous fish population. Angler limits may need to be imposed for piscivorous species which might include size and catch limitations and/or requirements to use barbless hooks and catch-and-release policies.

6 Qualitative Comparison of Measures

The following section provides a qualitative comparison of measures by categorizing them according to various criteria (Table 11). As it is a qualitative assessment, very few calculations were performed. While this approximates the most likely outcome given the current information, our understanding of the situation may change if additional analysis is performed.

Table 11: Categorization of measures by various criteria.

	Reductions in Algal Blooms	Habitat Creation	Downstream Reduction in Nutrients	Preserves Lake?
Measure 1: Full Wetland Restoration	Could fully mitigate algal blooms **(greatest potential for success)**	Most creation	Most reduction	No
Measure 2: Management of Upstream Nutrient Runoff	Could reduce algal blooms	None	Some reduction	Yes
Measure 3: Aeration	Could reduce algal blooms	Some	No reduction	Yes
Measure 4: Dredging	Could reduce algal blooms	None	Some reduction	Yes
Measure 5: Partial Wetland Restoration	Could reduce algal blooms	Some	Some reduction	Partial
Measure 6: Hydraulic Separation	Could fully mitigate algal blooms (pertains to Complete Separation only) - Additional analysis needed	None	No reduction (possibly an increase)	Yes
Measure 7: Flushing	Unlikely to reduce algal blooms	None	No reduction (possibly an increase)	Yes
Measure 8: Floating Wetland Islands (FWIs)	Could reduce algal blooms	Some	Some reduction	Yes
Measure 9: Biomanipulation	Unlikely to reduce algal blooms	None	Some reduction	Yes

6.1 Reduction in Algal Blooms

This criterion is defined as the mitigation of algal blooms and improvement in ecological habitat. The measure with the most potential to effectively eliminate algal blooms is Full Wetland Restoration (Measure 1). It is possible that algal blooms will still occur with Full Restoration, especially given that blooms have been observed in the North Wetland. However, this measure has the most potential to reduce their frequency and severity, if not eliminate them entirely. Complete Hydraulic Separation (Option 1 of Measure 6: Hydraulic Separation) could possibly eliminate algal blooms as well, but additional analysis is needed to ensure that the lake would not dry-out if inflow from the tributaries is diverted. Moreover, it would need to be done in conjunction with Dredging and/or Aeration (Measures 3 and 4).

Most other measures are categorized as "could reduce algal blooms"; at best, they would only lessen their frequency and severity. Flushing (Measure 7) is categorized as "unlikely to reduce algal blooms" since it would do very little to reduce nutrient concentrations within the lake if there are never periods of low phosphorous concentrations in the tributaries. This scenario is possible, as all tributary samples from June to October 2021 were eutrophic; in fact, all but one was hypereutrophic. Biomanipulation (Measure 9) is also categorized as "unlikely to reduce algal blooms", since the lake is highly eutrophic, and the zooplankton would do little to control algae populations.

6.2 Habitat Creation

Habitat creation is defined as the creation of new habitat for native plants, fish, birds, macroinvertebrates, amphibians, and other animals that inhabit the preserve. Full Wetland Restoration (Measure 1) would easily provide the most habitat creation, followed by Partial Wetland Restoration (Measure 5) and FWIs (Measure 8). Aeration (Measure 3) would also create some aquatic habitat by maintaining dissolved oxygen levels that support a richer community of fish. Other measures, including Management of Upstream Nutrient Runoff (Measure 2), Dredging (Measure 4), Hydraulic Separation (Measure 6), Flushing (Measure 7), and Biomanipulation (Measure 9), would create little to no new habitat.

6.3 Reduction in Downstream Nutrient Export

Reduction in downstream nutrient export refers to the decrease in nutrient concentration (i.e., phosphorous) of water that is sent downstream of the lake and leaves the preserve. Full Wetland Restoration (Measure 1) would provide the most reduction. Managing Upstream Nutrient Runoff (Measure 2), Dredging (Measure 4), Partial Wetland Restoration (Measure 5), FWIs (Measure 8), and Biomanipulation (Measure 9) would provide some reduction in downstream nutrient export. Aeration (Measure 3), Hydraulic Separation (Measure 6), and Flushing (Measure 7) would provide no reduction; in the case of Hydraulic Separation and Flushing, there may even be an increase in the amount of nutrients sent downstream, as highly eutrophic water from the tributaries would bypass Olgierd Lake and flow directly into Silver Creek.

6.4 Lake Preservation

Olgierd Lake is widely utilized for recreational activities. Removing the lake would mean a loss of such activities as paddling and fishing. While Full Wetland Restoration (Measure 1) has the most potential to eliminate algal blooms, create new habitat, and reduce the downstream export of nutrients, it would not maintain the lake. Likewise, Partial Wetland Restoration (Measure 5) would only maintain a portion of the lake. All other measures would preserve the entire lake.

