State of Apple Valley Lake 2024

Water Quality Assessment and Data Compilation

12/20/2024

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Executive Summary

Apple Valley Lake is a 511-acre private reservoir located within Knox County, Ohio. Traditionally known for its clear water and macrophyte (submersed aquatic vegetation; SAV) dominance, the contact recreation lake experienced its first noted algae bloom in the spring of 2024. Although the bloom was not considered harmful for contact recreation purposes, this unusual change prompted concerns regarding whether the reservoir is trending toward becoming impaired for its best categorical use. To add to these concerns stakeholders also noted a reduction in SAV growth that was typical to the lake in previous years. To investigate these issues, lake water quality data and SAV surveying was collected and conducted during the 2024 season to assess the current condition of Apple Valley Lake and help produce a Lake Monitoring and Sustainability Plan (LMSP). As the lake was not impaired for its best categorical use during the 2024 season, the goal of this plan was to provide direction to the stakeholders of Apple Valley Lake and reconstruct lake monitoring standard operating procedures (SOP) while suggesting actions that could improve the sustainability of the system. By working to accomplish these tasks, future impairment potential can be reduced. To assist in the creation of a LMSP, an update of relevant productivity information and lake categorization data was collected and added to historical water quality data provided by the Apple Valley Property Owners Association (AVPOA) and local stakeholders. This included collecting water column nutrient data and Secchi transparency to identify the trophic condition of the lake as well as depth profile information to determine mixing regime, oxygen behavior, algae biomass and others. In-situ information including temperature and dissolved oxygen depth profile data and Secchi transparency was also provided as historical data for reference conditions. A SAV sonar mapping survey was also conducted in August to determine the density of macrophyte growth in the lake at its assumed peak.

The results of collected data from 2024 and compiled historical data from stakeholders indicate that Apple Valley Lake is a stratified, likely dimictic and mesotrophic reservoir system that is relatively deep for its size. Phosphorus (P) data showcased spatial differences in nutrient concentrations from the inlet to the dam that has stayed consistent with historical data (mean 2024 concentration 35.3 µg/L vs. <50 µg/L historical). 2024 Secchi transparency (SD) values were lower compared to historically provided information from the past 24 years (mean SD historical was 1.78 m vs. 1.11 m for 2024). This noted decrease can be attributed to lower SD values collected during the confirmed algae bloom in the spring but was found to recover to values closer to the mean by the end of the lake season (October). Elevated algae concentrations were confirmed in June sampling with a maximum concentration of chlorophyll α (primary photosynthetic pigment of algae) being 19.52 µg/L in 12 ft of water depth. All following sampling periods showcased a severe reduction in chlorophyll α concentrations well below this maximum (nothing above 3.5 µg/L) suggesting the bloom had subsided by July. Vegetation survey data noted only 6.8% of the area of Apple Valley Lake had SAV growth in late August with 17.3% of the water column being occupied within the 6.8% of aerial SAV growth. These values would suggest that a low amount of the lake's littoral zone contained SAV and where SAV was present, it remained low in the water column. Investigatory rake tosses within zones of confirmed SAV showcased pondweed (*Potamogeton*) species and naiads (*Najas)*. Both plant genera are considered water level drawdown resistant.

The findings of this survey allow for the hypothesis that the early season algae bloom became the dominant form of primary productivity in the lake during spring and reduced competitive viability to SAV. As the annual drawdown already selects for specific plants to persist in Apple Valley Lake and normally retards their growth into the later half of the season, the additional reduction in littoral area (due to algal-based turbidity) and lack of available nutrients to SAV in a mesotrophic system likely pushed SAV growth further into the year than what is normally observed. Once the bloom subsided in July and clarity began to return to typical lake conditions, SAV growth started to showcase signs of recovery. A full stable-state change to an algae dominant system was not observed once bloom conditions subsided. As the lake never became impaired for its categorical use as a recreational reservoir, an aggressive management approach targeting primary productivity may not be suggested for Apple Valley Lake at this time. Rather, efforts should be made to increase monitoring presence and enact best management practices (BMPs) to sustain the lake's current condition and slow down cultural eutrophication. Suggestions to work toward these broad goals are briefly highlighted as follows:

1) Adopt an appropriate standard operating procedure (SOP) for the collection, analysis, and reporting of relevant water quality information as highlighted in Chapter VII and VIII of this report to build upon and create appropriate reference conditions for future management considerations (**2025 and beyond)**.
2) Construct hand-in-hand relationships with watershed groups to work toward the common goal of the enactment of watershed BMPs to reduce the overall nutrient load that may enter Apple Valley Lake. Focus should be on agricultural BMPs as a large amount of watershed land-use encompasses agricultural purposes based on data collected in Chapter II of this report. Lake homeowner BMPs should also be prioritized as education of BMPs to local stakeholders and enactment of bylaws to support them may be within the jurisdiction of the AVPOA **(2025 and beyond)**.
3) Should collected reference conditions and future water quality monitoring showcase an increase in P-loading and movement of the lake toward impairment, in-lake P-reduction strategies may need to be implemented as discussed in Chapter VI. Although not expected as a concern for 2025, early planning may help with capital costs associated with such projects on a large reservoir **(Future consideration)**.

Chapter VIII (LMSP) and the body of the State of the Lake Report go into these items in greater detail. These suggestions work together to keep Apple Valley Lake within a non-impaired status while simultaneously remaining dynamic to future management considerations that may arise.

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I. Introduction

Current Designation and Impairment Information

Apple Valley Lake is a reservoir that is approximately 511 acres (206.8 hectares) in size and represents one of four major reservoirs in the area (Knox Lake, Pleasant Hill Lake, and Lake Buckhorn represent the other three). The lake itself is located to the north of Howard, OH as the closest Township but can also be represented by Amity, OH and Danville, OH to the west and east of the reservoir respectively in Knox County. Its geographical location is approximately 40° 26’8.11” N Latitude 82° 20’47.76” W Longitude to lake center. Apple Valley Lake is primarily fed by Little Jelloway Creek from the north and primarily discharges from a dam located at the southern end of the reservoir. Although the State of Ohio does not classify water bodies by water quality thresholds and use designations, Apple Valley Lake could be best categorized as a contact-recreation water body and future water quality threshold development should reflect this.

Traditionally known for its clear water and submersed aquatic vegetation growth (SAV), Apple Valley Lake experienced an unusual planktonic algae bloom in the Spring of 2024. Although this bloom was not considered to be harmful (harmful algae bloom or HAB), the observed increase in turbidity by local stakeholders drew concern that the lake may be experiencing a regression in water quality. In addition, a noted decrease in SAV within the lake drew more concern as typical conditions for the reservoir were not occurring. The noted issues and concern for the health of the lake generated enough alarm for members of the community to investigate what may have caused the aforementioned condition and to determine if the lake is moving toward an impaired designation. Physical, chemical, and biological information has loosely been collected by various lake stakeholders but not compiled together. This information, including information collected by AQUA DOC: Lake and Pond Management in 2024 and stakeholder collected data, to the best knowledge of the author is compiled here and assessed with recommendations for Apple Valley Lake to proceed with a management strategy. The information used to characterize Apple Valley Lake, its management issues, and an assessment of the tools and techniques associated with them is presented in the chapters below.

II. Reservoir Morphology and Watershed Characterization

Reservoir Morphology

Apple Valley Lake represents typical, relatively deep reservoir morphology characteristics. The basin is dendritic in nature with coves dominantly being located along the western shoreline. The western shoreline has substantially more shoreline length than the eastern shoreline due to this characteristic. Apple Valley Lake follows typical longitudinal reservoir zonation with a riverine zone, transitional zone, and lacustrine zone (Kimmel & Groeger 1984). This morphometric characteristic showcases a “swimming pool” type basin design whereas the shallowest portions of the reservoir are located closer to the primary inlet (s) of the lake to the north and within dendritic coves while the deeper portions are near the dam (40°25’9.93” N Latitude 82°20’33.38” W Longitude). The deepest portion of the lake is central in the basin to the west of the dam with a suggested deepest known point (Z_{max}) of approximately 73.3 ft (22.3 m; approximately 40° 25’ 16.05” N 82° 20’ 49.06” W). A marina is located at the northern end of the lake near a small assemblage of channels surrounding a large island. The primary inlet is also located near this area (40°27’48.21” N Latitude 82°20’16.13” W Longitude). The central basin is commonly utilized for recreational boating and waterskiing activities are a highlighted sport enjoyed by the community. Available morphometric characteristics of Apple Valley Lake are highlighted below (Table 1). A bathymetric map of the lake is also provided with Figures 1 & 2 below (separated north and south due to scale).

Table 1: Summary of the physical morphology of Apple Valley Lake.

Reservoir Characteristic	**Unit**
Total Estimated Lake Area	511 ac
Total Estimated Lake Volume	12,619 ac ft
Total Estimated Gallons of Water	4.11×10^9
Max Estimated Length	18,060 ft
Max Estimated Width	3,950 ft
Average Estimated Depth	24.7 ft
Max Estimated Depth	73.3 ft

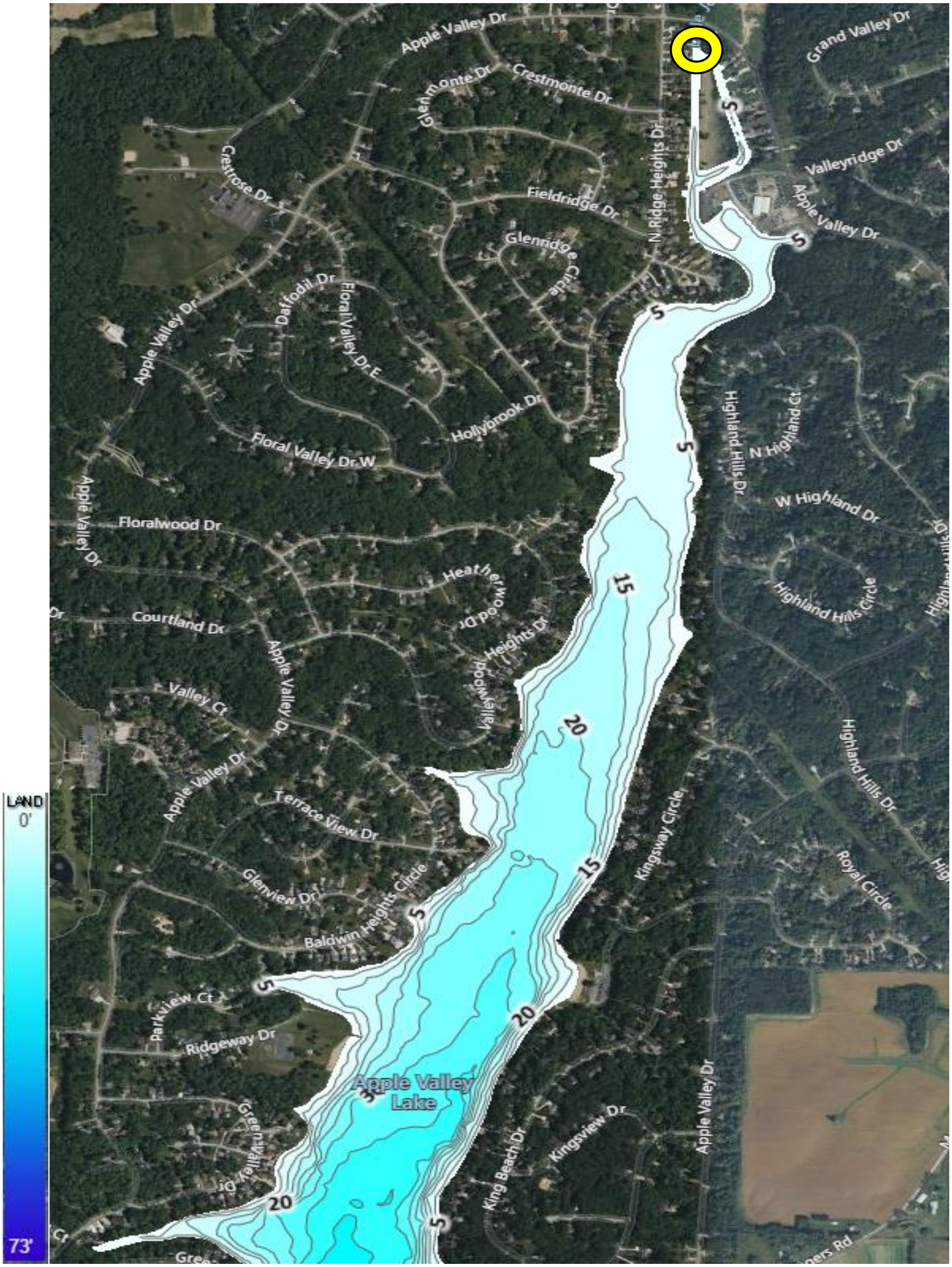


Figure 1: Bathymetric map of Apple Valley Lake (northern section). Darker blue colors indicate increasing depth contours. Yellow circle denotes the primary inlet of the reservoir. Data for map collected during this survey using Biobase® mapping program.

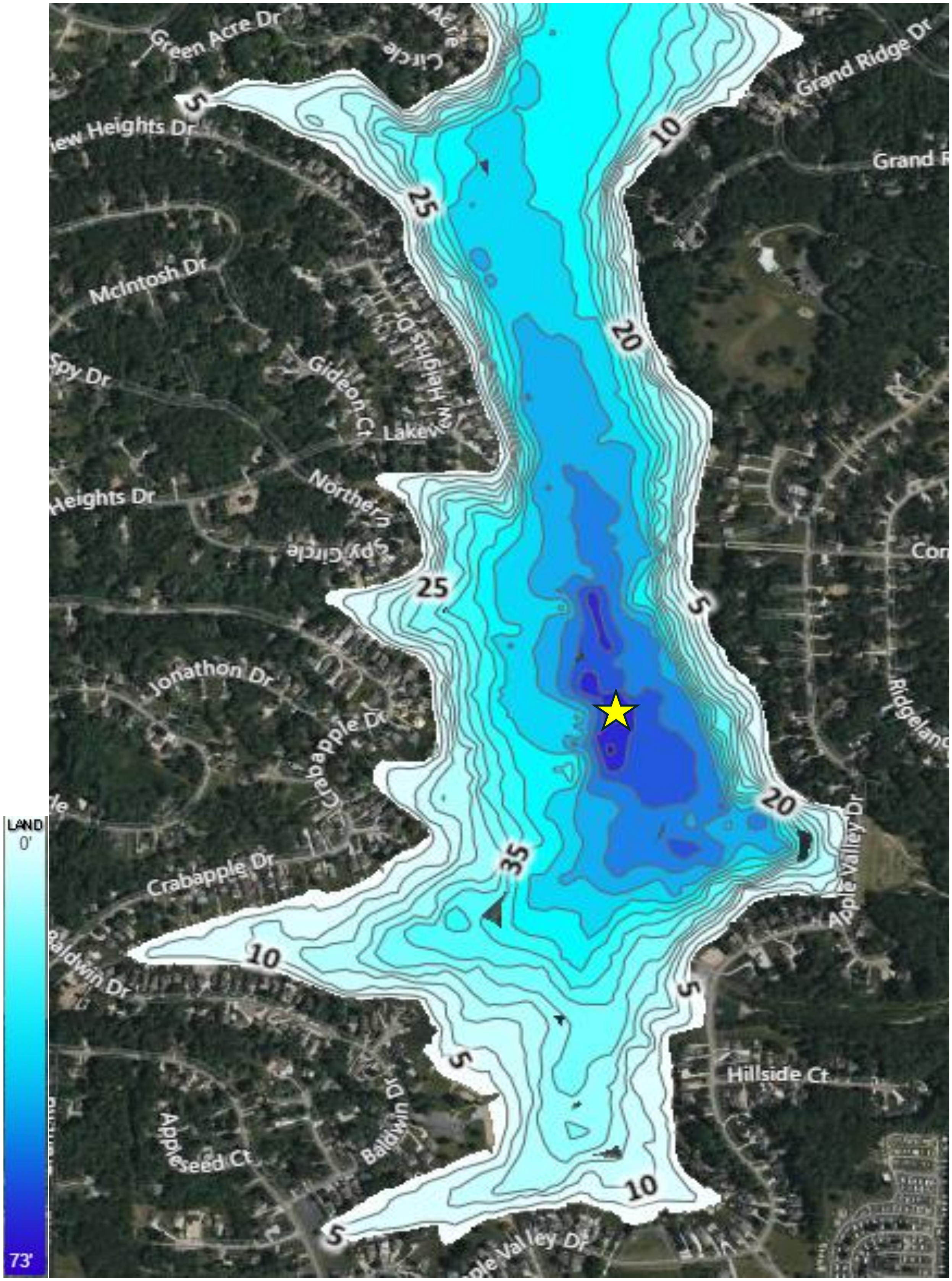


Figure 2: Bathymetric map of Apple Valley Lake (southern section). Darker blue colors indicate increasing depth contours. Yellow star denotes the determined deepest point of the reservoir. Data for map collected during this survey using Biobase® mapping program.

Watershed Characteristics

Size and scope – The Apple Valley Lake watershed is estimated to be 11,856 acres (4,798 hectares) in size. For conciseness, rounding 11,856 acres to 12,000 acres for the watershed and 511 acres to 500 acres for the surface area of the lake creates an approximate watershed-to-lake ratio of 24:1. The lake is located just west of Howard, Ohio and to the north of U.S. 36. The principal tributary to the lake is Little Jelloway Creek, which enters at the north end of the lake. Other smaller, ephemeral streams drain into the lake as well. The entire watershed is within Knox County, Ohio.

Land use and soils – Watershed land use is summarized in Figures 4 and 5 below. The watershed is mainly comprised of deciduous forest at 31.58%, pasture/hay at 27.36%, and cultivated crops at 14.13%. Some of the watershed is developed, with 12.68% Developed Open Space, 4.27% Developed Low Intensity, and less than 1% for Developed Medium Intensity and Developed High Intensity combined. The rest of the watershed is made up of smaller portions of varying land use as shown in Figure 5.

The vast majority of soils within the watershed are variations of silt loam soils as supported by Figure 6 and “Appendix A”. Silt loams tend to have a high degree of erodibility and hold nutrients like phosphorous and nitrogen, which are of consequence for the lake.

Most of the watershed contains soils not well suited for septic systems with 95.4% being rated as “Not well suited”, 0.2% being rated at “Somewhat limited”, and 4.0% being “Null or not rated” (Figures 7 and 8).

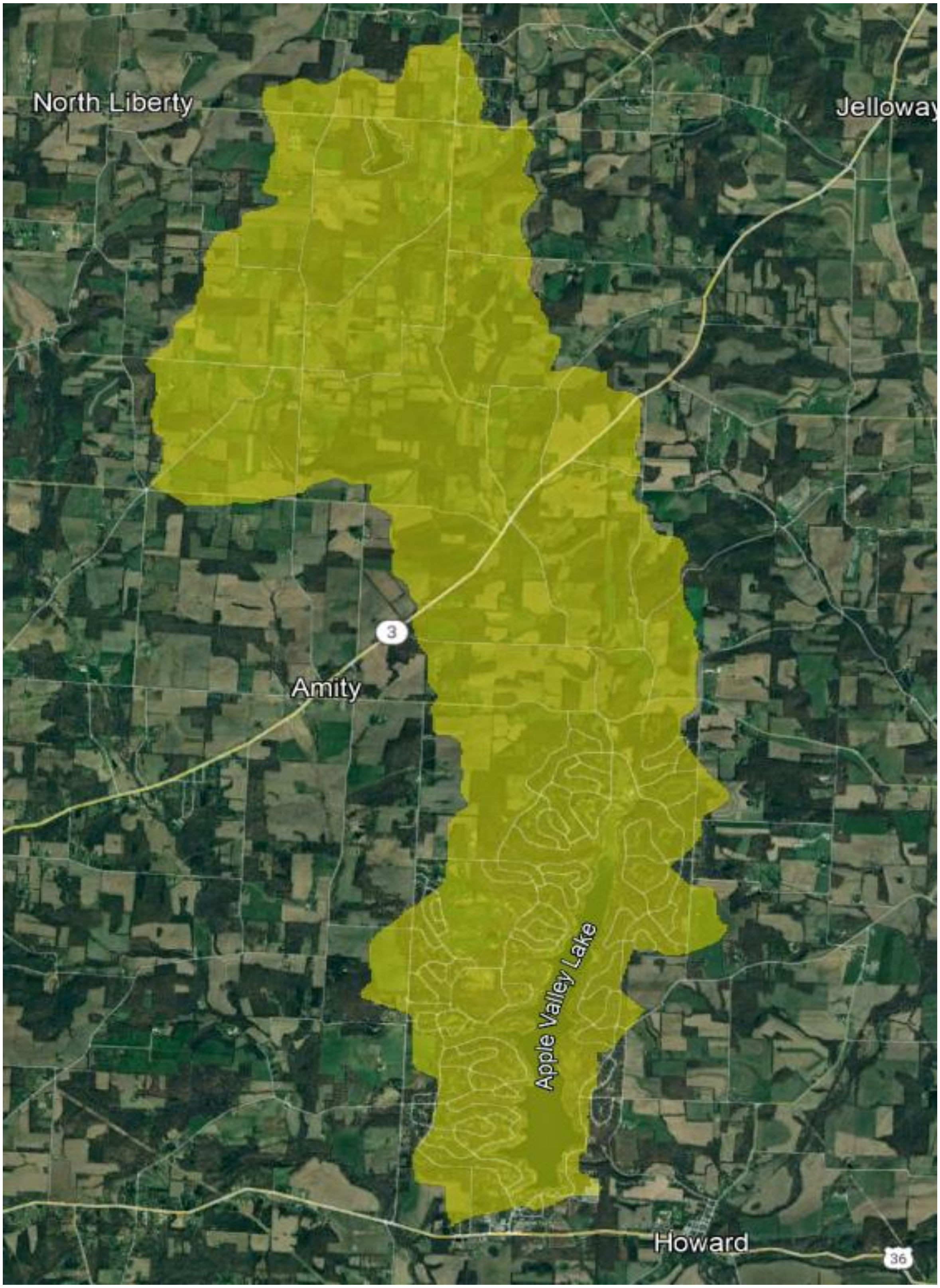


Figure 3: Apple Valley Lake watershed and local stream systems. Data retrieved with Model My Watershed (Stroud Research Center 2017).