7 Potential Options and Outcomes

This section describes groupings of the proposed measures that have the best chance of delivering different outcomes. Based on the goals for Garlo Heritage Nature Preserve, SCPD will ultimately need to decide which outcomes are most desirable. Note that this does not represent a full list of possible groupings, as there are virtually limitless combinations.

7.1 Best Budget (Measure 1)

A simple design for Full Wetland Restoration (Measure 1) could consist solely of installing an outlet control structure (i.e., a low head weir with stoplogs) and reducing the depth of Olgierd Lake. The wetland would naturally colonize with vegetation overtime. This would most likely be the cheapest means of mitigating algal blooms. Once vegetation establishes, this option would also create new habitat and reduce downstream nutrient export. However, it may take upwards of 5-10 years for emergent vegetation to fully establish and unplanted areas could become dominated by invasive or aggressive species.

7.2 Best Algal Bloom Reduction and Ecosystem Improvement (Measures 1 and 2)

When paired with the Management of Upstream Nutrient Runoff (Measure 2), Full Wetland Restoration (Measure 1) would provide the most effective means of mitigating algal blooms and could potentially eliminate them entirely. This combination addresses the root cause of the problem, while simultaneously removing conditions that are conducive to algal growth. In comparison to other options, this would also provide the most habitat creation and reduction in downstream nutrient export.

7.3 Best Way to Enhance Lake Uses while Addressing Algal Blooms (Measures 3, 4, and 6)

If, based on feedback from the community, SCPD is unable to convert Olgierd Lake to a wetland, then the next best option to address algal blooms is hydraulically separating the tributaries (Measure 6); this would be the complete separation option (as opposed to partial separation or periodic diversion, as discussed in section 5.6). While this would remove the source of nutrient inflow, phosphorous reservoirs within the lakebed sediment would likely need to be removed via dredging (Measure 4). Another option is installing some type of aeration system to maintain dissolved oxygen levels and prevent lake water from becoming stagnant or anoxic (Measure 3). It may be necessary to implement both dredging and aeration. This option could potentially eliminate algal blooms and enhance reactional activities associated with the lake, such as paddling and fishing. However, it would do nothing to reduce downstream nutrient export (and may even increase it) as highly eutrophic water from the tributaries would flow directly into Silver Creek. Before pursuing, a better understanding of the water budget is required. If the rate of evapotranspiration and infiltration outpace the rate of precipitation, then the lake will dry out.

7.4 Best way to Enhance Lake Uses while Addressing Algal Blooms and Reducing Downstream Nutrient Export (Measures 2, 3, 4, 5, 7, 8 and 9)

If SCPD wants to address the downstream export of nutrients or determines that the lake's water budget does not support Hydraulic Separation, then Partial Wetland Restoration (Measure 5) could be pursued. However, to provide any noticeable reduction in algal blooms, this measure should at least be paired with the Management of Upstream Nutrient Runoff (Measure 2), Aeration (Measure 4), and/or Dredging

(Measure 3). Floating Wetland Islands (FWIs) (Measure 8) and Biomanipulation (Measure 9) could also be incorporated to further increase the effectiveness of this option. Being able to flush the lake (Measure 7) if algal blooms are observed would allow for the removal of highly eutrophic water from the system and serve as a failsafe.

This combination of measures would result in a smaller lake with lower nutrient concentrations. However, even when pursing all seven measures in parallel, this option is unlikely to fully mitigate algal blooms; at best, it would only decrease the severity and frequency of occurrence. There would also be a high cost, given all the measures that it would entail.

7.5 Low Effort Option for Surrounding Ponds (Measure 3)

Regardless of any measures pursued for Olgierd Lake, Aeration (Measure 3) could be used to improve aquatic habitat within the smaller surrounding ponds. The higher dissolved oxygen levels would support a richer community of fish and prevent the ponds from becoming anoxic. This may also help reduce algal blooms, depending on how much phosphorous is stored in the sediment, since it would no longer reenter the water column under anoxic conditions. While Full Wetland Restoration would eliminate Olgierd Lake, improving the water quality of other ponds within the preserve could serve as a middle ground and enhance water-related recreational actives within the smaller ponds. It may be difficult to run a power line to the east pond, but it should be easier to deliver power to the northwest and southwest ponds.

8 Conclusion

This study was completed under USACE's Planning Assistance to States (PAS) authority to investigate the hydrologic and ecological conditions of the Garlo Heritage Nature Preserve. A total of nine conceptual measures to address algal growth and provide ecological uplift were evaluated. Full wetland restoration (i.e., converting the entirety of Olgierd Lake into a wetland) is most likely to mitigate algal blooms; this is especially true if it is combined with upstream nutrient management. If a full conversion of Olgierd Lake is not desirable, other measures, such as hydraulic separation, could potentially mitigate algal blooms; however, the effectiveness of these approaches is less certain and likely would require a combination of several different measures.

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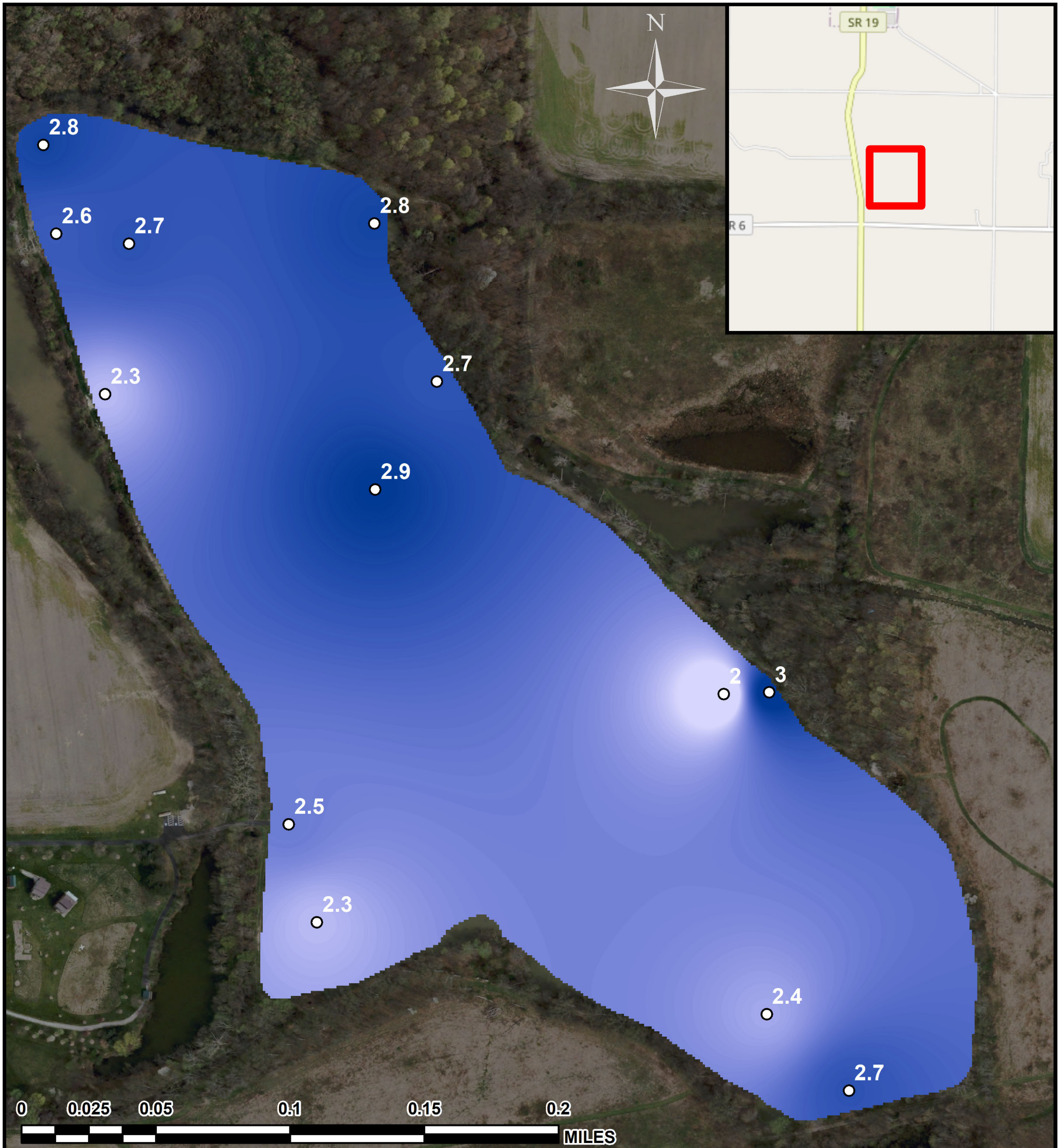
Garlo Heritage Nature Preserve, Section 22 PAS Bloomville, Ohio