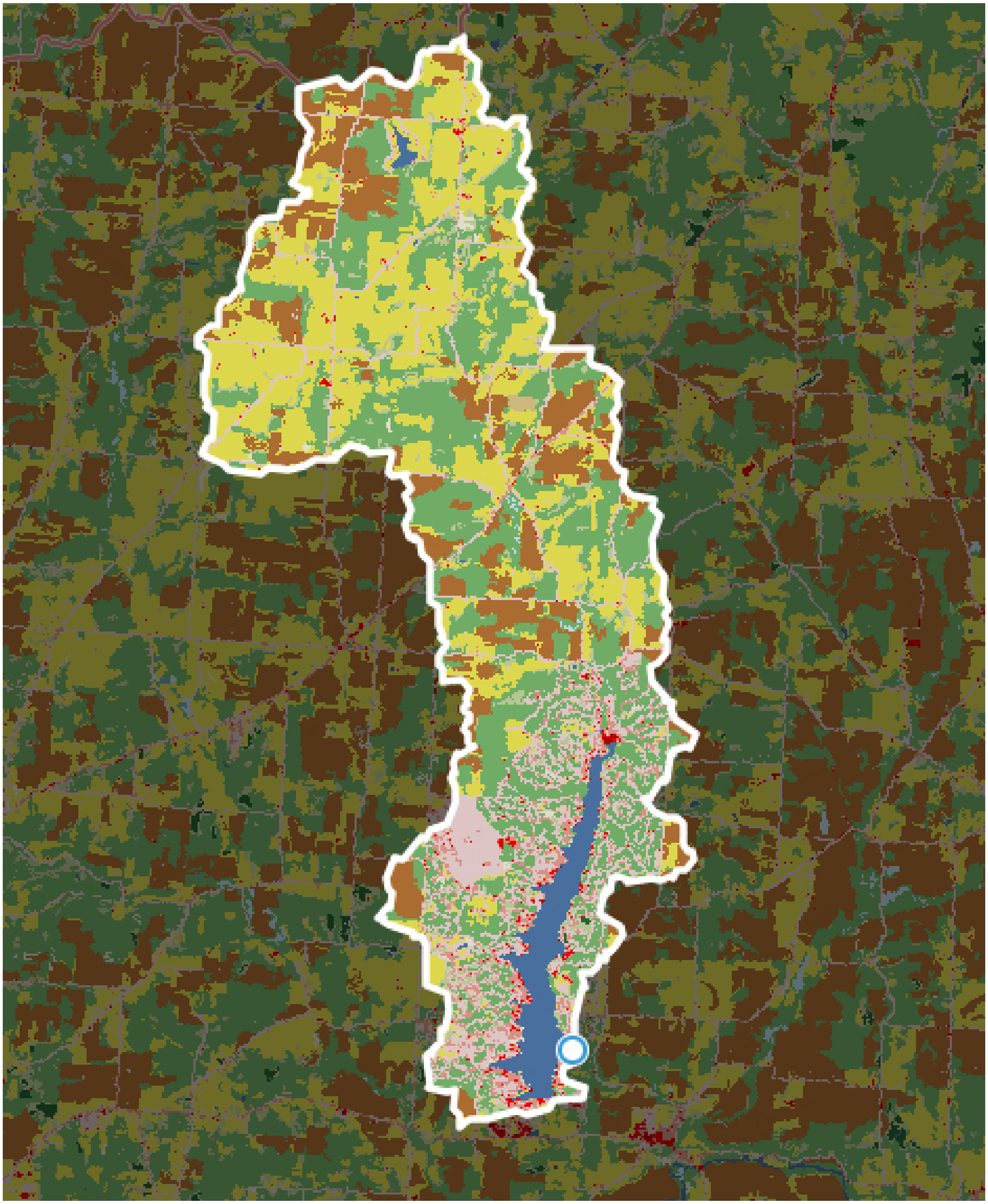


Figure 4: Apple Valley Lake watershed land use map. Coloration matches the bar graph found in Figure 5. Data retrieved with Model My Watershed (Stroud Research Center 2017).

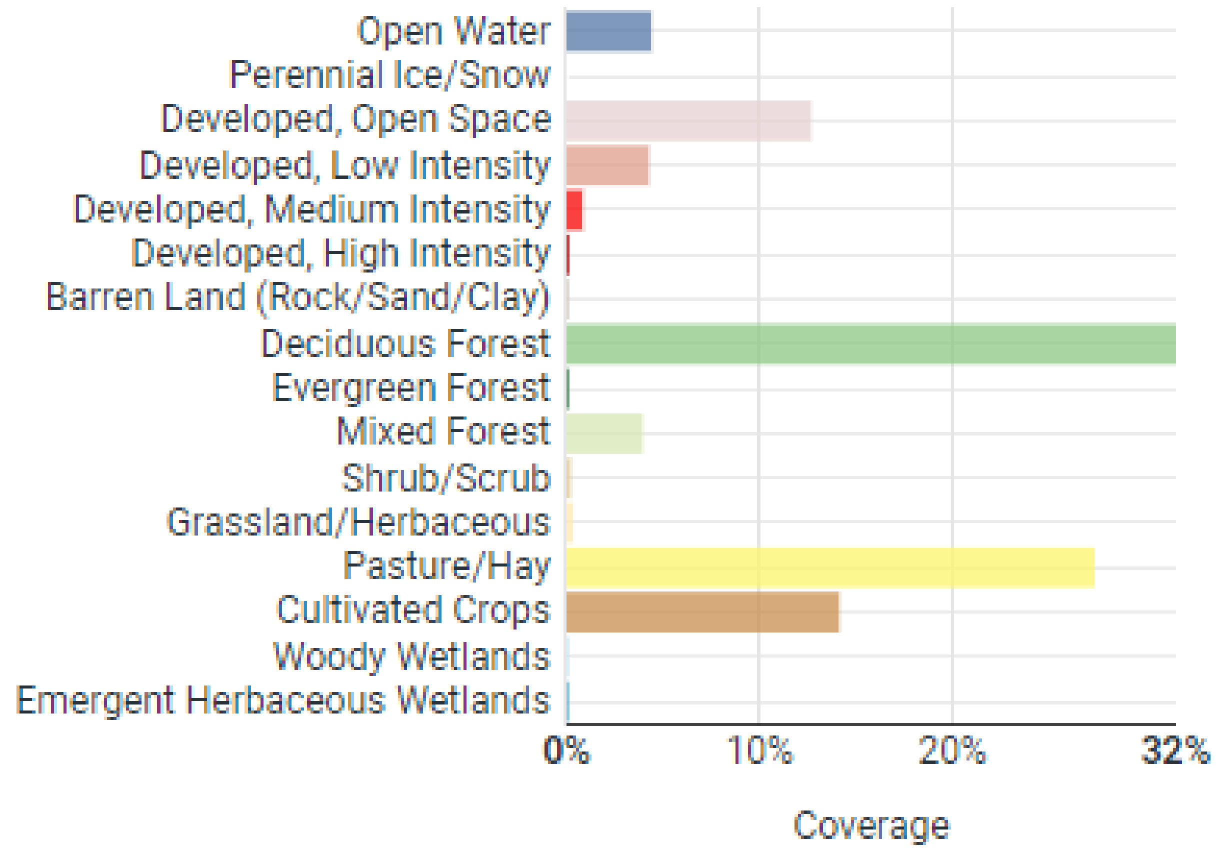


Figure 5: Land use coverage percentages in the Apple Valley Lake Watershed (Dewitz 2021).

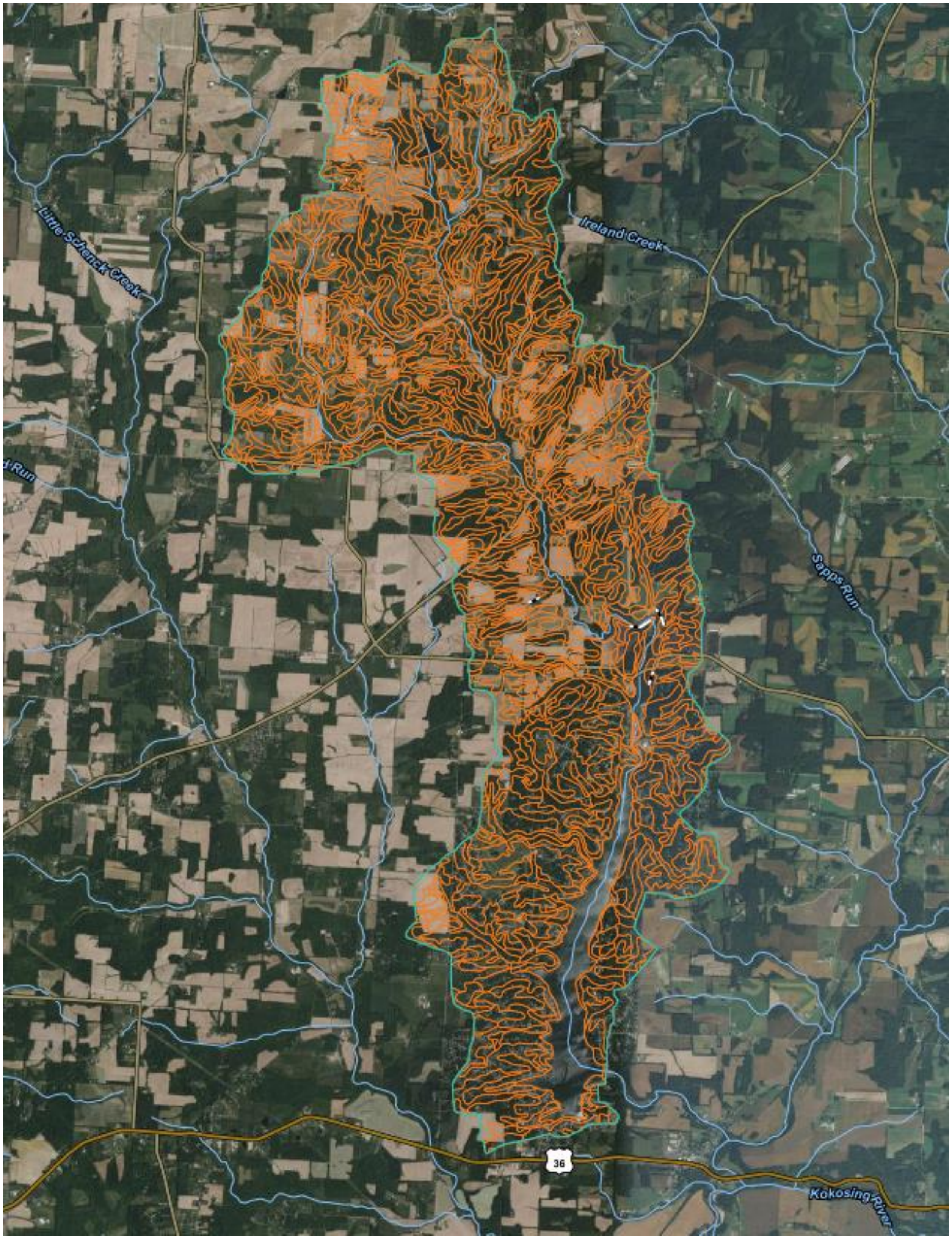


Figure 6: Apple Valley Lake watershed soils map. Data retrieved with USDA's Web Soil Survey (USDA 2024).

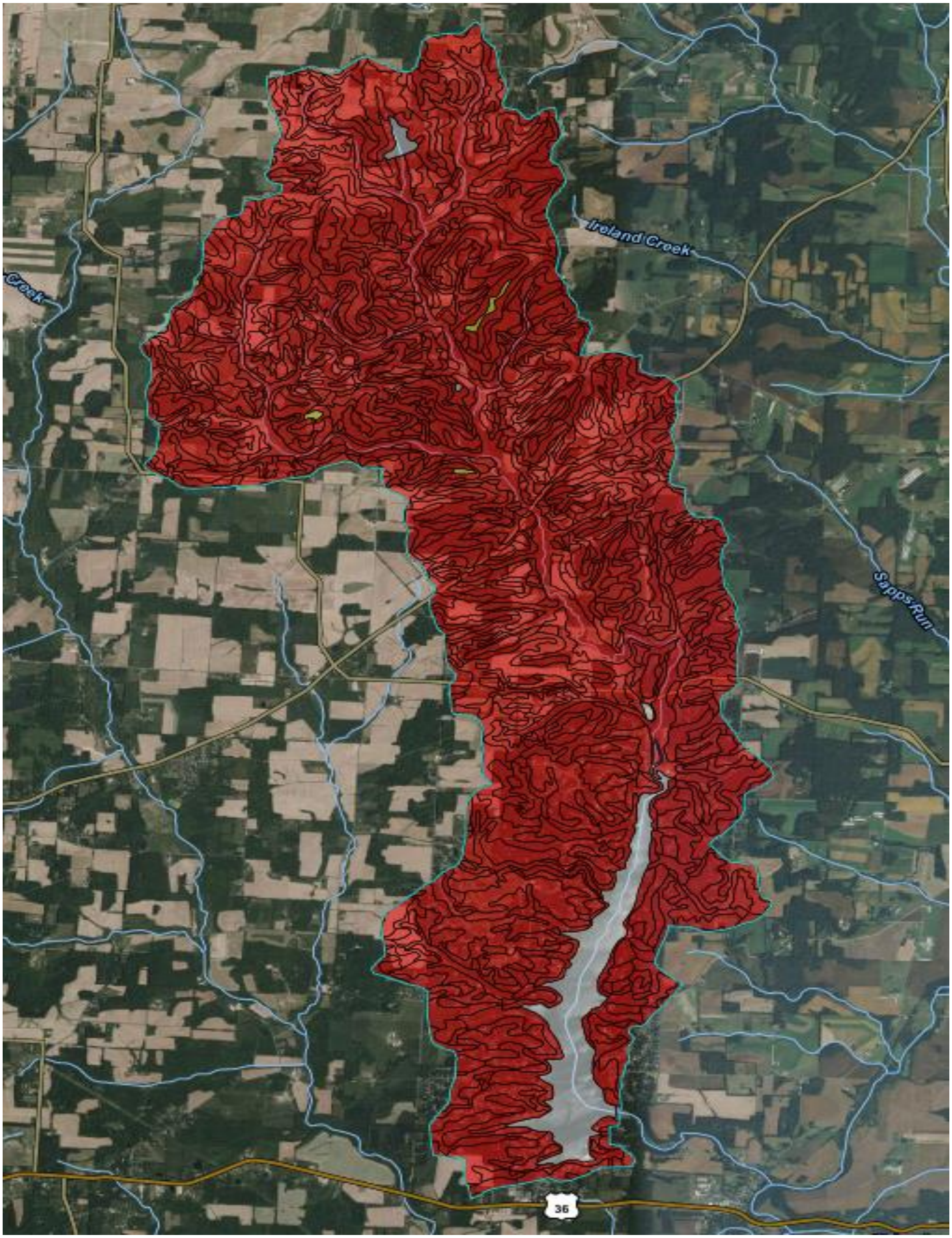


Figure 7: Apple Valley Lake watershed soils map for septic suitability. Red indicates soil that is “very limited” while green indicates soil that is “not limited”. Data retrieved with USDA’s Web Soil Survey (USDA 2024).

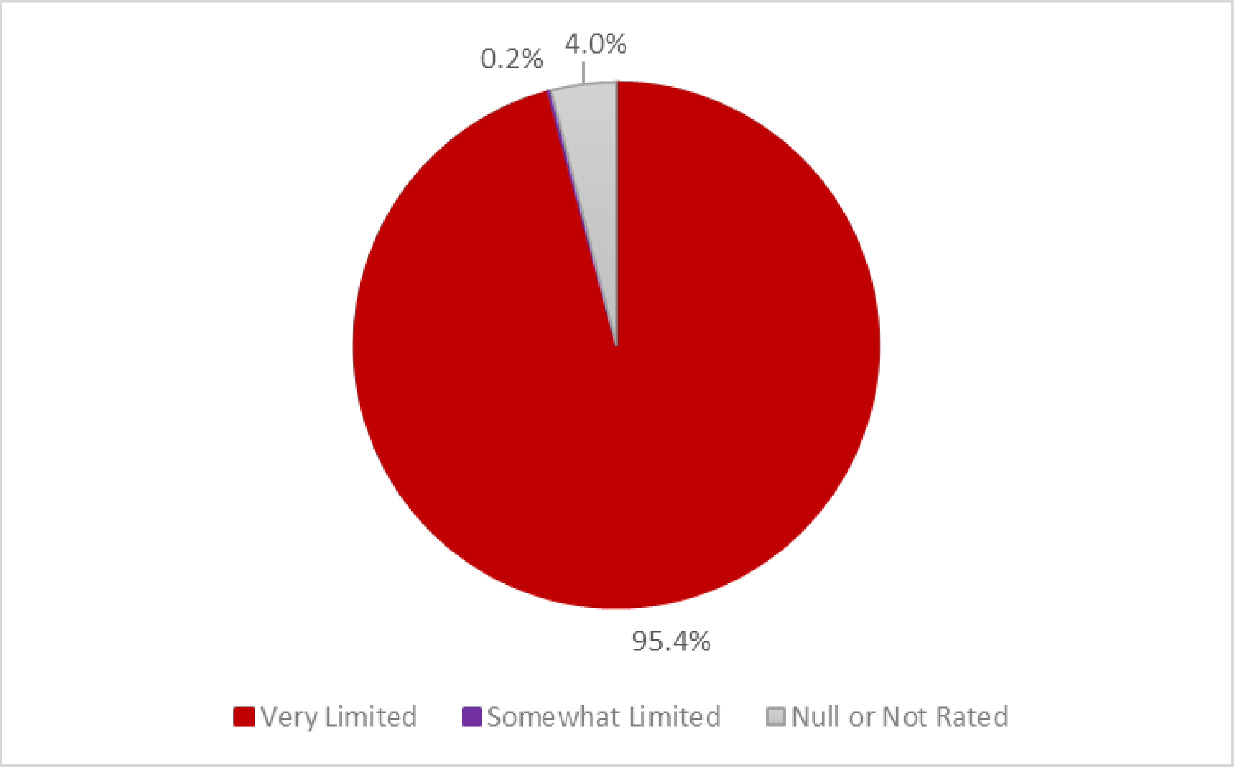


Figure 8: Soil suitability for septic systems in the Apple Valley Lake watershed (USDA 2024).

III. Physical and chemical characteristics of Apple Valley Lake

Introduction

Data collection of the physical and chemical characteristics of Apple Valley Lake have been sparsely recorded since 1986. However, there are large gaps and inconsistencies in this data. The most consistent data is Secchi transparency, with information consistently collected since 2000 at multiple locations throughout each lake-use season. This historical data is included in this report (Chapter V below), as it does provide a look at historical trends over time and offers some insight into potential reference conditions for the lake. Data collection of a variety of physical and chemical in-situ parameters was conducted in 2024 to characterize Apple Valley Lake. This information is typically collected by lake managers to identify the productivity behaviors of the water body, estimate nuisance growth potential, and assess management techniques pre- and post-enactment. Perhaps more importantly, physical and chemical characteristics collected in a consistent manner over a long period of time can become a powerful assessment tool that is used to develop water quality thresholds/goals and can define a waterbody as “impaired” or “non-impaired” for its categorical use beyond anecdotal observations.

It should be encouraged to continue to regularly collect the information presented within this report to develop reference conditions for the physical and chemical properties of the reservoir. To accurately define typical water quality conditions for Apple Valley Lake, multiple years’ worth of data collected consistently is suggested within the same spatial locations. By doing so, a stronger case can be made for impairment or non-impairment lake status should concerns regarding lake water quality develop in the future. With this in mind, it is always suggested to continuously collect relevant water quality information (like presented below) at least once per month (if not more) through the lake season (May – September in northern states). This is discussed in greater detail in Chapter VII of this report. “Appendix J” provides a glossary of terms that may be helpful to review prior to reading the full extent of this report.

Materials and Methods

Sampling Locations and Procedures

Five sampling locations were chosen to be sampled four different times throughout the 2024 season including the deepest known suggested point of the reservoir and additional zones north toward the primary inlet of the lake (Figure 9). All sampling locations except the inlet were sampled vertically within the water column for the following parameters utilizing a YSI ProQuatro Professional Plus multiparameter probe (YSI 2009): dissolved oxygen (DO), pH, temperature, conductivity, oxidation-reduction potential (ORP), estimated chlorophyll α, and estimated phycocyanin. At the deep point location, Zone 1, and Zone 2, the sonde was lowered from surface to bottom in 2-foot increments. In Zone 3, the sonde was lowered in 1-foot increments from surface to bottom due to the shallower noted depth. Primary profile information represented in this report derives from the deep point sampling while the other sampled locations acted as a form of confirmation to deep point sampling. All profile data is available within "Appendices B – D" at the end of this report. Water transparency collected at each sampling location and was calculated by use of a Secchi disk and reported as Secchi transparency (SD). Secchi transparency (SD) was collected following general procedures whereas a Secchi disk is lowered into the water column on the shade-side of the boat until it is no longer visible. The disk is then brought back up the water column until it becomes visible with the average of the two depths (when it disappears vs reappears) being the recorded Secchi transparency.

At the deep point location, total phosphorous (TP) and total Kjeldahl nitrogen (TKN) were collected at the surface and bottom. Surface samples were collected as standard grab samples (elbow depth). Bottom samples were collected at 60 ft within a confirmed hypolimnion utilizing a Kemmerer water sampler (Wildco 2010). At Zone 1, Zone 2, Zone 3, and the inlet, TP was collected at the surface via grab sample. No bottom samples were collected at these locations. Collected water samples were analyzed by BioSolutions at their laboratory testing facility in Chagrin Falls, OH and collected utilizing 250 mL high density polyethylene bottles. Nutrient bottles contained an acidic preservative for persulfate digestion. Water samples were stored in a cooler and delivered directly to BioSolutions. Laboratory methodology included standard methods 4500P-B5,E for TP samples and Hach 10242 for TKN samples.

Data Analysis

Data analysis was conducted within Microsoft Excel (Microsoft Corp 2024). YSI collected information was used to create parameter depth profiles by graphing observed values to water depth to analyze data trends within the water column. R statistical program was utilized for statistical analyses if necessary (R Core Team 2024).