Appendix A: Water Chemistry

July 2021

Sample ID	Collection Date and Time		Ammonia mg/L	TKN mg/L	NO2/NO3 mg/L	Total P mg/L	TSS mg/L	Chl a ug/L	pH	DO mg/L	DO % Sat	Turbidity NTU	Temp. Deg C	Spec Cond uS/cm	Depth feet	Other Notes
T1	20210603	10:07	0.014	0.70	3.10	0.60	20.8	10.86	7.71	6.49	70.1	24.04	16	444.2	-	Southeast Trib
T2	20210603	9:48	0.027	0.85	0.76	0.13	21.6	2.53	7.45	6.34	66.4	27.62	16.4	579	-	Northeast Trib
L1	20210603	10:58	0.830	2.10	0.82	0.72	73.2	15.54	7.78	5.96	66.1	158.90	19	308.4	2.7	Soft bottom, mucky
L2	20210603	11:02	0.860	2.00	0.79	0.59	66.8	19.20	7.80	5.13	56.3	121.70	18.9	308.7	2.9	Soft bottom
L3	20210603	11:17	0.830	1.90	0.79	0.61	70.0	25.19	7.72	5.40	60.5	169.60	19.2	307.8	2.35	Soft bottom
L4	20210603	11:32	-	-	-	-	-	-	7.82	6.28	70	163.60	19.7	308.3	2.7	Soft bottom
L5	20210603	11:41	-	-	-	-	-	-	7.89	6.75	70	111.10	19.6	320.5	2	Hard bottom
L6	20210603	11:50	-	-	-	-	-	-	7.61	5.56	62.1	62.06	19.2	473.9	3	Sandy bottom
L7	20210603	11:59	-	-	-	-	-	-	7.83	7.14	81.2	97.85	19.8	308.5	2.7	Hard bottom
L8	20210603	12:04	-	-	-	-	-	-	7.96	7.16	81.2	151.00	19.7	308.7	2.8	Soft bottom
L9	20210603	12:09	-	-	-	-	-	-	7.8	6.02	67.4	132.40	19.3	308.5	2.8	Soft, Mucky
L10	20210603	12:15	-	-	-	-	-	-	7.81	7.02	79.3	108.00	19.2	308	2.65	Soft bottom
L11	20210603	-	-	-	-	-	-	-	7.86	5.55	61.7	124.00	19.1	308.8	2.3	Soft bottom, Mucky
L12	20210603	12:32	-	-	-	-	-	-	7.61	4.83	53.8	164.90	19	308.8	2.3	Soft bottom
L13	20210603	12:40	-	-	-	-	-	-	7.73	5.7	65.1	82.09	20.4	308.1	2.5	Soft bottom
L14	20210603	1:07	-	-	-	-	-	-	7.86	5.37	56.2	13.10	19.3	353.1	-	Soft bottom



Depth (ft)

High : 5

Low : 0

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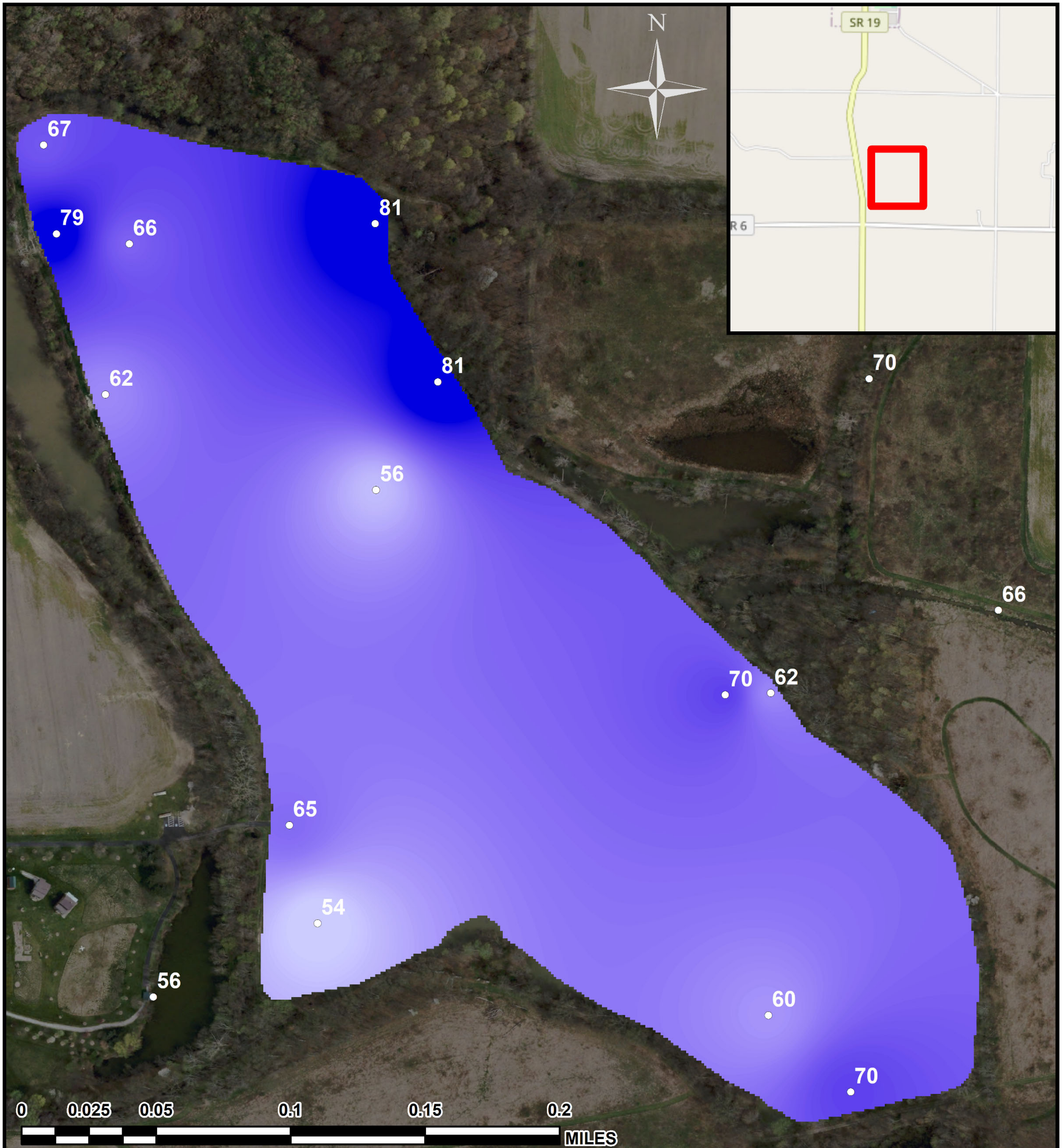
Olgierd Lake Depth

Document Name: Depth_Map
Drawn By: H5TDHTJP
Date Saved: 6/14/2021
Time Saved: 2:17:56 PM

Garlo Heritage Nature Preserve
Seneca County, OH

Sampled June 3rd, 2021 (10:00 AM - 1:00 PM)



Dissolved Oxygen (% Sat.)

High :85

Low : 50

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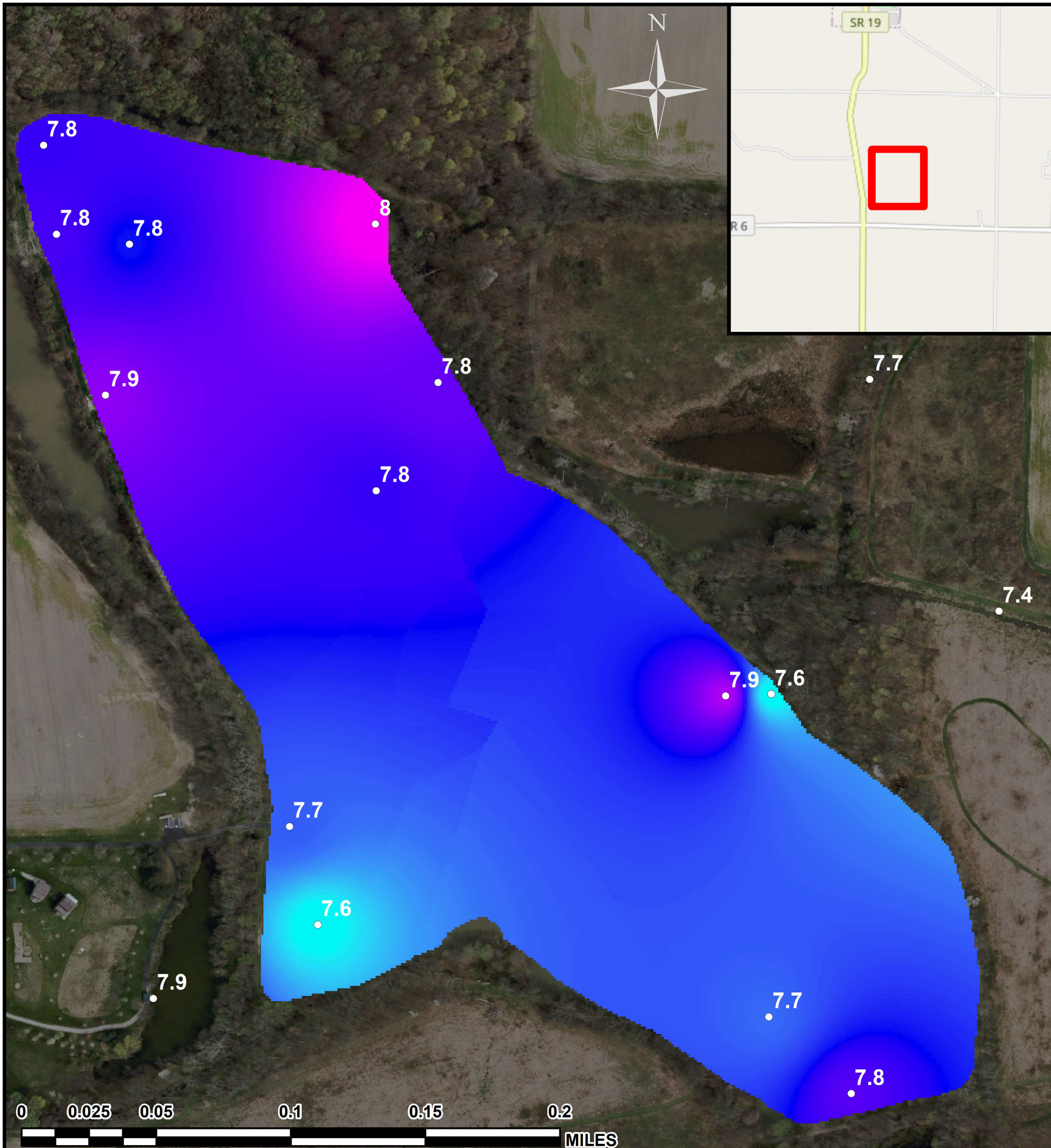
Olgierd Lake
Dissolved Oxygen