Trophic state of Apple Valley Lake – Carlson's Trophic State Index (TSI; Carlson 1977) is a commonly used predictor of how productive a water body is (its trophic state). It utilizes chlorophyll α concentrations, surface TP, and Secchi transparency to provide index numbers that can be used on a scale to define the water bodies trophic state. The equations used to generate index numbers based off these parameters are described below (top equation is SD, middle equation is chlorophyll α, and the bottom equation is TP; Carlson 1977 for SD and Cooke et al. 2005 for chlorophyll α and TP derivatives):

$$TSI_{SD} = 10\,(6 - \log_2 SD)$$

$$TSI_{\ Chl\ \alpha} = 10\ \left(6 - \frac{\log_2 7.7}{chl\ \alpha}\right)^{0.68}$$

$$TSI_{\ TP} = 10\ \left(6 - \log_2 \frac{48}{TP}\right)$$

TSI values range from 0 to 100 where TSI < 40 may indicate oligotrophy (low productivity), 40 – 50 may indicate mesotrophy (middling productivity), and >50 eutrophy (high productivity) (Cooke et al 2005).

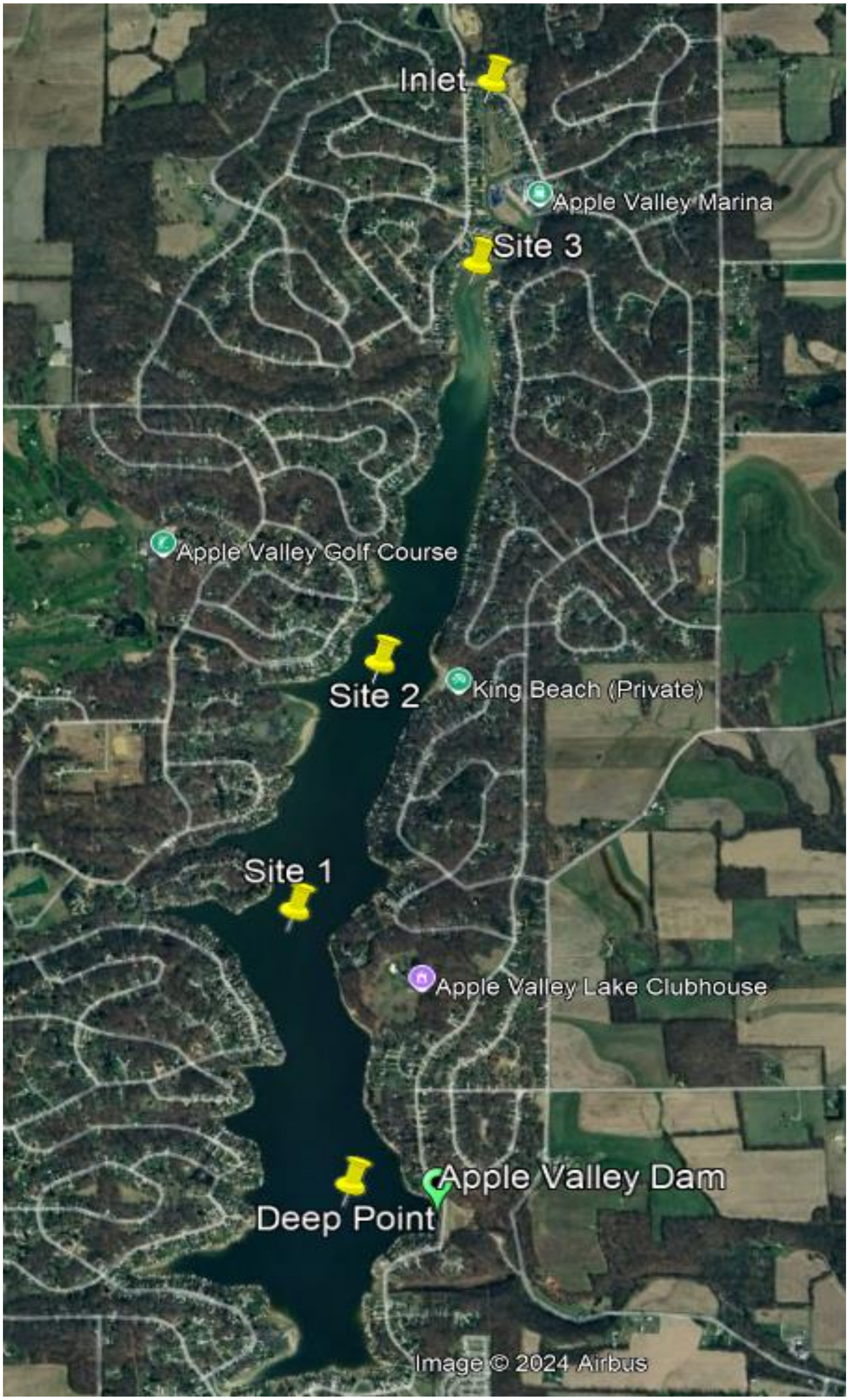


Figure 9: Apple Valley Lake sampling locations for the purpose of this study including A) The suggested deep point, B) Site 1, C) Site 2, D) Site 3, and E) The inlet.

Results

Deep Point Depth profiles

Temperature – Apple Valley Lake showcased a strong thermocline being present from the onset of sampling in June through October. The depth at which the thermocline was observed did increase over time as did its strength. In June, the thermocline developed between 12 and 20 ft and by October, the thermocline had moved between 26 and 32 ft (Figure 10).

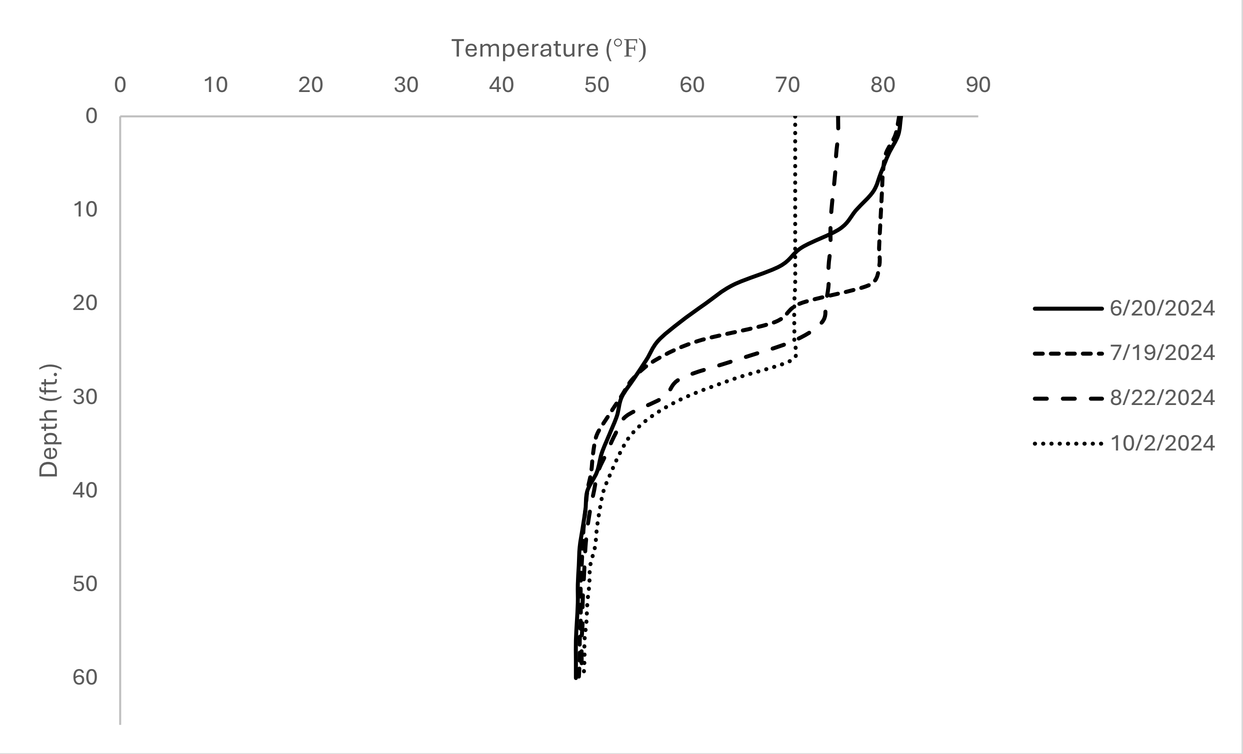


Figure 10: Temperature depth profiles at the deep point of Apple Valley Lake from 6/20/2024 to 10/2/2024.

Dissolved Oxygen (DO) – Sampled DO levels indicate the presence of an anoxic hypolimnion throughout the summer months and into the early fall. In June there was no oxygen below 16 feet, in July there was no oxygen below 20 feet, in August there was no oxygen below 26 feet, and in October there was no oxygen below 28 feet (Figure 11).

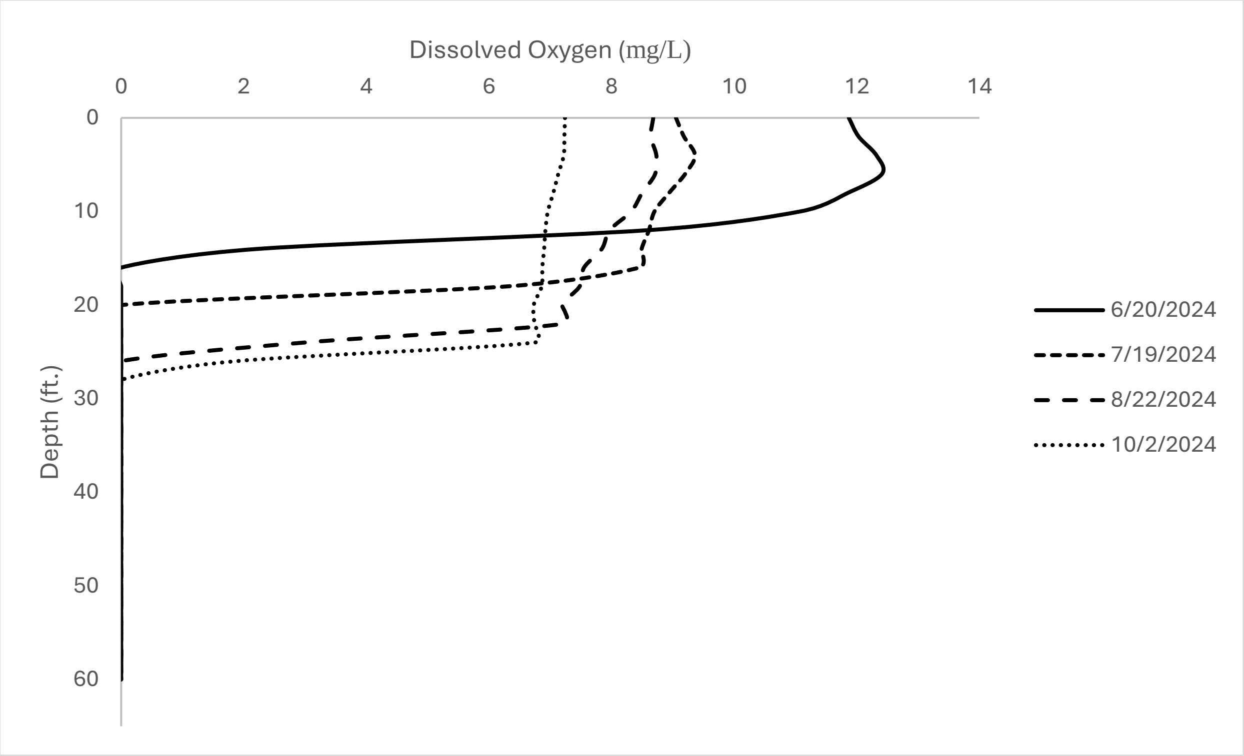


Figure 11: DO depth profiles at the deep point of Apple Valley Lake from 6/20/2024 to 10/2/2024.

pH – The pH of Apple Valley Lake showcased a consistent pattern matching stratification throughout the season with a maximum recorded value of 9.31, which was observed 6/20/24 near the surface. The lowest observed value was 6.89 on 10/2/24 near the bottom of the lake (Figure 12).

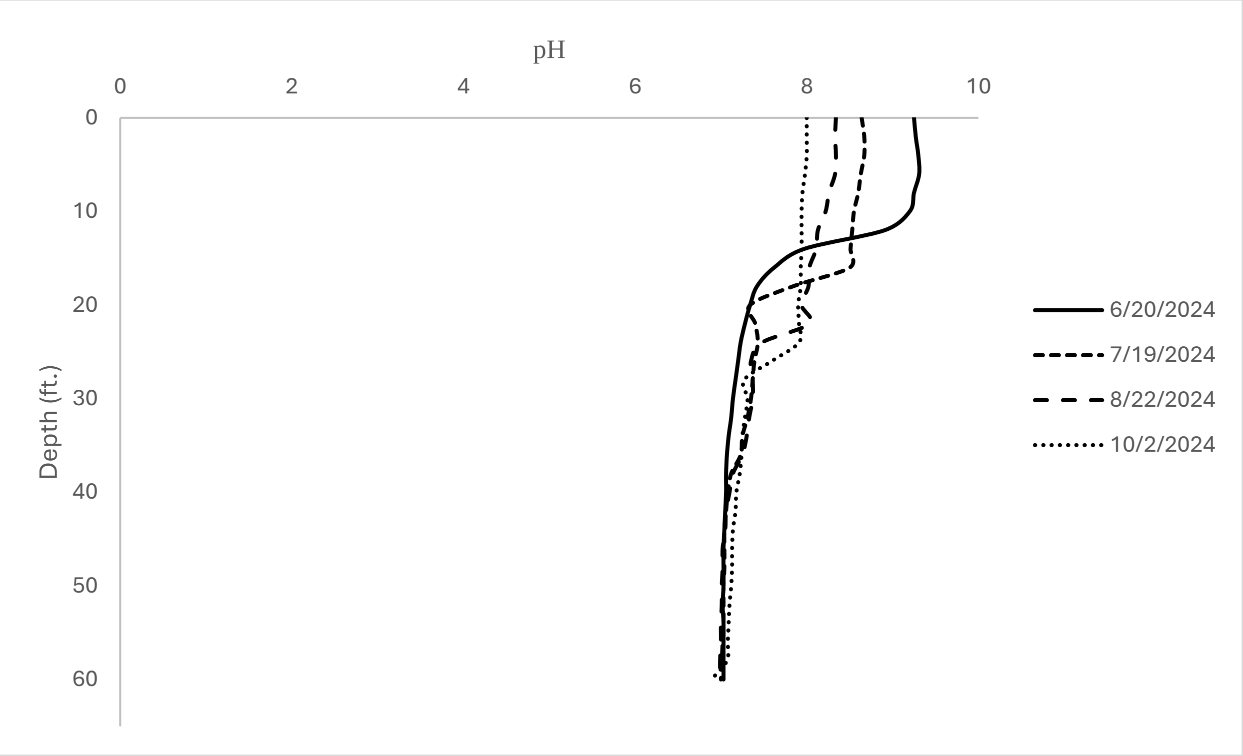


Figure 12: pH depth profiles of Apple Valley Lake at the deep point from 6/20/2024 to 10/2/2024.

Specific conductivity – Specific conductivity collected during the 2024 season showcased patterns suggesting impact by thermal stratification. The maximum recorded value was 307.4 µs/cm on 10/2/2024 at the bottom of the lake and the lowest recorded value was 196.1 µs/cm on 6/20/2024 also near the bottom of the lake (Figure 13).

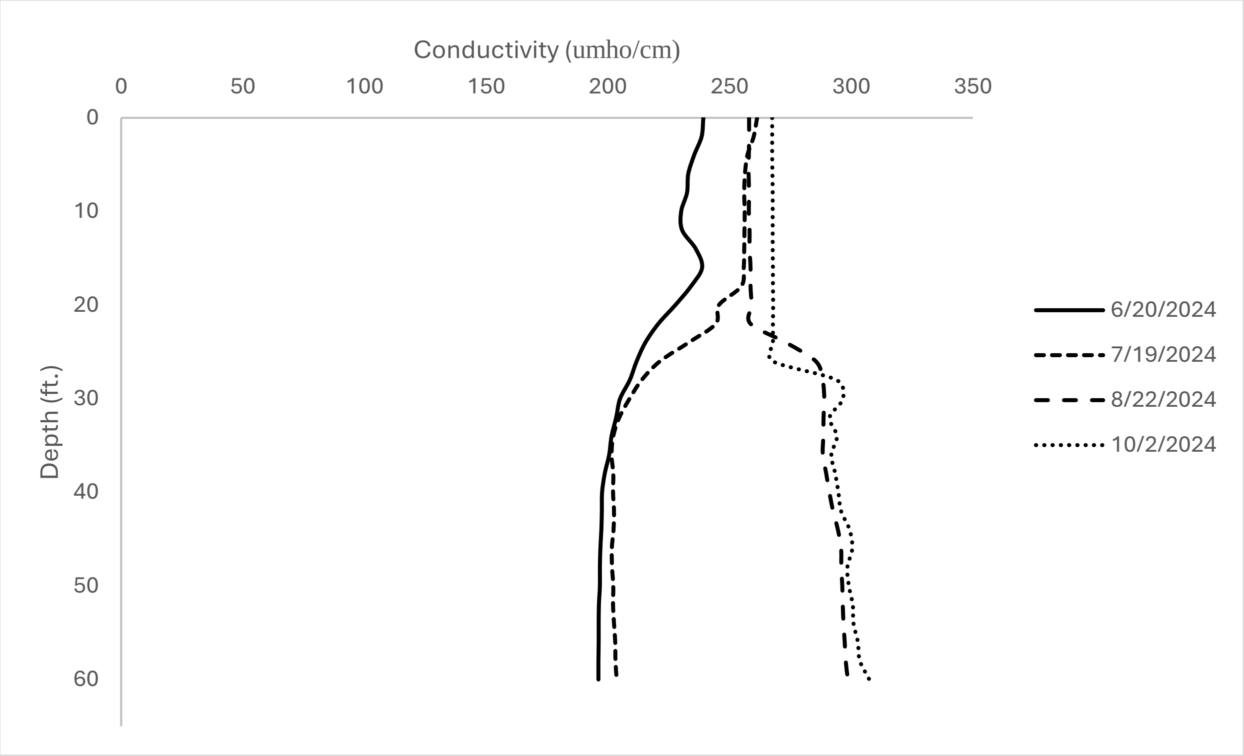


Figure 13: Specific conductance depth profiles of Apple Valley Lake at the deep point from 6/20/2024 to 10/2/2024.

Oxidation-reduction potential – ORP values varied throughout the water column and over time. The highest value recorded was 150.5 at the deep point on 10/2/2024 in 26 ft of water right before the anoxic zone. The lowest value recorded was -264.9 at the deep point on 10/2/2024 in 46 ft of water. The general trend seen is positive values where dissolved oxygen is present and negative values once dissolved oxygen levels become anoxic, which is expected. The exception to this is at the deep point on 6/20/2024, ORP values remained positive into the anoxic zone (Figure 14).

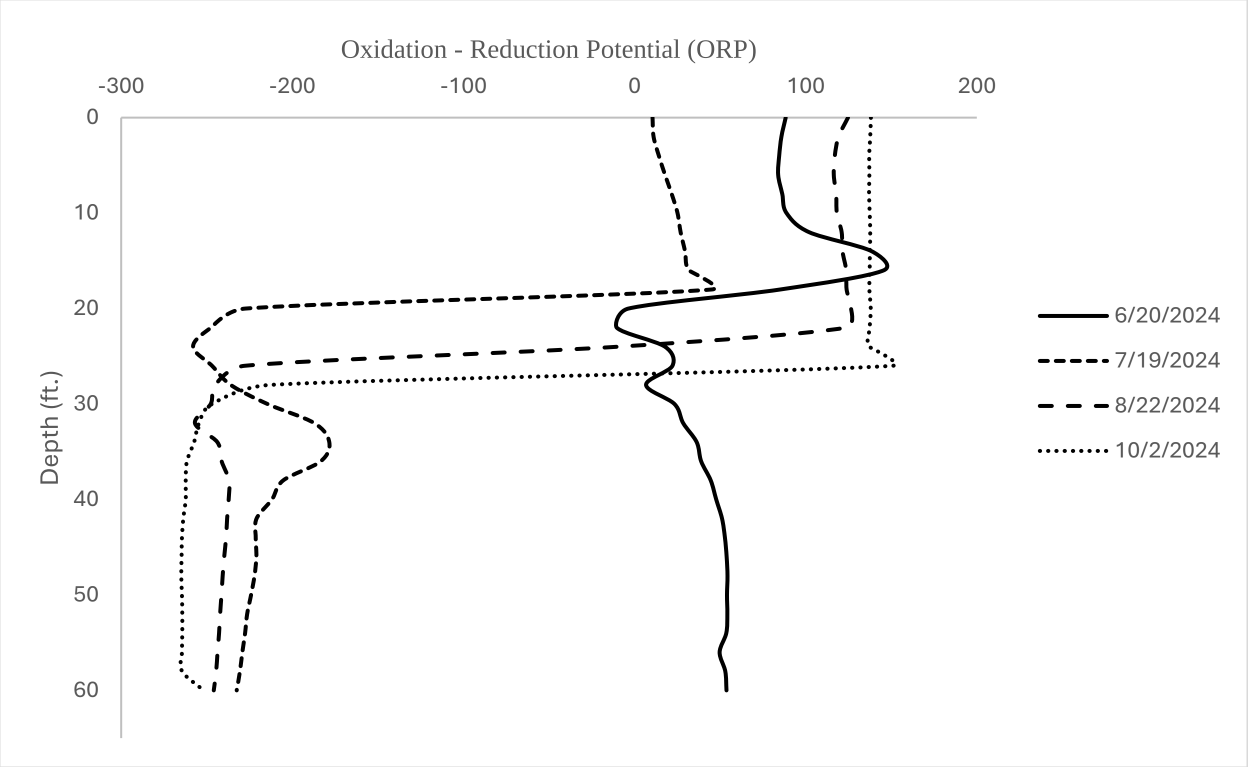


Figure 14: ORP depth profiles of Apple Valley Lake at the deep point from 6/20/2024 to 10/2/2024.

Chlorophyll α – Chlorophyll levels were substantially elevated for the 6/20/2024 sampling date. There was a large jump in concentrations from 8 to 12 feet, with readings between 14.47 µg/L and 19.52 µg/L. Our other sampling dates showcased a maximum concentration of 3.7 µg/L in the first 20 feet of water. Overall, chlorophyll α levels trended slightly higher above the thermocline than below (Figure 15).

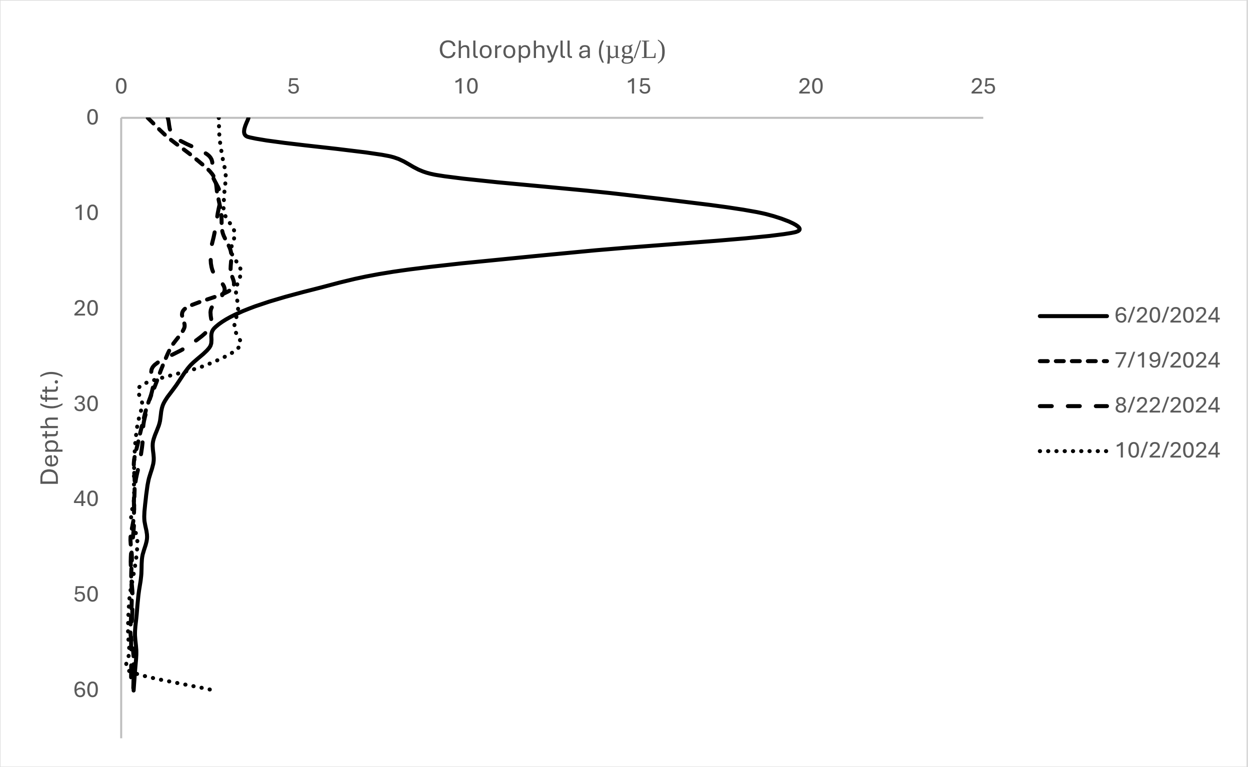


Figure 15: Depth profile of chlorophyll α concentrations collected from 6/20/2024 to 10/2/2024 on Apple Valley Lake.

Phycocyanin – Phycocyanin levels followed patterns exhibited by the chlorophyll α data above with much lower overall concentrations. A slight bump in concentration was noted on 6/20/20204 but was hardly elevated enough to be considered a bloom. The highest recorded value was on 6/20/2024 of 1.06 µg/L at 14 ft and the lowest recorded value was 0.11 µg/L on 10/2/2024 at 30 ft (Figure 16).

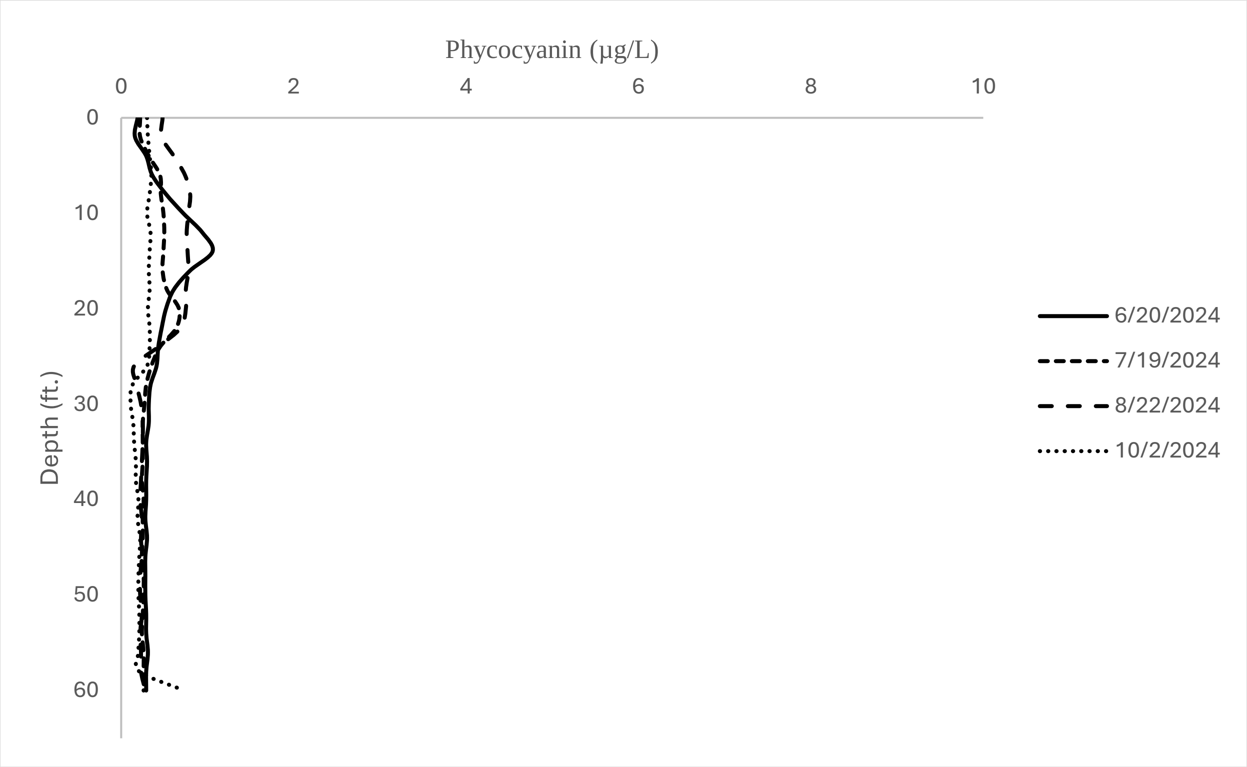


Figure 16: Depth profile of phycocyanin concentrations collected from 6/20/2024 to 10/2/2024 on Apple Valley Lake.

Nutrient data

Total phosphorous – Collected TP values ranged from 0.01 mg/L (10 µg/L) to 0.14 mg/L (140 µg/L). The highest value was recorded on 7/19/2024 at Site 3, a sampling date which saw the grab samples from Sites 1 and 2 return values below detectable levels (BDL). Generally, benthic TP at the deep point increased in concentration throughout the lake use-season (Tables 2 - 5).

Total Kjeldahl nitrogen – Recorded TKN values ranged from <1 mg/L to 3 mg/L in the basin. The highest value recorded was from the bottom sample taken on 8/22/2024 and the lowest values recorded from the surface samples taken 7/19/2024 and 8/22/2024 (Tables 2 - 5).

Table 2: Nutrient information collected from Apple Valley Lake on 6/20/2024.

Location ID	***Depth***	***Test***	***Lab Method***	***Date***	***Unit***	***Value***
Deep Surface 1	Grab	TP	SM 4500P-B5,E	6/20/2024	mg/L	0.01
Deep Surface 2	Grab	TKN	Hach 10242	6/20/2024	mg/L	1
Deep Bottom 3	60 ft.	TP	SM 4500P-B5,E	6/20/2024	mg/L	0.04
Deep Bottom 4	60 ft.	TKN	Hach 10242	6/20/2024	mg/L	2
Site 1	Grab	TP	SM 4500P-B5,E	6/20/2024	mg/L	0.04
Site 2	Grab	TP	SM 4500P-B5,E	6/20/2024	mg/L	0.02
Site 3	Grab	TP	SM 4500P-B5,E	6/20/2024	mg/L	0.04
Inlet	Grab	TP	SM 4500P-B5,E	6/20/2024	mg/L	0.05

Table 3: Nutrient information collected from Apple Valley Lake on 7/19/2024.

Location ID	***Depth***	***Test***	***Lab Method***	***Date***	***Unit***	***Value***
Deep Surface 1	Grab	TP	SM 4500P-B5,E	7/19/2024	mg/L	0.03
Deep Surface 2	Grab	TKN	Hach 10242	7/19/2024	mg/L	<1
Deep Bottom 3	60 ft.	TP	SM 4500P-B5,E	7/19/2024	mg/L	0.07
Deep Bottom 4	60 ft.	TKN	Hach 10242	7/19/2024	mg/L	2
Site 1	Grab	TP	SM 4500P-B5,E	7/19/2024	mg/L	BDL
Site 2	Grab	TP	SM 4500P-B5,E	7/19/2024	mg/L	BDL
Site 3	Grab	TP	SM 4500P-B5,E	7/19/2024	mg/L	0.14
Inlet	Grab	TP	SM 4500P-B5,E	7/19/2024	mg/L	0.02

Table 4: Nutrient information collected from Apple Valley Lake on 8/22/2024.

Location ID	***Depth***	***Test***	***Lab Method***	***Date***	***Unit***	***Value***
Deep Surface 1	Grab	TP	SM 4500P-B5,E	8/22/2024	mg/L	0.03
Deep Surface 2	Grab	TKN	Hach 10242	8/22/2024	mg/L	<1
Deep Bottom 3	60 ft.	TP	SM 4500P-B5,E	8/22/2024	mg/L	0.10
Deep Bottom 4	60 ft.	TKN	Hach 10242	8/22/2024	mg/L	3
Site 1	Grab	TP	SM 4500P-B5,E	8/22/2024	mg/L	0.03
Site 2	Grab	TP	SM 4500P-B5,E	8/22/2024	mg/L	0.05
Site 3	Grab	TP	SM 4500P-B5,E	8/22/2024	mg/L	0.03
Inlet	Grab	TP	SM 4500P-B5,E	8/22/2024	mg/L	0.05

*BDL = below detectable levels

Table 5: Nutrient information collected from Apple Valley Lake on 10/2/2024.

Location ID	***Depth***	***Test***	***Lab Method***	***Date***	***Unit***	***Value***
Deep Surface 1	Grab	TP	SM 4500P-B5,E	10/2/2024	mg/L	0.02
Deep Surface 2	Grab	TKN	Hach 10242	10/2/2024	mg/L	<1
Deep Bottom 3	60 ft.	TP	SM 4500P-B5,E	10/2/2024	mg/L	0.13
Deep Bottom 4	60 ft.	TKN	Hach 10242	10/2/2024	mg/L	3
Site 1	Grab	TP	SM 4500P-B5,E	10/2/2024	mg/L	0.01
Site 2	Grab	TP	SM 4500P-B5,E	10/2/2024	mg/L	BDL
Site 3	Grab	TP	SM 4500P-B5,E	10/2/2024	mg/L	0.01
Inlet	Grab	TP	SM 4500P-B5,E	10/2/2024	mg/L	0.02

*BDL = below detectable levels

Secchi transparency (SD) – Collected Secchi transparency values generally increased as the lake use-season progressed until our final sampling date on 10/2/2024 (Table 6). The lowest observed value was 2.0 ft at Site 3 on 7/19/2024 and 8/22/2024. Highest value was 5.5 ft on 10/2/2024 at the deep point sampling location. Mean Secchi transparency of all sampling events was 3.68 ft.

Table 6: Secchi transparency observed on Apple Valley Lake during the study.

Location ID	***Test***	***Date***	***Unit***	***Value***
Deep Point	Secchi transparency	6/20/2024	ft	3.25
Site 1	Secchi transparency	6/20/2024	ft	3.25
Site 2	Secchi transparency	6/20/2024	ft	3.25
Site 3	Secchi transparency	6/20/2024	ft	3.0
Deep Point	Secchi transparency	7/19/2024	ft	4.5
Site 1	Secchi transparency	7/19/2024	ft	3.75
Site 2	Secchi transparency	7/19/2024	ft	3.5
Site 3	Secchi transparency	7/19/2024	ft	2.0
Deep Point	Secchi transparency	8/22/2024	ft	3.75
Site 1	Secchi transparency	8/22/2024	ft	3.75
Site 2	Secchi transparency	8/22/2024	ft	3.5
Site 3	Secchi transparency	8/22/2024	ft	2.0
Deep Point	Secchi transparency	10/2/2024	ft	5.5
Site 1	Secchi transparency	10/2/2024	ft	5.1
Site 2	Secchi transparency	10/2/2024	ft	5.0
Site 3	Secchi transparency	10/2/2024	ft	3.75

Carlson's TSI (Trophic State) – The trophic state of Apple Valley Lake based off spatial surface in-situ chlorophyll α ($\text{TSI}_{\text{chl a)}}$, surface TP ($\text{TSI}_{\text{TP}}$), and SD ($\text{TSI}_{\text{SD}}$) collected throughout 2024 and converted to Carlson's TSI (Carlson 1977) represent the lake as primarily mesotrophic with some variable eutrophic and oligotrophic values based on the parameter (Figures 17, 18, and 19). $\text{TSI}_{\text{chl a}}$ data showcased mesotrophic values during the June and October sampling periods and was firmly oligotrophic during July and August (Figure 17). The maximum $\text{TSI}_{\text{chl a}}$ value collected during this study was 44.2 on 6/20/2024 while the minimum was 0 on 7/19/2024 and 8/22/2024 (neglectable chlorophyll concentrations). Mean $\text{TSI}_{\text{chl a}}$ value for 2024 was 27.0 (with "0"'s included). TSI_{TP} data showcased a range of mesotrophic and eutrophic values through all sampling dates (Figure 18). The maximum TSI_{TP} value collected during this study was 75.4 on 7/19/2024 while the minimum was 37.4 during the 6/20/2024 and 10/2/2024 sampling dates. Mean TSI_{TP} value for 2024 was 52.1. TSI_{SD} data showcased primarily mesotrophic values through all sampling dates (Figure 19). The maximum TSI_{SD} value collected during this study was 50.0 on 7/19/2024 and 8/22/2024 while the minimum was 36.8 during the 10/2/2024. Mean TSI_{SD} value for 2024 was 41.7.

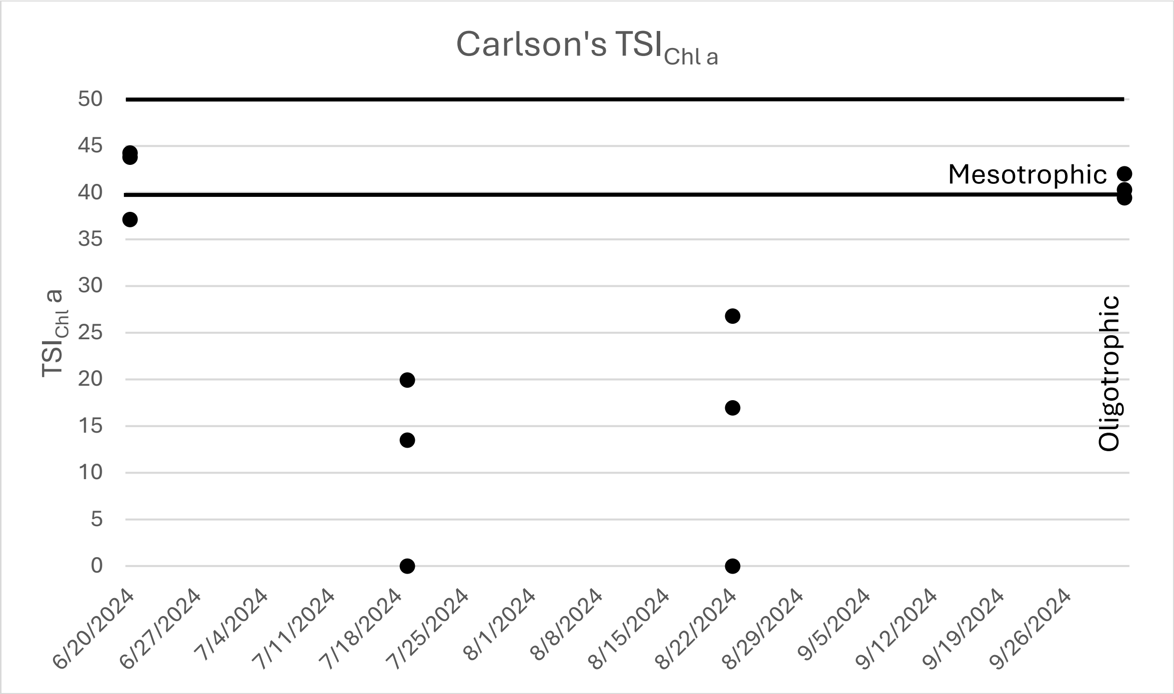


Figure 17: Carlson's TSI$_{Chl\ \alpha}$ values (n = 12) for Apple Valley Lake from in-situ surface chlorophyll α data collected through the 2024 lake season. Different estimated trophic designations are identified on the right of the graph.

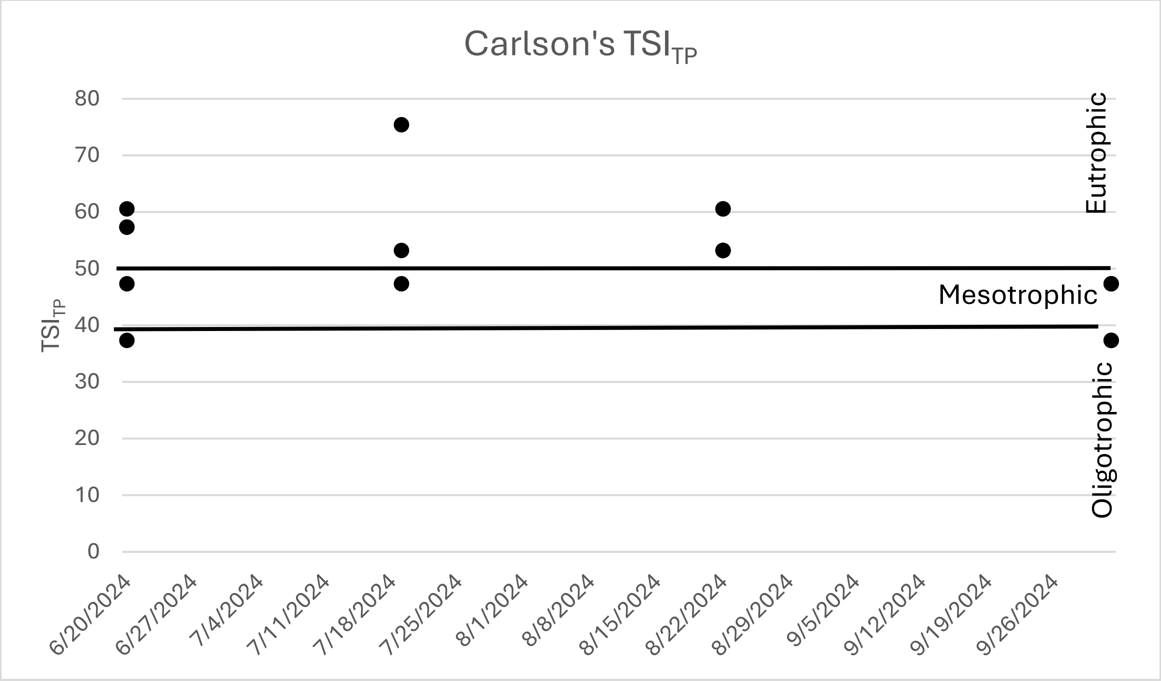


Figure 18: Carlson's TSI$_{TP}$ values (n = 17) for Apple Valley Lake from surface TP data collected through the 2024 lake season. Different estimated trophic designations are identified on the right of the graph. Samples denoted as BDL were omitted.

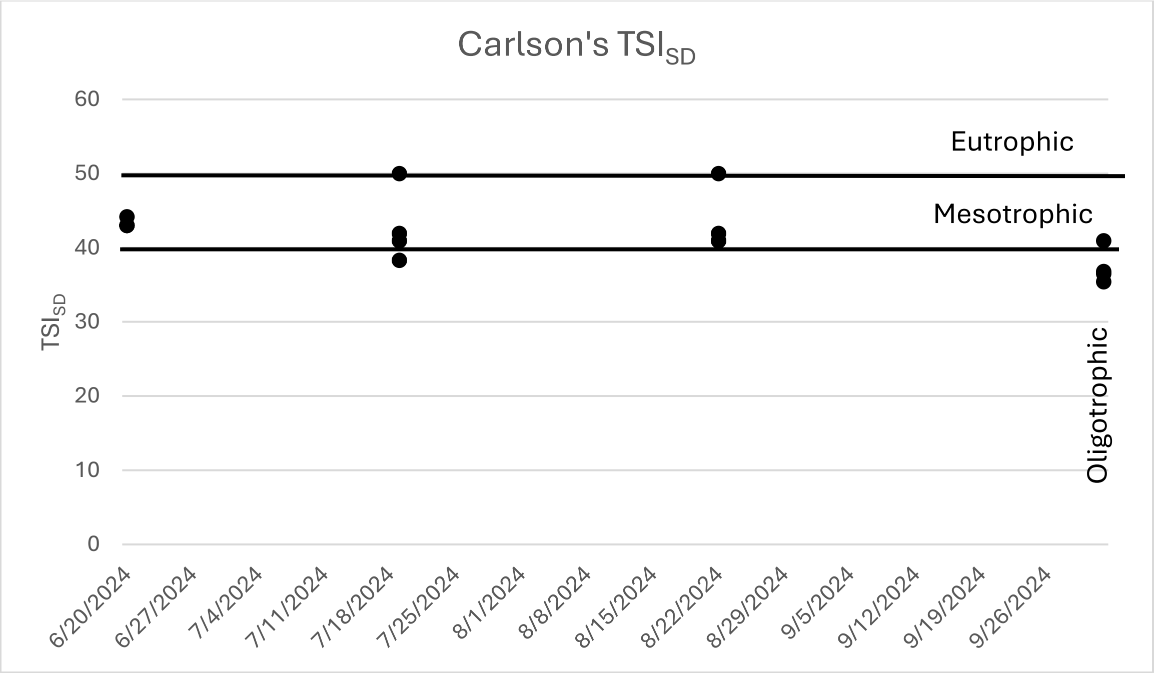


Figure 19: Carlson's TSI_{SD} values (n = 16) for Apple Valley Lake from Secchi transparency data collected through the 2024 lake season. Different estimated trophic designations are identified on the right of the graph.