Document Name:
DO_Map
Drawn By: H5TDHTJP
Date Saved: 6/14/2021
Time Saved: 2:21:08 PM

Garlo Heritage Nature Preserve
Seneca County, OH

Sampled June 3rd, 2021 (10:00 AM - 1:00 PM)



pH

High : 8

Low : 7

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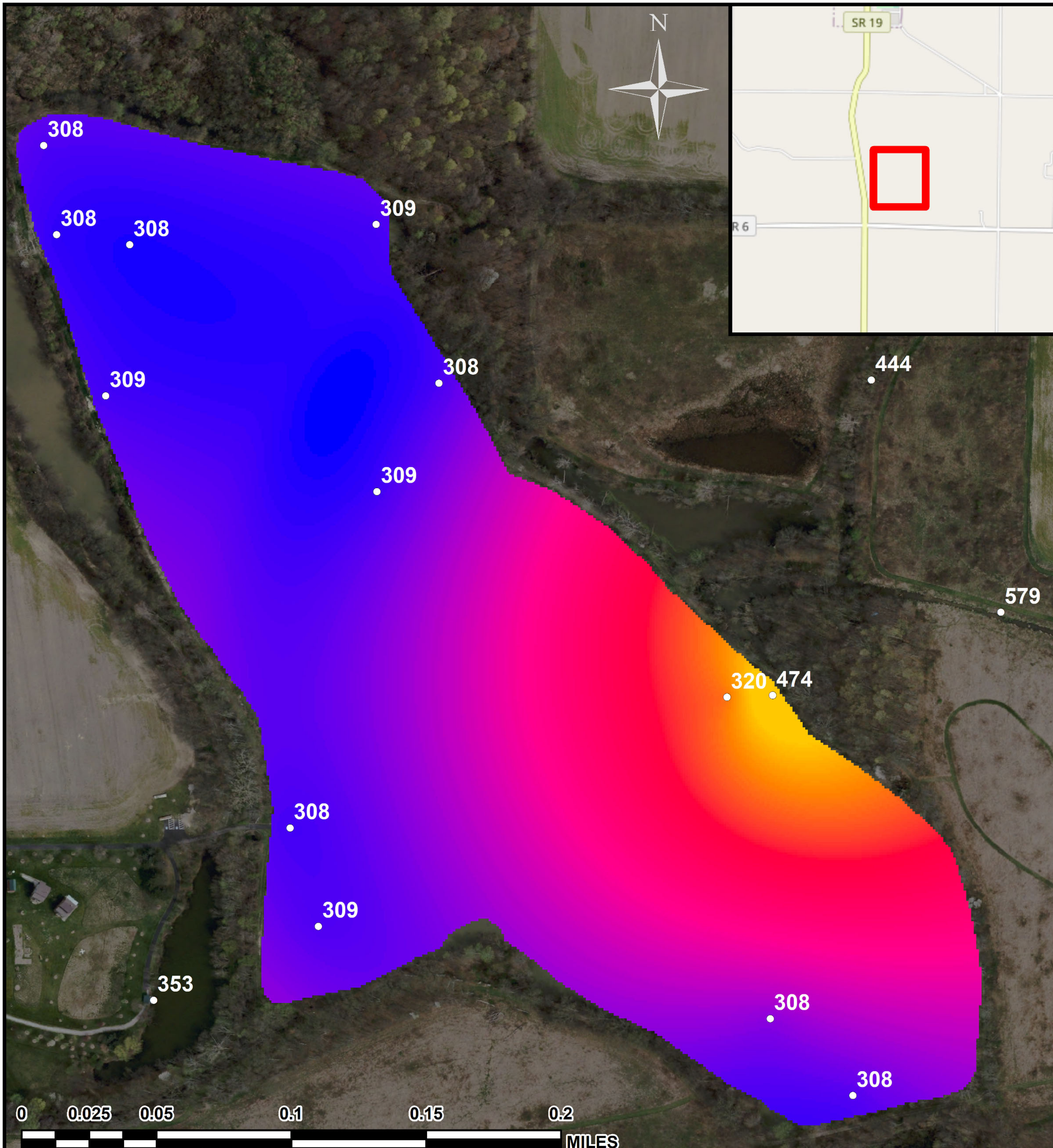
Olgierd Lake
pH