Discussion

Apple Valley Lake characterization (depth profiles)

Physical and chemical YSI in-situ data profiles collected during the 2024 lake-use season denote Apple Valley Lake as a stratified, potentially dimictic reservoir with a strongly anoxic hypolimnion. Thermal characteristics of the lake showcased stratification with a defined epilimnion (upper, less dense layer of water), hypolimnion (more dense, bottom layer), and metalimnion (transitional area; 6/20/2024) with a thermocline that progressed deeper as the season progressed (Figure 10). Thermocline strength grew through the season with a notedly shrinking metalimnion (noted by an increasingly sharper temperature change at the thermocline's depth). Epilimnion depth steadily increased with each sampling event to a maximum of 26 ft on our final sampling date of 10/2/2024 (compared to approximately 12 – 14 ft during June). This increase corresponded with a reclamation of dissolved oxygen (DO) and positive ORP values (described more below). This is counterintuitive to many strongly stratified eutrophic waterbodies that may typically experience an increase in hypolimnetic anoxic water depth when organic detritus sinks from the surface and increases respiration rate. As chlorophyll α concentrations decreased substantially post-June (early season algae bloom regression), one could hypothesize that algae biomass may be one contributor to thermocline deepening and DO expansion as the amount of detritus (e.g. dead algal cells and byproducts) would be reduced once the bloom subsided and less organic material would be falling from epilimnetic waters. The reduction in respiration would slow anoxic build-up while warming waters from the surface pushed the epilimnion deeper into the water column. Regardless, further examination of thermal characteristics into the fall, winter, and spring may be suggested to confirm Apple Valley Lakes mixing qualities. As the June sampling period denoted a much weaker thermocline than in subsequent sampling dates, there is a small amount of supporting evidence to suggest the lake does mix during the fall and spring. However, a temperature profile produced in late November and post-drawdown would confirm this.

Dissolved oxygen (DO) patterns closely followed those presented by temperature profile data (Figure 11). All DO profile data showcased typical stratified lake characteristics whereas epilimnetic waters contained net-positive quantities of DO while hypolimnetic waters were anoxic ("0" oxygen). The highest noted concentration of DO did coincide with a notable bump in chlorophyll α (Figures 11 and 15) suggesting elevated photosynthetic activity from algal biomass may explain the overall increase in DO during that sampling event (6/20/2024). This same sampling event also showcased the shallowest depth of oxic conditions within the water column likely due to decomposing algal biomass below the epilimnion/ thermocline. Sampling events beyond June demonstrated a recovery of DO deeper into the water column (14 ft in June to 26 ft in October) with lower surface DO concentrations (11.87 mg/L in June to 7.24

mg/L in October). This coincides with chlorophyll α reduction post-June and may be connected to a reduction in photosynthetic activity once the algae bloom subsided. Future DO profile data collection should be collected at the deepest known point of the lake to ensure benthic anoxia can be identified if present particularly if redox reactions are of concern. Anoxic conditions in lakes and reservoirs are important to consider as phosphorus (P) can be released from the sediment layer of the lake itself as iron as the ion Fe^{3+} is reduced to the ion Fe^{2+}. When iron is in the Fe^{3+} form, it will readily bind to phosphorus and make it biologically unavailable for utilization by algae and submersed plants. However, when in the Fe^{2+} form, there is a greater chemical affinity for sulfur (S) in the form of the ion S^{2-} and will release P it may have been previously bound to. Since iron is no longer binding to P, it can become released into the hypolimnion where it may build up until a mixing event. This process appears to be occurring in Apple Valley Lake as evident by the build-up of TP noted during deep water nutrient sampling (Tables 2 - 5).

In addition to the redox concerns noted above, loss of DO concentrations can also coincide with a loss of gilled organism habitat availability and, in extreme cases, result in the death of gilled organisms. All sampling dates did note epilimnetic DO concentrations well above 3.0 mg/L throughout the water column despite anoxic hypolimnetic conditions. Below this concentration, the likelihood of negative impact to gilled organisms can increase dramatically when net respiration rate exceeds that of photosynthesis through night hours. This partly explains why many oxygen-related fish kills are noted at dawn as this is the anticipated time where oxygen levels would be lowest. As Apple Valley Lake has substantial depth and epilimnetic DO levels were rarely below 3.0 mg/L, DO loss is not likely to be concerning at this time but, should still be sampled during all sampling events to confirm positive oxygen concentrations exist throughout the water column.

pH values found during the 2024 season mimicked stratified conditions showcased by the temperature data and stayed well within acceptable levels for aquatic organism survival (Figure 12). All collected data points showcased near neutral to alkaline conditions during the 2024 lake season (between 6.9 – 9.25). pH values below 6.5 may begin to show detrimental impacts on aquatic biota (Campbel and Stokes 1985) while acidic values (occasionally noted below 5.3) may alter aluminum ions in water bodies to a form that can harm gills. Very high alkaline values can also have a negative impact on aquatic biota, but pH extremes are rare for a typical Ohio water body. Slight fluctuations in pH are common in water bodies as they are dynamic entities. Increasing photosynthetic activity is one way that pH can naturally rise in water bodies that should be noted in this report. Calcium carbonate ($CaCO_3$; a component of alkalinity and impacts pH) production increases as a product of photosynthetic activity, driving increasing pH levels. With the noted algal bloom occurring on Apple Valley Lake during the spring and still being present during the initial sampling event on 6/20/2024, it is possible that elevated pH concentrations observed in the epilimnion during that time can be connected to increased photosynthetic activity from algal biomass.

Observed conductivity values did not showcase any indication that Apple Valley Lake is impacted by excessive ion introduction via pollutant discharge into the system (e.g. road salt introduction from the watershed; Figure 13). For some water bodies, aggressive salt usage or other ionic pollutants can create a dense layer of water that can remain in the benthic zone of a lake or reservoir. In very extreme instances, this may result in a dense layer of water that can restrict interaction with the water column above it. This could result in a static layer of water that can lose DO like that of an anoxic hypolimnion in stratified systems. If this were to be a concern in Apple Valley Lake, a relatively large spike in conductance at the bottom of the lake would be noted but was not present during sampling in 2024. Rather, conductivity concentrations matched patterns matched by thermal stratification without any notable aggressive or notable increase.

Oxidation-reduction (ORP) patterns also matched thermal stratification and DO patterns (Figure 14). Generally, ORP moved toward negative values under anoxic conditions which is to be expected. The presence or absence of oxygen will alter chemical reactions in water (redox reactions). With oxygen present, positive ORP values are typically observed and suggest a strong likelihood of oxidative reactions such as biological P entrapment in iron (as described above) and nitrification. Negative values would suggest a reduced state and drive reduction reactions such as P release from iron and methane production.

Apple Valley Lake characterization (nutrients)

The connection between phosphorus (P) concentrations and nuisance algae growth (such as cyanobacteria) are well established within primary literature with P considered a major limiting nutrient for freshwater systems (e.g. Dillon and Rigler 1974, Yuan and Jones 2020, Quinlan et al. 2021). This makes P one of the most critical parameters to monitor and control if primary productivity reduction is a goal of lake management. Apple Valley Lake’s water column total phosphorus (TP) concentrations were relatively variable but did showcase spatial and vertical patterns during sampling events. Generally, increases in surface water TP concentrations were noted closer to the inlet than the dam (e.g. deep point sampling location to the inlet location; Figure 20). With average TP concentrations being nearly double that of those collected further south toward the dam, one could hypothesize nutrient increase via watershed inputs. This is further supported by watershed land use analysis showcasing a significant amount of the watershed being used for agricultural purposes and soil analysis showcasing a watershed with soils that have a high capacity for erosion (Figures 4, 5, 6, and

"Appendix A"). However, a more intensive P-budget that takes a more holistic view of P-introduction and precipitation dynamics should be conducted to support this hypothesis as elevated P concentrations near the inlet represents a minimal amount of evidence to suggest heavy watershed inputs. This is especially relevant considering average TP concentrations are still relatively low compared to more eutrophic lake systems.

Increases in benthic TP values were noted in hypolimnetic waters as the season progressed (Tables 2 - 5). As mentioned previously above, this is due to the "iron trap" effect that occurs when anoxic conditions persist in the bottom of lakes and reservoirs. For some water bodies, this build-up can lead to late season algae blooms when a mixing event allows for built-up P concentrations to reach epilimnetic waters. The increase of epilimnetic P while environmental conditions may still be favorable for growth create an optimal scenario for algae growth particularly when macrophyte biomass has regressed for the season. As Apple Valley Lake has a heightened amount of water volume and depth compared to the typical, shallow reservoir in Ohio, concerns for a late season algae bloom would be low as the water volume would dilute the overall quantity of P available for growth. However, should a substantial increase in hypolimnion growth occur during an unusual season (e.g. aggressive benthic decomposition) and P concentrations increase more than typical, it is possible for a late season algae bloom to occur. It should also be noted that the annual lake drawdown likely assists in the reduction of hypolimnetic P concentrations in the lake from bottom water release via the dam (discussed more in Chapter VI below).

The Ohio EPA utilizes Inland Lake Nutrient Criteria guidelines to characterize and compare water bodies across Ohio (OEPA 2010). Although perhaps dated at the time of this report and in need of updating, it is still a useful tool to assess how lakes and reservoirs compare to state averages with regards to productivity. According to the 2010 Lake Nutrient Criteria guidelines, 67% of Ohio lakes have average surface TP values between 0.03 – 0.07 mg/L (30 – 70 µg/L). The mean surface TP value collected throughout the 2024 season was 0.0353 mg/L (35.3 µg/L) falling at the lower end of this threshold but within what may be considered typical for Ohio lakes. Data collected in 2024 also did not stray far from historical TP concentrations (2021 – 2023; Table 7; represented here over Chapter V for relevance). Although, it should be mentioned that the wide majority of collected samples were taken to a laboratory that did not have a detectable level below 0.05 (50 µg/L) making comparison difficult. Additionally, many lake managers across the U.S. utilize a threshold of 0.02 – 0.03 mg/L or 20 - 30 µg/L as a targeted threshold for sustainable overall reduction in algae and submersed plant growth. In some instances, this threshold denoted the difference between eutrophy and mesotrophy (high productivity vs. middling productivity; See Carlson's TSI below). Apple Valley Lake highlighted a mean TP concentration in 2024 just above this threshold which puts the reservoir in a unique situation where minimal nutrient reduction may progress the lake to a lower trophic status. It should be noted that mean TP values collected at the main basin of the lake (disregarding Site 3 and Inlet; Figure 20) would showcase an average within the management threshold listed above.

Table 7: Historical Nutrient information collected from Apple Valley Lake.

Location ID	***Depth***	***Test***	***Date***	***Unit***	***Value****
Cove 1	Grab	TP	9/23/2021	mg/L	<0.05
LS	Grab	TP	9/23/2021	mg/L	<0.05
LMI	Grab	TP	9/23/2021	mg/L	<0.05
Cove 1	Grab	TP	5/19/2022	mg/L	<0.05
LS	Grab	TP	5/19/2022	mg/L	<0.05
LMI	Grab	TP	5/19/2022	mg/L	0.065
Cove 1	Grab	TP	8/18/2022	mg/L	<0.05
LS	Grab	TP	8/18/2022	mg/L	<0.05
LMI	Grab	TP	8/18/2022	mg/L	0.091
Cove 1	Grab	TP	6/29/2024	mg/L	<0.05
LS	Grab	TP	6/29/2024	mg/L	<0.05
LMI	Grab	TP	6/29/2024	mg/L	0.054
Cove 1	Grab	TP	10/19/2023	mg/L	<0.05
LS	Grab	TP	10/19/2023	mg/L	<0.05
LMI	Grab	TP	10/19/2023	mg/L	0.057

* Note that many values were undetectable below 0.05 mg/L with provided historical TP data.

Similarly to TP concentrations, total Kjeldahl nitrogen (TKN) showcased vertical differences were collected at the deep point of Apple Valley Lake. Overall TKN levels were higher within the hypolimnetic waters compared to the epilimnion. Overall concentration of TKN remained <1 to 1 mg/L within epilimnetic waters compared to 2 – 3 mg/L within the hypolimnion (Tables 2 – 5). Although nitrogen is still considered a limiting nutrient for freshwater systems, it normally takes a back seat to P levels as changes in P concentrations will typically have a more dramatic impact on nuisance algae and plant growth. Per the 2010 Inland Lake Nutrient Criteria guidelines, greater than half of the lakes listed by the Ohio EPA had total nitrogen values between 0.6 and 1.9 mg/L showcasing Apple Valley Lake as typical for the state (OEPA 2010). Elevated concentrations noted in the hypolimnion could be connected to growing ammonia levels which are known to increase in anoxic waters. Additional ammonia testing in the hypolimnion of the reservoir would need to occur to confirm this.

Apple Valley Lake characterization (trophic state)

Carlson's TSI calculations primarily showcase Apple Valley Lake as dominantly mesotrophic with occasional eutrophic and oligotrophic values depending on the parameter utilized (Figures 17 - 19). TSI_{SD} values were the least variable amongst the three parameters demonstrating a relatively consistent mesotrophic designation throughout all sampling dates (Figure 19). A pattern of increasing SD toward oligotrophic status was also observed as sampling approached its final date on 10/2/2024. Improving clarity corresponded with noted post-algae bloom recovery (Figure 15) suggesting lake recovery toward lower productivity values. TSI_{TP} values generally hugged the line between mesotrophic and eutrophic characterization with one noted outlier value being present on 7/20/2024 (TP value = 140 µg/L; Table 3; Site 3). Values generally trended toward mesotrophy as the season progressed somewhat mimicking TSI_{SD} trends. $TSI_{Chl\ a}$ values were the most variable of all the sampled parameters showcasing firm oligotrophic values during the July and August sampling period and generally mesotrophic values in June and October (Figure 17). Although it may be hypothesized that the presence of the noted algae bloom during the 6/20/2024 sampling date may impact $TSI_{Chl\ a}$ scores, it should be noted that Carlson's TSI utilizes surface chlorophyll α values which were notably above the observed algae mass in the water column. This caused the bloom to "miss" TSI calculations for the purpose of this report representing mesotrophic surface water conditions.

Despite noted drawbacks to the use of a productivity index like Carlson's TSI, its ability to be utilized as a management tool is useful for a wholistic look at general productivity alterations that a lake may experience over time. For example, when attempting the remediation of eutrophic water bodies, the observed movement of regularly collected TSI scores toward oligotrophy may be an indicator of management success. For Apple Valley Lake, it was described above that TSI_{SD} and TSI_{TP} scores appeared to denote fringe eutrophic to mesotrophic conditions with trends moving toward oligotrophy. Should management decisions be enacted that reduce algal and non-algal turbidity (e.g. P-inactivation, watershed management, etc.) it may be possible to see the impact of these management decisions when expected TSI_{SD} and TSI_{TP} values begin to trend closer toward oligotrophic values. Continual collected of relevant chlorophyll α, Secchi transparency, and TP data would need to continue to continue to generate TSI estimates.

Figure 20: Average/mean surface TP shown spatially in Apple Valley Lake and collected during 2024 sampling events.

IV. Biological characteristics of Apple Valley Lake

Introduction

Similarly to the physical and chemical characteristics of a lake or reservoir, reviewing its biological components are an additional critical piece to understanding its behaviors and capabilities. Many times, the physical and chemical identity of a water body will create the foundation for understanding its biological identity and as such, it's important to understand these components first. Regardless, many lake stakeholders often think about a lake or reservoir's biological components when assessing its recreational condition and, as such, this topic deserves its own chapter. As a recreational reservoir, Apple Valley Lake and its community should strive to meet use-thresholds to ensure biotic conditions do not impair the lake for its categorical use (i.e. favorable cyanotoxin readings, bacteria levels, invasive or nuisance organism biomass). For example, an altered stable state change in the lake from a macrophyte (submersed plants and macroalgae) dominant one to an algae dominant one may increase the potential for harmful toxins to be present in the lake. This could result in harmful conditions that would push the lake to not meet its designated use as a contact recreational lake and would therefore be considered impaired. Comparatively, an altered stable state change to a macrophyte dominant one could reduce usable boating zones due to aquatic plant entanglement in props. If a lake community identifies boating as a priority recreational activity of the lake and the significant reduction in boatable area cripples the activity, then again, the lake may become impaired for its categorical use. Additionally, as a component of a complex ecosystem and food web, Apple Valley Lake should also support the wealth of functioning ecosystem services provided by its biota. This can include such actions as supporting native vegetation to reduce nuisance algae growth while also providing habitat for desired fish species among others. Often holistic lake management plans focus on the altering of biological, chemical, and physical components together to accomplish short- and long-term threshold goals with the overall goal of sustainable well-being of the lake's ecosystem and its community.

During the spring of 2024, stakeholders were concerned about the noted lack of submerged aquatic vegetation (SAV) in the lake. These concerns prompted the addition of SAV mapping as a part of lake sampling procedures represented in this report. Excessive submerged aquatic vegetation has traditionally been an area of concern to the community due to the value placed on recreational activities such as boating and water sports. Aggressive growth of SAV can quickly cause Apple Valley Lake to not meet its use goals and designation as a recreational waterbody by reducing boatable areas and hindering navigation within the lake. However, in addition to contact recreation activities, Apple Valley Lake is also valued by the community for the fishing opportunities it presents to anglers. Because of this potential conundrum, due concern must be placed upon the importance of SAV to the lake ecosystem and the variety of services they provide including erosion control for shoreline rehabilitation, nutrient sequestering to compete with algae growth, improved habitat availability to a host of aquatic organisms which strengthens food web dynamics, and supporting a hearty fishery, amongst a host of other benefits (Figure 28; Cooke et al. 2005, Wersal and Madsen 2012; Figure 21). With cultural eutrophication (human induced P increases into water bodies) becoming a growing issue for inland lakes and reservoirs across the United States, more focus is being put on how to balance SAV growth with the best use of their respective water body (e.g. Lake Monona, WI, Lake Kegonsa, WI; Marshall 2011, Marshall 2007). Although a noted severe reduction in SAV may be looked upon well by Apple Valley Lake boaters and swimmers, it is important to note that macrophytes are a necessary part of a lake or reservoir system, and complete eradication of all growth is never suggested in most situations. Rather, a balance of non-nuisance, native SAV growth should complement the best categorical use of the lake system to attempt to provide a sense of balance. This may mean suggesting future management decisions that assist in SAV recovery should their populations be severely reduced.

As this is the first known SAV survey conducted on Apple Valley Lake, it would be suggested to repeat these procedures in future seasons. This way the spread and density of macrophyte biomass can be tracked and followed into the future. This should become more prioritized if decision making on lake management goals include SAV recovery or reduction to assess management success or failure. Additionally, further sampling could incorporate Point Intercept Rake Toss Relative Abundance Methodology (PIRTRAM) to further enhance our understanding of the macrophyte community on Apple Valley Lake by denoting SAV species richness and individual specie spread (e.g. Indian Lake, Kwietniewski 2023).

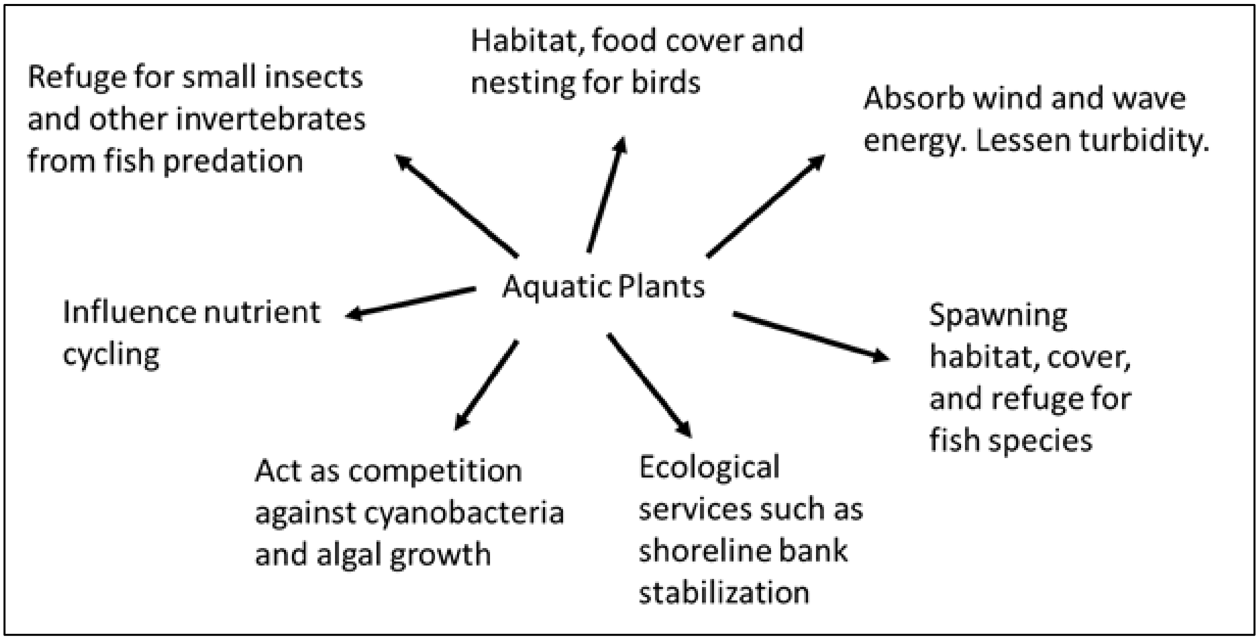


Figure 21: Diagram depicting some of the benefits and services submersed aquatic plants provide to a lake or reservoir environment (adapted from Cooke et al. 2005).