Document Name:
pH_Map
Drawn By: H5TDHTJP
Date Saved: 6/14/2021
Time Saved: 2:38:49 PM

Garlo Heritage Nature Preserve
Seneca County, OH

Sampled June 3rd, 2021 (10:00 AM - 1:00 PM)



Specific Conductivity (uS/CM)

High : 580

Low : 300

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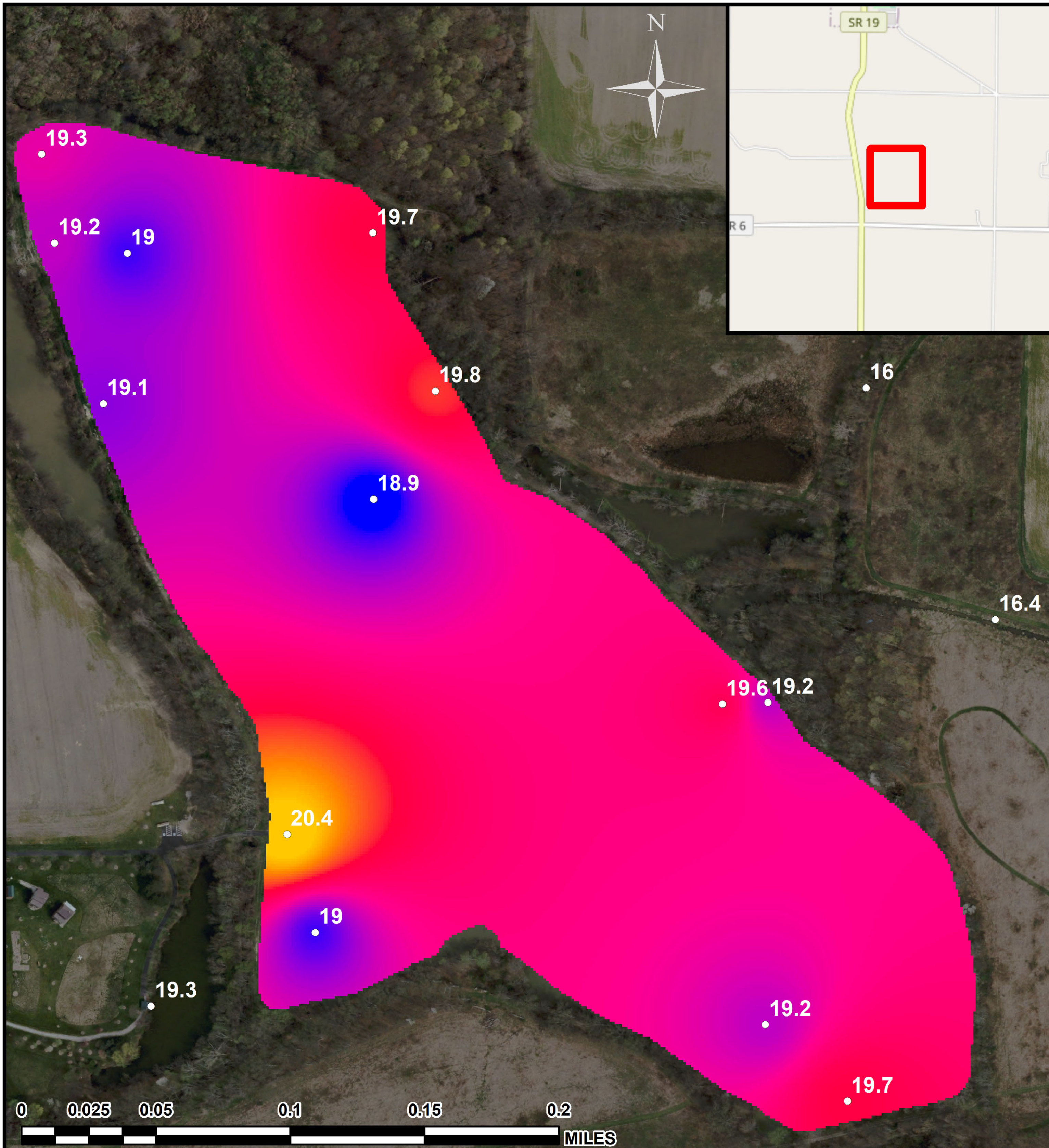
Document Name:
Cond_Map
Drawn By: H5TDHTJP
Date Saved: 6/14/2021
Time Saved: 2:15:02 PM