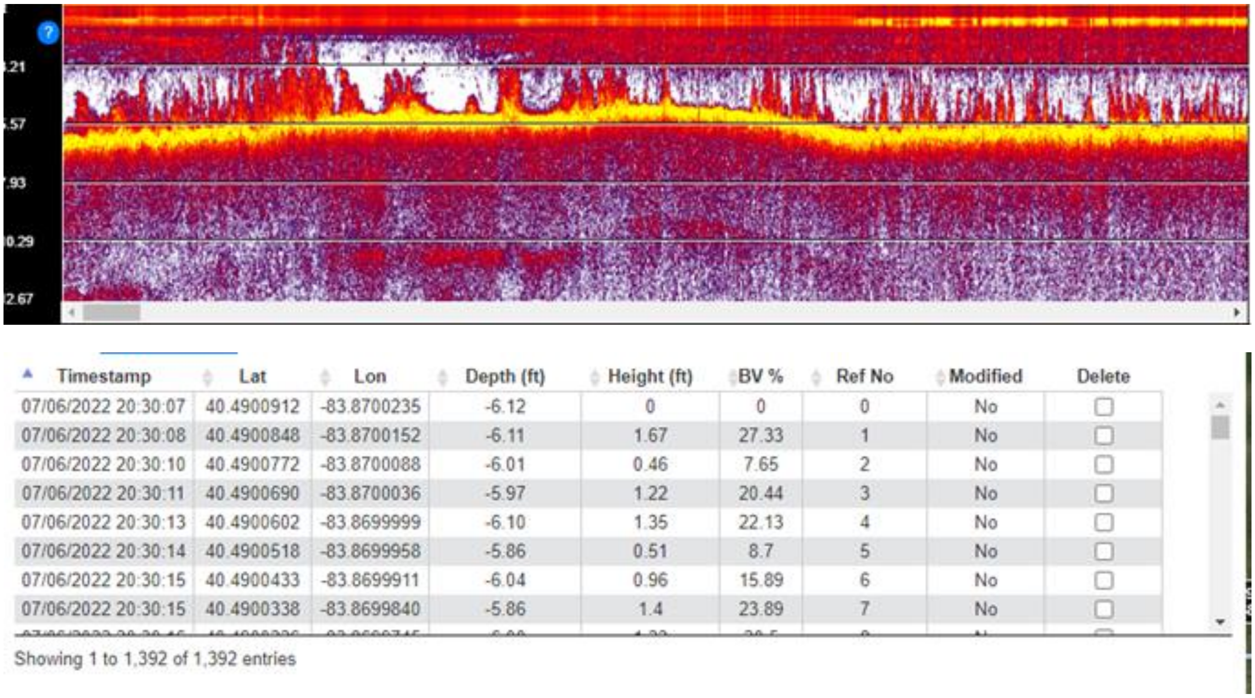
Materials and Methods

SAV mapping was a focus of biological sampling for the purposes of this report. Future assessments of Apple Valley Lake's biological components can include methodology for phytoplankton enumeration and analysis, zooplankton enumeration and analysis, and fisheries metrics. Although some information on these components of the lake may be known by stakeholders, no survey or study materials were provided for the purpose of the State of the Lake Report. This information can be added to updates of this report as it is gathered or understood in the future.

SAV Density Mapping

Vegetation density sonar mapping was conducted with Biobase® mapping programming. Biobase® utilizes sonar "pings" to identify the bottom of Apple Valley Lake as well as any vegetation in the water column. Each "ping" would represent a data collection point where a timestamp, GPS coordinates, depth of the reservoir, and a percentage of the water column covered in macrophyte biomass were collected (Figure 22, 72,143 total point "pings"). To collect necessary sonar data, a Lowrance Hook Reveal TS7 was used on a Carolina Skiff and a path was created by "tracing" Apple Valley Lake slowly (2 – 3 mph) ensuring to cover as much of the reservoir as possible (Figure 23). To accommodate the scale of Apple Valley Lake, much of the reservoir had to be sampled in chunk sections and combined through the Biobase®

analysis software portal used online. The use of the online analytical portal also allowed for manual entry of data should an area have been restricted or missed by the Lowrance unit. Once the lake had been completely sonar scanned, Biobase® is able to generate a heat map layout for vegetation density as well as a bathymetric map for water depth (Figures 1 and 24). The program was also used to estimate biomass percentages and total water column coverage percentages throughout the reservoir. Mapping was conducted 8/22/2024 to collect as many different macrophyte species as possible ("peak" season) and identify the best spread of potential aquatic plants present in the reservoir.



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07/06/2022 20:30:08	40.4900848	-83.8700152	-6.11	1.67	27.33	1	No	☐
07/06/2022 20:30:10	40.4900772	-83.8700088	-6.01	0.46	7.65	2	No	☐
07/06/2022 20:30:11	40.4900690	-83.8700036	-5.97	1.22	20.44	3	No	☐
07/06/2022 20:30:13	40.4900602	-83.8699999	-6.10	1.35	22.13	4	No	☐
07/06/2022 20:30:14	40.4900518	-83.8699958	-5.86	0.51	8.7	5	No	☐
07/06/2022 20:30:15	40.4900433	-83.8699911	-6.04	0.96	15.89	6	No	☐
07/06/2022 20:30:15	40.4900338	-83.8699840	-5.86	1.4	23.89	7	No	☐

Showing 1 to 1,392 of 1,392 entries

Figure 22: An example of a track of "ping" readouts from Biobase® sonar mapping software. In this case, you can see the bottom of the lake (bright yellow in the upper photo) as well as vegetation within the water column. On the bottom half, data from the track is collected for analysis (note: BV% indicates percent biovolume of plant material at that respective "ping").

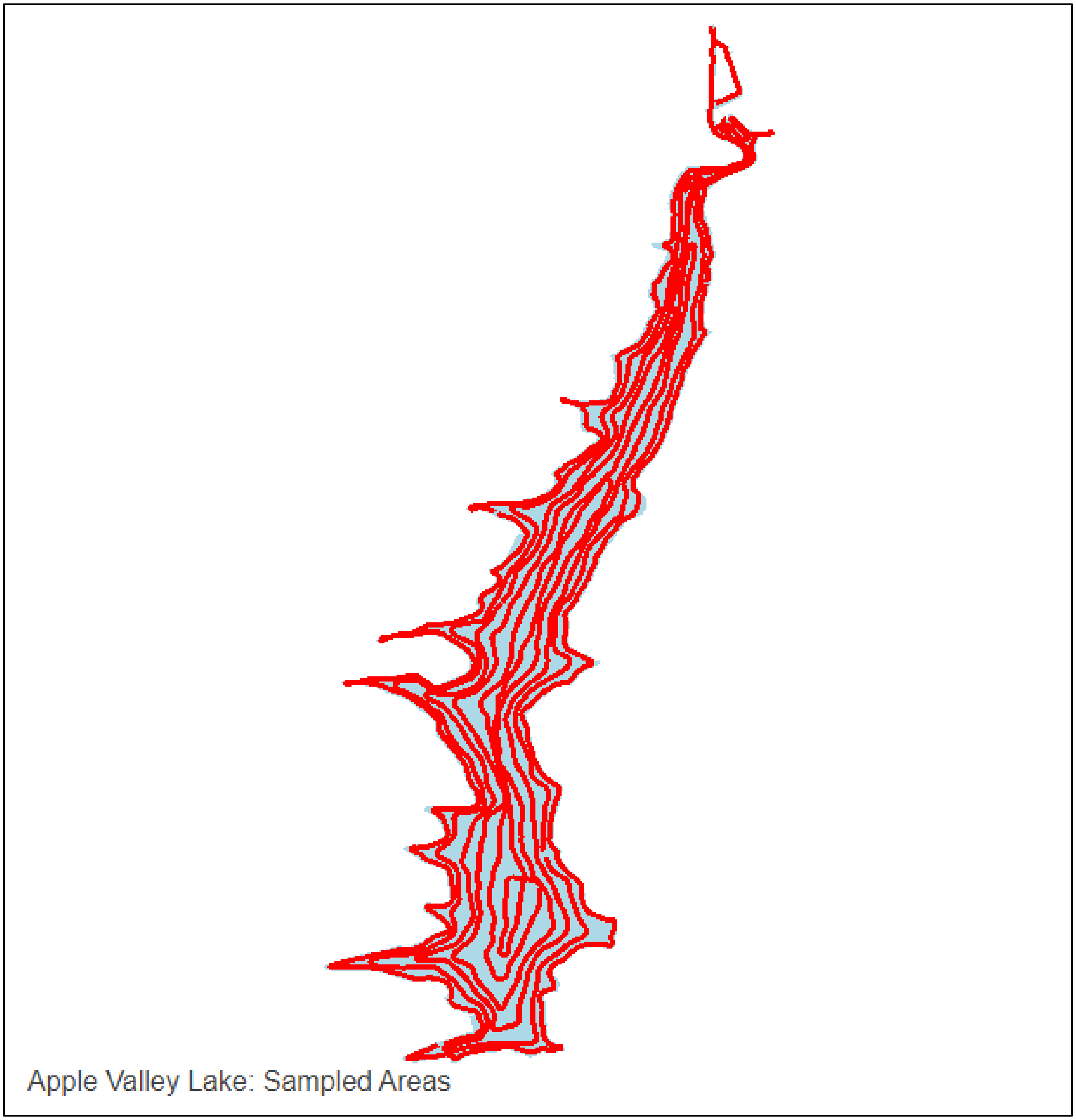


Figure 23: Map of the track used to sonar map macrophyte/SAV density utilizing Biobase®. Red lines indicate the boat track.

Results

Overall SAV abundance

Sonar mapping through Biobase® indicated that 6.8% of the area of Apple Valley Lake was covered with macrophyte growth encompassing 17.3% of the total water column area during the time of the survey (average biovolume, Table 8). When looking at these metrics by means of depth ranges, 0 – 1 m of water depth had 52.6% of its area covered in vegetation encompassing 53% of average biovolume. 1 – 2 m of water depth had 15.3% of its area covered in vegetation encompassing 23.4% of average biovolume. Other depth ranges are included in Table 9 below. A heat map of overall SAV abundance is included in Figure 24.

Table 8: Vegetation cover statistics on Apple Valley Lake based on Biobase® software analysis. Note 1 m = 3.3 ft.

Parameter	***Value***
Percent Area Covered Whole Lake (PAC)*	6.8%
Average Biovolume Whole Lake**	17.3%

*Overall percentage of lake with SAV growing.
** Refers to the average water column percent occupied by aquatic vegetation growth.

Table 9: Vegetation cover on Apple Valley Lake broken up by depth range including the area covered and average biovolume. Note: 1 m = 3.3 ft.

Depth	***Area Covered (of the 6.8% above)***	***Average biovolume****
0 - 1 m	52.6%	53%
1 - 2 m	15.3%	23.4%
2 - 3 m	6.7%	22.3%
3 - 4 m	13.9%	26.2%
4 – 5 m	28.6%	31.3%
5 – 6 m	20.1%	12.4%

* Refers to the average water column percent occupied by aquatic vegetation growth.

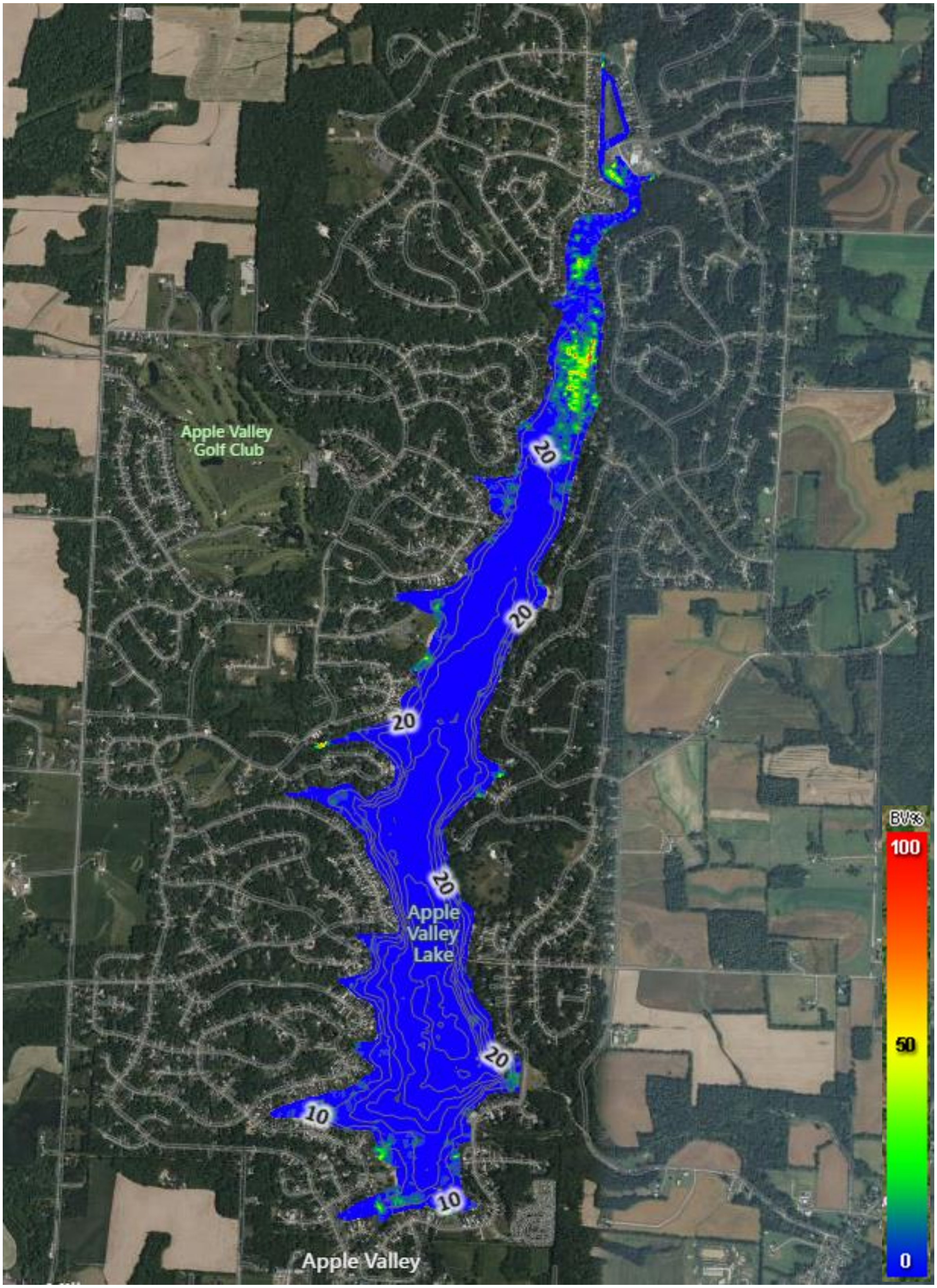


Figure 24: Heat map of vegetation spread and abundance in Apple Valley Lake during the July vegetation survey. Areas in red represent the highest density of plant biomass while areas in blue represent the lowest.

Discussion

Sonar mapping of Apple Valley Lake showcased relatively little SAV growth with only 6.8% of the lake area reporting the presence of macrophytes (Table 8, Figure 24). When accounting for vertical water column space, SAV was encompassing only 17.3% of the water column that had plant biomass. This suggests that the minimal noted amount of SAV growth in the lake also did not grow high into the water column where it was present. It can be hypothesized that the lack of water column presence could be connected to the heightened likelihood of naiad (*Najas*) species being present in areas with noted SAV growth. Naiads are a group of aquatic plants that typically present themselves later in the lake season due to their "bushy" and low-growing appearance. They are also known to be water drawdown and desiccation resistant, allowing them to thrive in water drawdown reservoirs where selection can favor their growth. Although rake toss sampling was not a component of the methodology developed for the goals of this survey, investigatory rake tosses were conducted post-sonar sampling to roughly observe species richness in locations where SAV was identified. Brittle naiad (*Najas minor*) was found during these rake tosses further supporting the naiad growth theory (Figure 26). An additional hypothesis can be connected to plant growth behavior post multiple drawdowns and further connected with the observed algae bloom. Some water drawdown resistant macrophyte species (such as cool water pondweed species like curly-leaf pondweed [*Potamogeton crispus*]) can begin their growth season immediately after ice-off in northern states or even while ice is still present if sunlight can penetrate the ice cover. As Apple Valley Lake refills its volume of water in the spring typically past ice-off, it can be surmised that SAV growth is restricted to later in the season compared to non-drawdown lakes and reservoirs. In conjunction to this, the 2024 algae bloom likely added to compounding the slower growth presence of SAV in the lake by limiting the reservoir's littoral zone through shading and competing with macrophyte growth through nutrient sequestering. The result of this could be a further push of SAV growth into the season once noted algae bloom biomass was reduced.

As briefly mentioned above, the annual drawdown on Apple Valley Lake substantially impacts SAV growth in the reservoir. Different species of SAV demonstrate differing susceptibilities to water loss and desiccation. When annual drawdowns occur on a reservoir system, those species whose reproductive strategies allow for survival in these conditions have a significant competitive edge over those that don't. The result is selection favoring these species of SAV which typically includes members of the pondweed genus (*Potamogeton*) and naiads (*Najas*). Duckweed (*Lemna*) and its derivatives (i.e. watermeal, etc.) can also survive annual drawdowns as they are unrooted and free-floating. With other species of SAV being unable to survive water loss and desiccation, an open niche is presented for these plants to thrive in Apple Valley Lake. AQUA DOC: Lake and Pond Management records since 2017 support this idea as general SAV records need to be maintained for herbicide treatment purposes (Table 10). It should be noted that the SAV species listed in Table 10 have been observed anecdotally and not by means of official surveying and additional species of SAV could be present in the lake.

Table 10: List of macrophyte/SAV species historically noted in Apple Valley Lake based off AQUA DOC records.

Common name	***Latin name***
Large-leaf pondweed	*Potamogeton amplifolius*
American pondweed	*Potamogeton nodosus*
Curly-leaf pondweed	*Potamogeton crispus*
Illinois pondweed	*Potamogeton illinoiensis*
Brittle naiad	*Najas minor*
Slender naiad	*Najas flexilis*

*Note: Red lettering denotes an invasive plant in Ohio.

Figures 25 and 26: Images of SAV observed in Apple Valley Lake in August of 2024 including American pondweed (*Potamogeton nodosus*; left) and brittle naiad (*Najas minor*; right on rake).

V. Review of Historical Data

Introduction

Regular collection, analysis, and data storage of water quality monitoring information is an integral component of the development of reference conditions that are then used to develop water quality management thresholds. As mentioned previously, these thresholds can become important to be able to define the lake or reservoir as “impaired” or “unimpaired” beyond anecdotal observations. The Apple Valley Property Owner’s Association (AVPOA) was able to provide a selection of historical data that dates back as far as 1986 for the purpose of this report. Additionally, stakeholder collected dissolved oxygen (DO) and temperature profile data was provided by Jim Winkler on behalf of the Apple Valley Fish Club. The AVPOA data provided includes surface parameters that include transparency (Secchi depth), water temperature, dissolved oxygen, pH, total phosphorous (TP), nitrate and nitrite. While this is useful information to provide historical context on water quality in Apple Valley Lake and some conclusions regarding reference conditions can be drawn from it, data such as temperature, pH, and DO are better analyzed as a depth profile for vertical analysis making their usage limited in scope. In addition, Various individuals have contributed to data collection over the years and may or may not have been trained in proper standard operating procedures for water quality purposes. Finally, some of the collected parameters reviewed are limited in scope without consistent collection, providing limited insight. As such, for some of the provided data direct conclusions on true reference conditions cannot be ascertained. However, SD, temperature profile data, and DO profile data provided appear to have been regularly collected in uniform fashion and can be analyzed for pattern discernment. Historical nutrient data was included during the discussion of physical and chemical parameters in Chapter III above. A map of lake sampling locations mentioned in this chapter was provided amongst the data provided denoted in Figure 27 below. All provided historical data is included within “Appendices G and H” below for future consideration and usage.

As monitoring continues on Apple Valley Lake it would be suggested to enact a standard operating procedure (SOP) for the collection of water quality data. By enacting such a document, procedures can be standardized even with a rotating cast of volunteers. Through standardization, quality assurance can be achieved and consistency in reported data can better denote patterns that can be used for the development of reference conditions. A water quality monitoring SOP should include information on what information is critical to collect annually and in what frequency, where the data should be collected, how to collect it, and how it should be represented or analyzed to denote patterns. This information is represented in Chapter VII below in detail and highlighted more specifically for Apple Valley Lake in the LMSP in Chapter

VIII. The following information in this chapter represents relevant historical data provided for the purpose of this report.

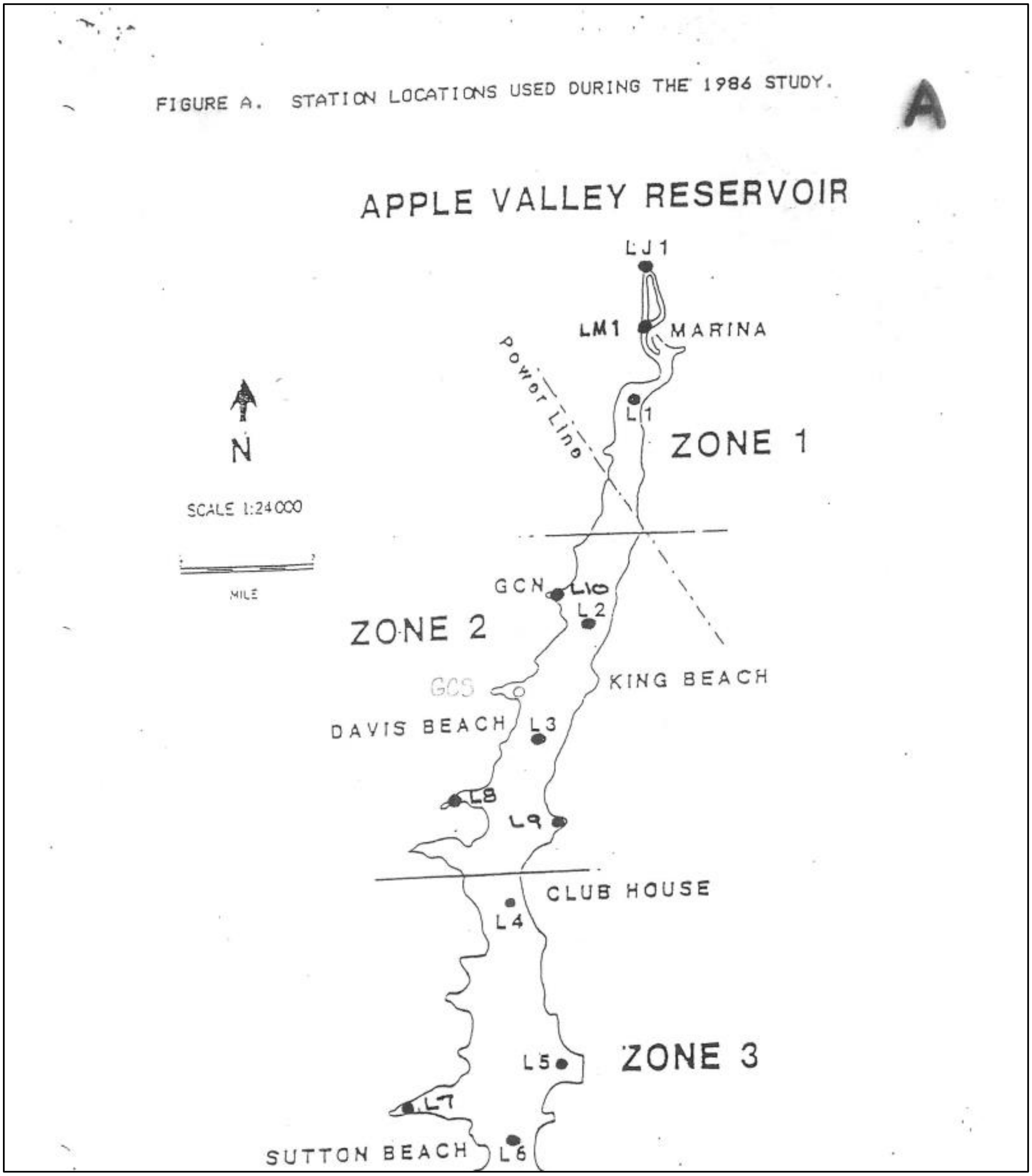


Figure 27: Historical sampling locations used by the AVPOA. Provided by Jim Winkler.

Historical Parameters Summarized and Discussed

Secchi transparency (SD) – SD was the most useful parameter provided for historical purposes as it was sampled consistently at multiple locations (L1 – 10; Figure 27) and regularly during the sampling season for multiple years. Additionally, SD represents data that can assist in the determination of Apple Valley Lake's productivity characterization. Because of this, a regular pattern of the lake's behavior can be extrapolated and additionally, converted into a productivity index (Carlson's TSI; Carlson 1977). As location L5 represents the closest location to the deep point of the reservoir, this location is the most useful for representation of historical data relative to collected data for the purpose of this report in 2024 (Figure 28). Mean Secchi transparency for all provided historical data at site L5 (also including collected 2024 data from the deep point) is 1.78 m. Lowest SD values from 2000 – 2024 were collected during the 2024 sampling period in May and June when the algae bloom was noted to be present on the lake (0.75 m and 0.76 m for May and June respectively). It should be noted that SD increased to depths more typical for Apple Valley Lake and closer to the historic mean in following sampling periods cumulating to a maximum SD on October 2 of 1.67 m (Figure 29). Reduced SD in May and June is likely attributed to algae biomass growth confirmed at this time as SD recovery seemed to occur gradually once the bloom had subsided (Figure 15).

All SD data for all historical sampling sites were compiled and converted into spatial yearly means and then further converted to Carlsons TSI (Carlson 1977) to estimate SD-derived productivity reference conditions (Figure 30). Based on this analysis, Apple Valley Lake has showcased fairly consistent TSI_{SD} values between approximately 50 – 60 from 2000 to 2024. The greatest noted TSI pattern change does seem to appear in 2024 due to a reduction in SD means from low SD values in May and June (during the algae bloom). Again, it is important to note that SD values did return to those historically noted and the increase in TSI score is likely due to the lower SD values shifting the total mean for the year. With the noted SD recovery post-June that progressed further toward the end of the lake use season, additional seasonal data would be needed to build any mounting evidence that the lake is showcasing a pattern of moving toward a more eutrophic state or not. Should an early season algae bloom not occur early into the 2025 lake season as it did in 2024, it could be hypothesized that these TSI values would be reduced from deeper SD values not impacted by algal-derived turbidity. Collecting SD values and converting them to TSI values should continue as a standard practice to continue the construction of historical reference conditions. In addition to this, TP and Chlorophyll α derived TSI values should become a component of creating reference conditions so that a holistic productivity picture can be developed.

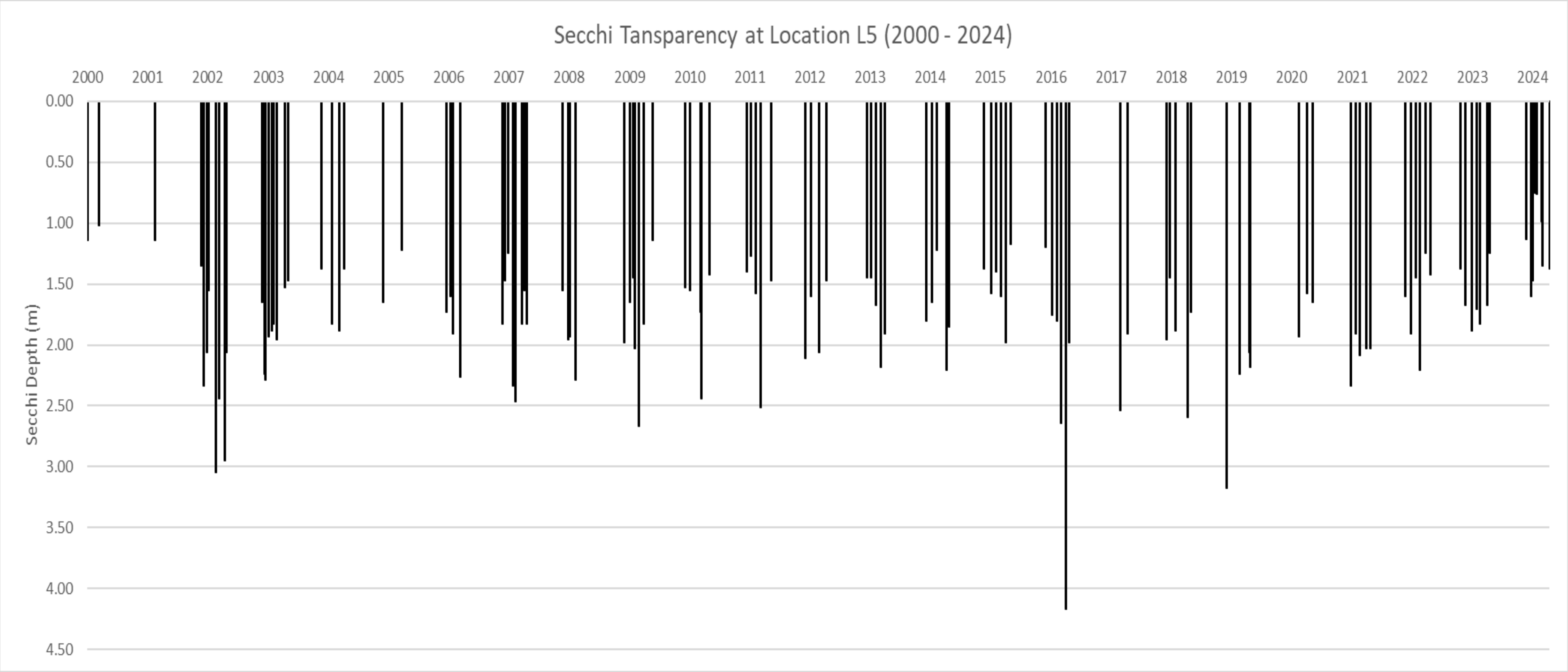


Figure 28: Secchi transparency values noted on Apple Valley Lake from 2000 to this past lake-use season (2024).

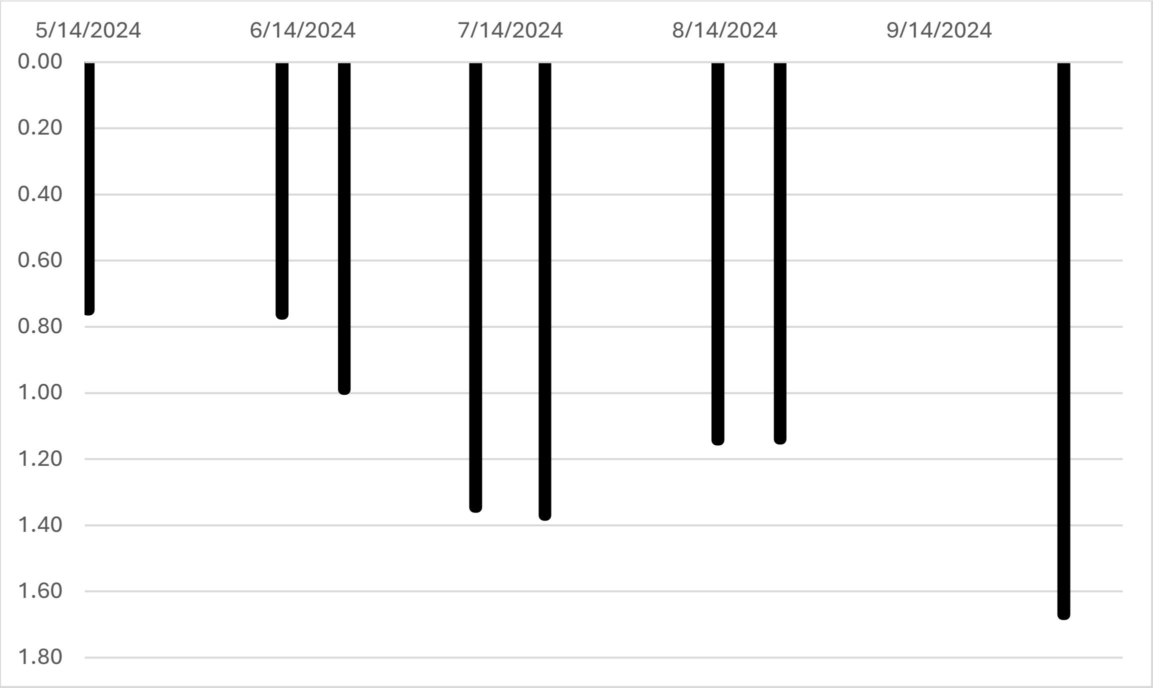


Figure 29: Secchi transparencies (SD) noted during the 2024 lake-use season. Note the increasing depth trend post-noted spring algae bloom.

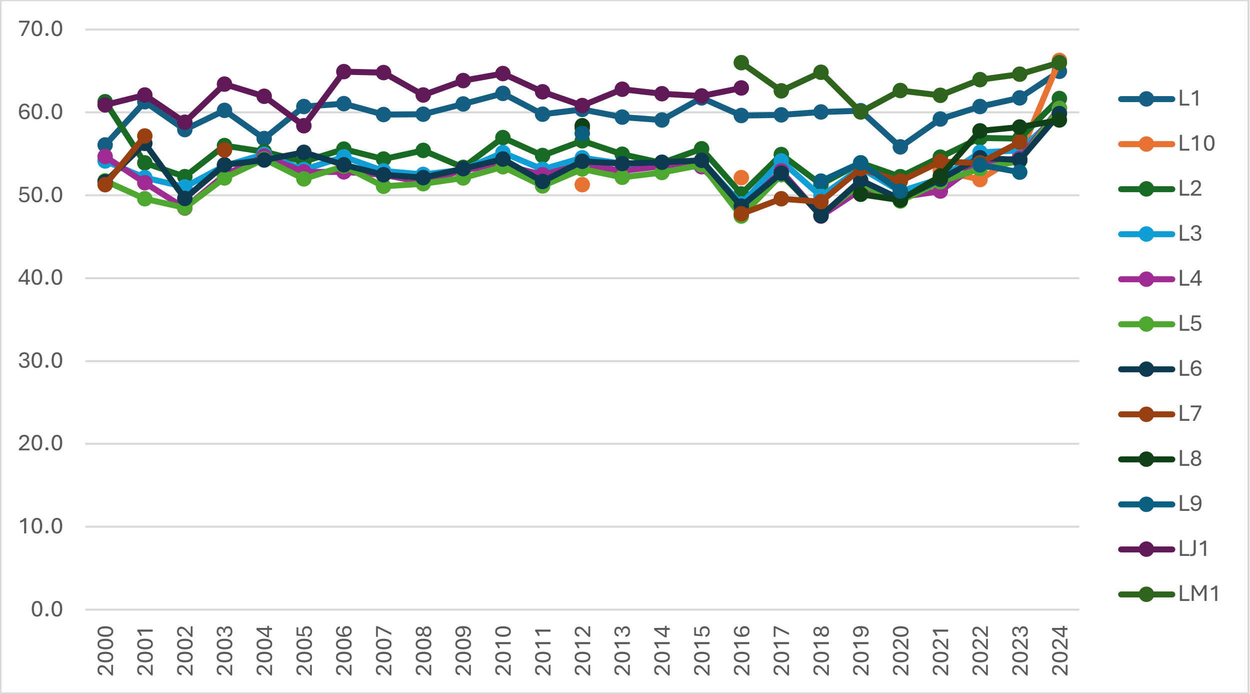


Figure 30: Carlson's TSI$_{SD}$ for all historical sampling locations on Apple Valley Lake from 2000 to 2024 (L1 - L10).

Temperature - Vertical temperature profile data was provided by Jim Winkler on behalf of the Apple Valley Fish Club from 2021 to 2023. Although not a metric that can suggest an increase or decrease in primary productivity, having reference conditions on vertical temperature changes can determine typical stratification patterns as well as the size and scope of epilimnetic and hypolimnetic water layer sizes. Unfortunately, the temperature meter utilized by the volunteers for the collection of historical temperature information appears to have a maximum sampling depth of 30 ft as all available historical data is limited to that depth (Z_{max} = 73.3 ft). This means that more than half of the water column was unsampled for the purposes of historical data analysis. This does not make the data unusable however, as thermocline location during the 2024 season was noted to range between 16 – 28 ft as the season progressed (Figure 10). However, if thermocline development in historical data is deeper than 30 ft, then it would not be observable in the provided data. Regardless, the provided data allows us to at least roughly compare thermocline location and therefore, likely water density separation from 2024 to as far back as 2021. With an understanding of thermocline depth, we can also relatively accurately estimate hypolimnion size as hypolimnetic water quality profile values typically are consistent below the thermocline.

Historical temperature profile information showcases varying degrees of stratification strength from 2021 to 2023 (Figure 31). Onset of stratification appears to begin between June and July during these years with the thermocline progressing deeper into the fall or becoming mixed in the fall (the sampled depth restriction does not allow for full thermocline analysis). Based on this information, the stratification patterns noted in 2024 were stronger than in the previous two sampled years with more defined thermocline depths and epilimnetic recovery (Figures 10 and 31). As the bloom regressed past June, it is possible that dead algae biomass (detritus) may have sunk into the hypolimnion increasing respiration rate through decomposition and strengthening it. The result could be a stronger thermocline as noted during our 2024 sampling. It should be mentioned however, that sampling protocols were followed by an assortment of volunteers and standard operating procedures may not be standardized. This also could explain minor differences from year to year if either a) calibration of the sampling equipment was not conducted or b) if time was not given for temperature values to stabilize from the sampling device readout prior to writing down the data resulting in a “less clean” depth profile. Regardless, future profile sampling should try to incorporate sampling at the deepest point of Apple Valley Lake to better track thermal stratification patterns within the whole water column. This same location should be the standard critical location for all depth profile sampling.

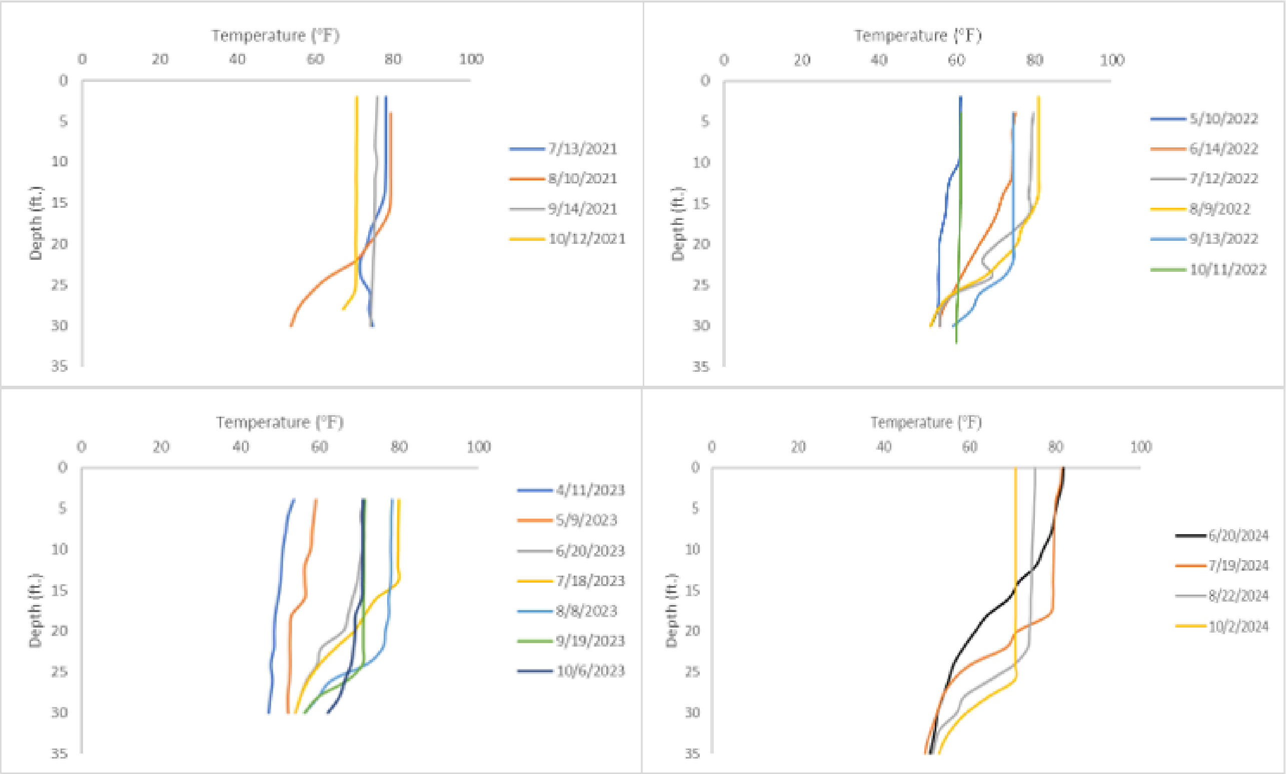


Figure 31: Temperature profiles of provided historical data from 2021 to 2023 (upper left, upper right, lower left respectively) and temperature profile data collected during this study (lower right) in 2024 truncated to match the scale and depth of historical data.

Dissolved Oxygen (DO) - Vertical DO profile data was also provided by Jim Winkler on behalf of the Apple Valley Fish Club from 2021 to 2023. As with temperature, DO is not a direct metric that can suggest an increase or decrease in primary productivity. However, as DO is instrumental in understanding internal P loading due to the iron trap (Chapter III), knowing what depth Apple Valley Lake becomes anoxic is important to understanding the potential risk of internal P-loading. Unfortunately, the DO meter utilized by the volunteers for the collection of historical DO information appears to have a maximum sampling depth of 30 ft as all available historical data is limited to that depth (Z_{max} = 73.3 ft; same as temperature). This means that more than half of the water column was unsampled for the purposes of historical data analysis. This does not make the data unusable however, as thermocline location during the 2024 season was noted to range between 16 – 28 ft as the season progressed and DO loss closely followed this pattern (Figures 10 and 11). This allows us to at least compare thermocline location and therefore, likely anoxic area from 2024 to as far back as 2021.

Historically collected DO data showcase regular patterns of reduction below estimated thermocline locations (Figures 31 and 32). Strength of oxygen loss was variable and ranged between hypoxic (low oxygen) to anoxic (“0” oxygen) from sampling date to sampling date and year to year. As mentioned in Chapter III, DO loss in 2024 was restricted to areas below the lake’s noted thermocline at the time of sampling and almost immediately progressed to anoxia (vs hypoxia). This can be related to what was mentioned in the “temperature” description above whereas an increase in decomposition could have strengthened hypolimnion depth via oxygen loss. The same set of procedural limitations mentioned in that section also apply to DO as the same equipment was used for temperature and DO.