Olgierd Lake
Specific Conductivity

Garlo Heritage Nature Preserve
Seneca County, OH

Sampled June 3rd, 2021 (10:00 AM - 1:00 PM)



Temperature (Deg C)

High : 21

Low : 16

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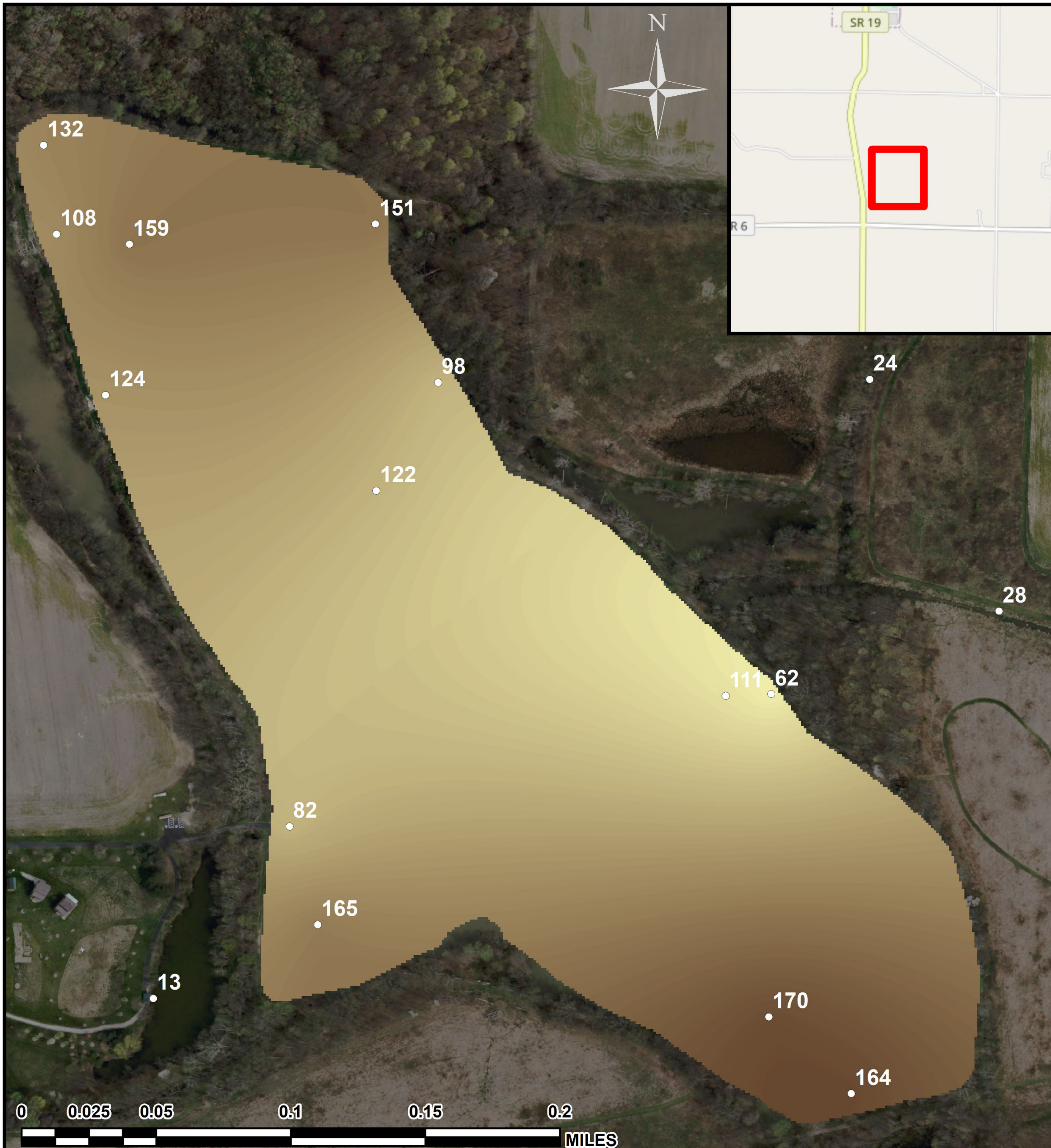
Olgierd Lake
Water Temperature

Document Name: Temp_Map
Drawn By: H5TDHTJP
Date Saved: 6/14/2021
Time Saved: 2:42:47 PM

Garlo Heritage Nature Preserve
Seneca County, OH

Sampled June 3rd, 2021 (10:00 AM - 1:00 PM)



Turbidity (NTU)

High : 180

Low : 0

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Olgierd Lake Turbidity

Document Name: Turb_Map
Drawn By: H5TDHTJP
Date Saved: 6/14/2021
Time Saved: 2:45:10 PM

Garlo Heritage Nature Preserve
Seneca County, OH

Sampled June 3rd, 2021 (10:00 AM - 1:00 PM)