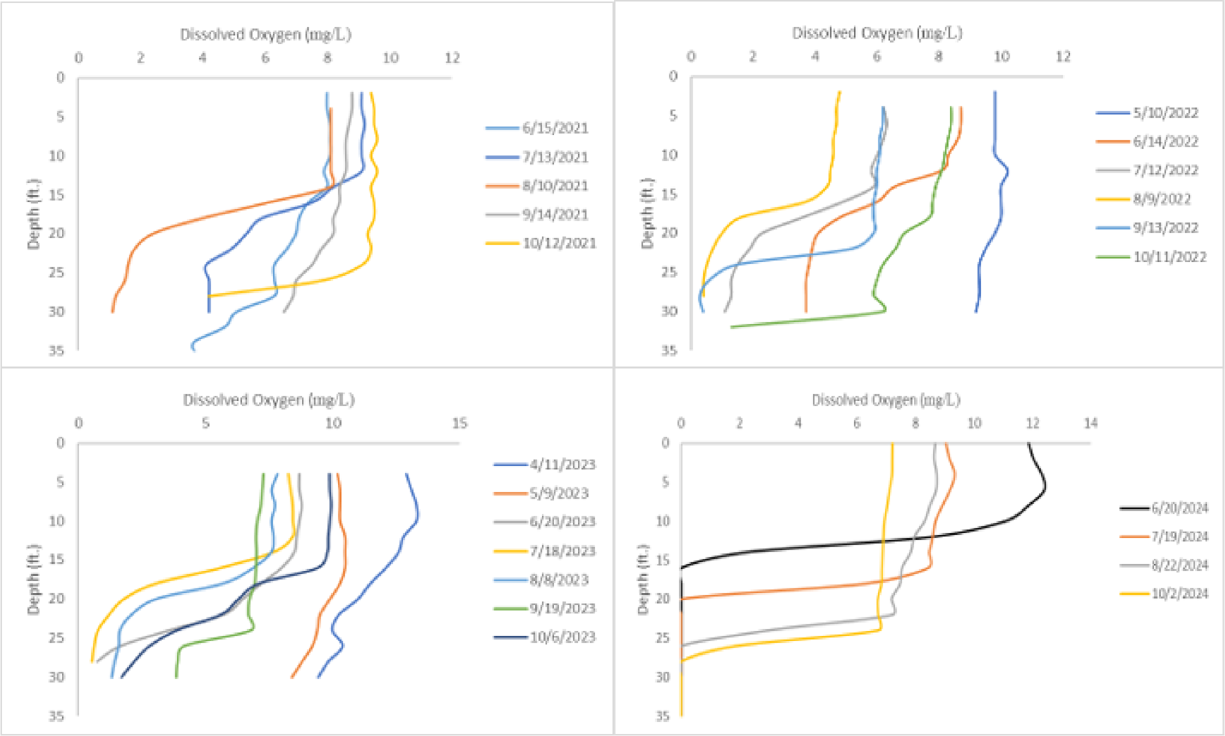


Figure 32: DO profiles of provided historical data from 2021 to 2023 (upper left, upper right, lower left respectively) and temperature profile data collected during this study (lower right) in 2024 truncated to match the scale and depth of historical data.

VI. Assessment of In-Lake Management Techniques

Introduction

Management of aquatic environments can become a difficult task when considering costs, variability in success, and potential risks (e.g. stable state shifts that can cause new, additional management concerns post-enactment of management techniques). Additionally, management technique choice can become a complex process when needing to consider the scale of the project, identification of nuisances to be managed, and technique feasibility when water body characteristics are taken into consideration. Selection of viable management techniques to be utilized on Apple Valley Lake should be multifaceted. This is to say knowledge of multiple techniques and a degree of flexibility will be needed to account for changes in a dynamic system. This concept allows lake managers to adequately plan for potential issues that may require troubleshooting while adjusting techniques to fit specific locations when it is deemed necessary.

At the time of this report, Apple Valley Lake is not considered to be impaired for its best categorical use as a recreational reservoir. Because of this, aggressive management of the reservoir and its biota will likely be unnecessary unless there is a noted substantial change in the physical, chemical, and/or biological components that cause impairment going into the 2025 season. As such, assessment of viable in-lake management techniques for 2025 is more limited in scope since more efforts should be placed on sustaining its positive lake-use condition vs. aggressive short- and long-term management options to alter the lake's stable state. These efforts include the utilization of best management practices (BMPs) as well as suggestions to improve upon current monitoring protocols connected to Apple Valley Lake and its constituents (described in more detail in the next chapter). Additionally, and as mentioned previously in this report, a noted reduction in SAV was anecdotally observed in the lake with 2024 mapping seeming to confirm this. This could be pointed to as an item of concern for the lake as a potential indicator of the system shifting toward an algal-based stable state. However, monitoring data collected throughout 2024 showcased signs of natural recovery with SAV growth reappearing later in the season and algae bloom conditions subsiding past June sampling dates. The suggestions above of increasing monitoring efforts while supporting BMPs is echoed again with this information as future monitoring surveys can confirm future concerns of increased algae growth patterns or showcase the lake simply experiencing temporary stable state ebb and flow. If trends appear to move Apple Valley Lake toward impairment, then a revisit of collected data (which should be more robust with more years included for analysis) coinciding with an amended management plan should occur.

Regardless of the need for aggressive management (or lack thereof), understanding stable state theory is critical to lake management technique selection, particularly with regards to control of primary productivity (i.e. algae and plants). As algae and SAV directly compete with one another for resources such as light and nutrients, making decisions that severely impact one group can support or restrict the growth of the other. This is the basis of stable state theory, the idea that algae and SAV growth almost seem to work as a "teeter-totter" whereas one group typically dominates the other competitively and thus may dominate the system in question (Figure 33). In some (and growlingly fewer) instances, lessened overall primary productivity and adequate management have allowed for a balanced "teeter-totter" resulting in equal competition amongst these two groups. Many lake managers and lake management plans are centered around this concept by altering one stable state (plant or algae dominant) to move the "teeter-totter" towards a preferred balanced state. Often, however, lake managers may accidentally push the stable state "teeter totter" too far causing lake impairment. A recent example of this is Indian Lake in Howard, OH where a stable state change (turbid/algae dominant to submersed plant dominant) occurred after invasion by invasive Eurasian watermilfoil (*Myriophyllum spicatum;* EWM; Kwietniewski 2023). The lake became impaired as recreational use of the resource was strongly hindered (e.g. lack of adequate swim areas, boat prop entanglement, loss of tourism income). In this instance, significant and costly management of the EWM was necessary using herbicides and mechanical harvesters to move the lake back to its reference condition (algae based/turbid). As mentioned before, Apple Valley Lake is not impaired by primary productivity as the lake exhibits adequate depth, and relatively lower productivity index scores (i.e. an uncommon instance of being relatively balanced). However, as cultural eutrophication is a growing problem amongst lakes and their management, steps should be taken to create and maintain a balanced quantity of primary productivity that allows Apple Valley Lake to fulfill its designation as a recreational water body. This is always suggested as an overarching goal as future decisions are made.

To help address the complexity of the point above, this chapter of the report was created to assess the various management techniques that can be used to manage nutrient concentrations (P) as P is directly connected to primary productivity and eutrophication in freshwater systems. Techniques that directly control algae and plant biomass are left out of this assessment but should be revisited if future management necessitates these tools. Understanding these techniques will allow current and future lake managers to have a more complete "lake management toolbox" that will allow them to become dynamic as the lake changes. This way, Apple Valley Lake can be prepared to investigate all options available for when lake goals and problems change. Please note that the techniques and methods presented in this report represent what is known and available at the time of writing. New techniques and methods could be developed or introduced in the future and keeping up with trends in lake management is always suggested.

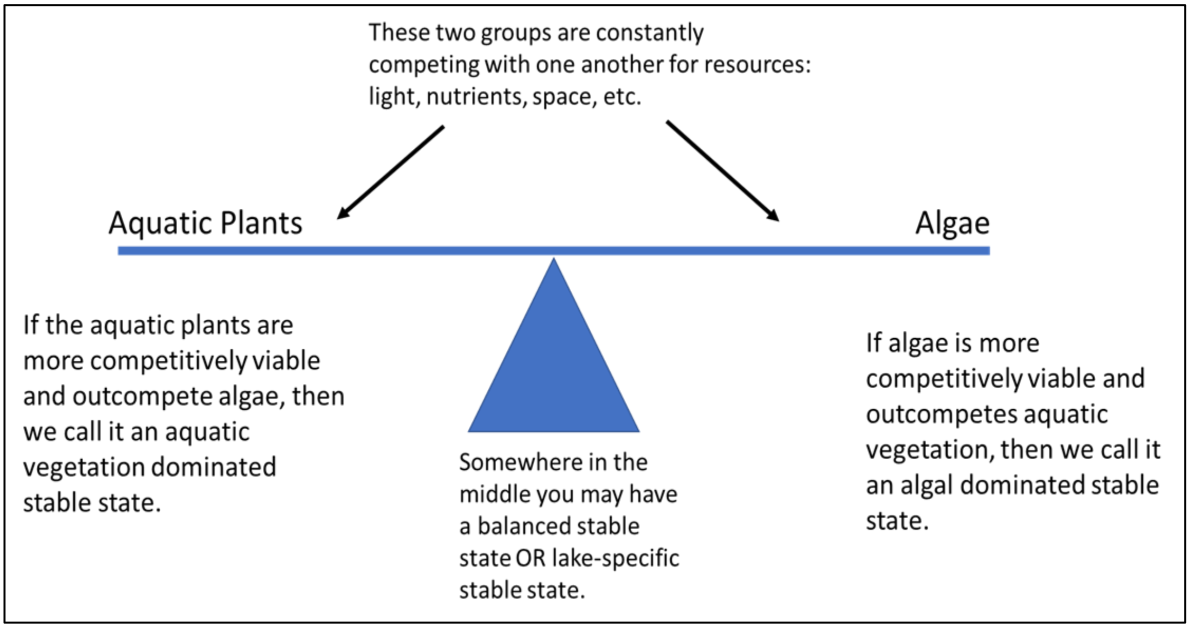


Figure 33: Diagram highlighting the relationship between algae vs. SAV dominated stable states.

Technique Identification and Assessment

Management of nuisance aquatic vegetation, algae, and the nutrients that feed them (primary productivity) can be broken down into four distinctive categories: physical, mechanical, biological, and chemical methods. Within these categories are a myriad of subcategories that allow for management flexibility based on the behavior of the lake in question, the identification and scale of the nuisance target(s), and stakeholder acceptance/ financial feasibility. All the techniques within each of these categories can be successful for the management and control of primary productivity or nutrients in water bodies. However, not all techniques are feasible in all situations and in some cases, are not suggested at all. Below is a summary of some of the various techniques associated with nutrient management and their feasibility in Apple Valley Lake.

Physical techniques

Whole-lake drawdown – Water level drawdown is an extremely common practice in reservoirs across the United States and Ohio. The technique involved the lowering and release of water from the basin to accomplish any number of specific management goals. Although there are multiple reasons for a reservoir to conduct a water level drawdown, many lake managers may commonly consider it as a management technique for aquatic plant control.

However, whole-lake water drawdown can also be utilized as a nutrient management tool should favorable conditions exist. For plant control, water reduction is usually restricted to the extent of the littoral zone where the process of draining, exposure to ambient air, and desiccation will eliminate plants (Figures 34 and 35). For nutrient reduction, the goal may be overall P-reduction via dilution from incoming watershed water or altering of the reservoir's sediment and biogeochemical characteristics (Furey et al. 2004). In these instances, water release beyond the littoral zone may be necessary to achieve the dilution effect. For lakes that are deep enough and confirmed as stratified, release of hypolimnetic waters may also reduce the impact of internal P-loading especially if the water release mechanism is utilized below a confirmed hypolimnion and an anoxic condition exists long enough for P to accumulate within it. It is also important to consider incoming water to refill the lake as a reservoir with heavy watershed P-inputs may increase overall P-concentrations vs. diluting them. Since drawdown requires the ability to release water, it is typically a technique that is reserved for reservoirs with the capacity to do so. Many natural lakes (e.g. kettle lakes, plunge pool, etc.) are unable to utilize this technique because of this. Costs associated with water drawdown are typically negligible if the reservoir already has the capacity to perform the technique.

As a reservoir with a water release mechanism, Apple Valley Lake has the potential to and does conduct an annual water level drawdown. As a nutrient management tool, this has likely benefited the lake even if unintentionally so. Data collected during the 2024 sampling season indicated that Apple Valley Lake was heavily stratified throughout the sampling period with a hypolimnetic build-up of TP that grew through the season (Figure 10; Tables 2 - 5). With a release mechanism located near the bottom of the dam, P-enriched benthic water is likely released from the lake preventing it from being redistributed through the water column should mixing occur. This prevents a potential increase in late fall nutrient levels and a likely subsequent algae bloom that is relatively common in more shallow, non-drawn down reservoirs. Despite elevated nutrient levels noted near the inlet during the survey (Tables 2 - 5), incoming water in the spring is still likely to be less nutrient enriched than outgoing anoxic hypolimnetic water in the fall, allowing for a dilution effect until concentrations rise again in the hypolimnion when stratification strengthens in the summer.

As highlighted previously, water level drawdown is more commonly associated with aquatic plant management than nutrient or algae reduction and the techniques impact on aquatic plants is more frequently documented. Although Apple Valley Lake is currently not likely to need aggressive SAV management and is already influenced by water level drawdowns, it should be mentioned again in this section due to the importance of this impact. As drawdown is selective to submersed plants whose reproductive structures and strategies can survive desiccation, drawdown is likely a major contributor to the species richness and spread of SAV found in the lake (Table 11; Carmignani and Roy 2021, Holdren et al. 2001). Therefore, if management direction demands native aquatic plant additions to Apple Valley Lake, it may be beneficial to add varieties that are likely to return on an annual basis and can survive annual drawdowns like those presented in Table 11 (below).

Figures 34 and 35: Image of a winter whole lake drawdown of Green Lake in Orchard Park, NY (left) and partial drawdown of Rushford Lake in Canadea, NY (right). Exposed benthic sediment and materials are showcased in both images. (Photos: Edward Kwietniewski).

Table 11: Response of select species of submersed aquatic plants to water level drawdown (adapted from Holdren et al. 2001).

Decrease in abundance	Variable or no change	Increase in abundance
Brazilian elodea (*Egeria densa*)	Bladderworts (*Utricularia sp.*)	Duckweed (*Lemna spp.*)
Coontail (*Ceratophyllum demersum*)	Cattails (*Typha sp.*)	Naiads (*Najas spp.*)
Hydrilla (*Hydrilla verticillatum*)	Common waterweed (*Elodea canadensis*)	Pondweeds (*Potamogeton spp.*)
Milfoil spp. (*Myriophyllum spp.*)	Eelgrass (*Vallisneria americana*)	Water bulrush (*Scirpus spp.*)
Yellow waterlily *(Nuphar sp.*)	Muskgrass (*Chara vulgaris*)	Curly-leaf pondweed (*Potamogeton crispus*)
Southern naiad (*Najas quadalupensis*)		
Water shield (*Brasenia schreberi*)		

Red lettering denotes an invasive plant in Ohio.

Artificial circulation – artificial circulation involves the utilization of machines or other methods to increase the strength of water circulation in water bodies. Bottom-diffused aeration (BDA) is the most common of these techniques and involves the release of bubbles through a diffuser head delivered by onshore compressors. Other devices such as surface circulators can also be utilized but are not nearly as common as BDA (Figures 36 and 37). The goal of many of these devices involves the circulation of the entire body of water a predetermined number of times. Doing this prevents the establishment of a thermocline, reducing the likelihood of hypolimnetic oxygen loss and thus, reducing internal P-release from anoxic conditions. Additionally, with regards to algae control in deeper bodies of water, increasing the depth of circulation may push algae biomass below the compensation point (where net respiration rate exceeds photosynthetic energy gains) of these lakes. If algae biomass is pushed for an extended period in this manner, growth can be impactfully slowed and reduced. Correct implementation of artificial circulation, especially on larger lakes, is a deeply involved process that demands proper construction, modeling, equipment placement, and potential cost limitations. A cheaply constructed system haphazardly applied is highly unlikely to be able to produce the joules of energy necessary to move water in a manner effective enough to produce credible results. In addition, shallow lakes or lakes with large, shallow areas may require further engineering efforts to account for the loss of circulation strength due to minimal vertical water movement (at least for BDA systems). In these instances, additional or site-specific diffuser heads may be necessary, further increasing costs. For deeper systems where part of the goal of artificial circulation is destratification, iron concentrations may also need to be monitored to assess the longevity of P-reduction success. This is because a common purpose behind destratification is oxygen consistency or renewal to the bottom to push redox reactions to an oxidative state allowing for P-sequestering through the iron-trap process (explained above in Chapter III). If benthic iron concentrations are too low, binding sites for P-sequestering may be inadequate to accommodate P-loading or availability in the basin.

Due to the bathymetry of Apple Valley Lake, utilizing artificial circulation for the purpose of nutrient reduction would be difficult and costly but could yield positive results. With an average depth of 24.7 ft and a maximum depth of 73.3. ft (Table 1) as well as confirmed hypolimnetic P build-up due to anoxia (Figures 10 and 11 and Tables 2 - 5), BDA could be implemented to eliminate strong stratification characteristics in the lake and reduce hypolimnetic P concentrations deriving from the iron-trap process. Enactment of this technique would demand shoreline locations for compressors as well as a well-engineered BDA plan for diffuser head placement purposes. Typically, this would be done by aeration vendors by simply providing lake bathymetry with depth metrics (provided in Chapter I) to the vendor and they would utilize in-house modelling to design a plan around the specifications of their products. At times, this may be provided at no additional cost if the community is willing to pay for the BDA system through the vendor. To turn over the entire volume of water, diffuser heads would need to be more closely positioned in shallower areas of the lake compared to deeper areas which will increase price if full turnover is desired. Although risky, a BDA system installed only in the southern half of the lake to a suggested minimum thermocline depth could still be beneficial for mixing purposes. However, given that thermocline depth can vary year to year, and historical temperature information showcased thermocline variability (Figure 31), there is elevated risk of incomplete or inefficient turnover should seasonal temperatures alter thermocline position to areas not impacted by BDA or if an internal seiche (shift of thermocline position from wind and water movement) alters thermocline development spatially.

Anthropogenically mixing Apple Valley Lake could force higher surface TP concentrations if normally heightened TP levels from deeper depths homogenize with the surface. This could result in a higher capacity for algae blooms when heightened TP concentrations reach the photic zone of the lake, creating prime bloom conditions. This could also occur if a substantial increase in watershed P enters Apple Valley Lake and is repeatedly recycled to the surface due to mixing. However, given the lake's depth, compensation point may negate these concerns when mixing causes algal biomass to be pushed deep into the reservoir. Regardless, increasing algae bloom risk in order to eliminate stratification may not be the best management consideration when algae growth is already typically low through the season (Figure 15) and annual drawdowns may already reduce internal P concentrations prior to natural dimictic mixing. Costs associated with the addition of BDA in Apple Valley Lake would vary depending on the design of the system, brand, and hours of operation (electric costs). Based on known costs of other BDA systems in relatively larger lakes, it would be very roughly estimated that a BDA system installed in Apple Valley Lake would well exceed six figures with additional thousands needed annually for maintenance of the system and electric costs. Given the high cost, risky potential for an increase in primary productivity in the epilimnion, and current lack of impact stratification has on the best categorical use of the lake, it could be difficult to suggest artificial circulation as a management technique for the system unless a there becomes a greater demand for reducing the anoxic hypolimnion.

Figures 36 and 37: Surface aerators being utilized at the inlet of a reservoir to assist with anoxia derived from decomposition (Photos: Edward Kwietniewski).

Chemical techniques

Phosphorus inactivation (P-inactivation) – Perhaps an under-utilized technique for large-lake and reservoir remediation in the United States, P-inactivation involves the use of a phosphorus precipitate (usually a metal ion like aluminum, calcium, lanthanum, etc.) that can sequester and flocculate P, by binding to it and dropping it to the bottom of the water body making it biologically inert. For many P-precipitates, enough product also must be applied to generate a "cap" at the bottom of the water body if goals include the reduction of sediment-derived nutrients from anoxic material. This technique is commonly used within water treatment facilities, typically during tertiary treatment procedures to meet water treatment P thresholds. In surface waters, the technique may be conducted by barges with the P-precipitant being slowly applied through low-flow hosing just above the surface of the water (Figures 38 and 39). Many different varieties of P-precipitates exist as individual chemicals and as proprietary blends produced by venders (Table 12). All these products react differently under variable environmental conditions and rate adjustments are needed to incorporate this. Usually, rates need to be determined by calculation and modeling using phosphorus data derived directly from the lake and will vary depending on the product(s) used.

Table 12: List of common P-precipitates with common names and comments.

P-Precipitate	**Common/Vender Names**	**Comments**
Aluminum (Al^{3+})	Alum, aluminum hydroxide	Greatly impacts pH, may require buffer
Lanthanum (La^{3+})	Phoslock, EutroSORB	Large quantity may be necessary for results
Calcium (Ca^{3+})	Lime, quicklime, gypsum	Works best under high pH situations
Iron (Fe^{3+})	Ferric sulfate, ferric chloride	Need oxic (oxygen rich) conditions

One of the most common of the P-precipitates utilized is aluminum sulfate (Alum). Alum has a long track history of use since the 1960's with key instances of its use in Ohio including Dollar Lake and West Twin Lake, Kent (Cooke 1979) and Grand Lake St. Mary (Welch et al. 2017). Success has been documented in many instances utilizing a variety of different rates and with longevity lasting between 4 – 20 years (Welch and Cooke 1999). Despite the success track, monitoring pH is imperative to ensure a successful application will not cause potential unnecessary harm to aquatic organisms. Free aluminum will become toxic at pH levels below 4.6 – 5.3. Most natural lakes do not exhibit pH levels at or below this threshold, however the addition of alum tends to temporarily lower the pH of water bodies. This tendency forces the need to utilize a proper pH buffer to ensure safe application of the product. This will increase product costs. But if proper pH buffers are in place, the likelihood of unintended harm to the lake's environment is low.

Lanthanum based P-precipitates (typically lanthanum modified bentonite or LMB) encompass the next greatest category for use in surface waters. Since Development by CSIRO Australia in the 1990s (Douglas et al. 1990; Douglas et al. 2000), many lanthanum products are heavily marketed and available today by venders including Phoslock (Phoslock Environmental Technologies; PET) and EutroSORB (Eutrophix/SePRO). Most are compiled as a "proprietary blend" by the manufacturer with actual lanthanum concentrations ranging between 5 and 10% of the total solution. Only the manufacturer knows the total compilation of ingredients to create the blend. This usually means a higher quantity of material is necessary to accomplish full P-inactivation as the concentration of active ingredient is lower than non-blended products like alum. Despite this, the addition of vender technical support allows for a greater degree of "ease of use" for these products as rate modelling and application design are more standardized and fine-tuned. Additionally, lanthanum does not have the pH restrictions noted by other P-inactivation products making them a less risky option for environmental harm although some sources indicate a reduction in efficiency when pH exceeds 9 (Ross et al. 2008, Haghseresht et al. 2009). Due to the larger quantity of product necessary to achieve results, lanthanum can become more costly than other options. Regardless, the low risk/high reward nature of lanthanum products have made it a favorite for surface water nutrient mitigation projects in countries outside of the U.S. Case studies of LMB use in lakes have showcased reduction in cyanobacteria growth with alterations of phytoplankton assemblages to various mixed species including Loch Flemington (Meis 2012) and Laguna Niguel Lake, California (Bishop et al. 2014). Chlorophyll α concentrations were also found to have been reduced for multiple years in a field trial conducted on the Vasse River (Robb et al. 2003) demonstrating the potential long-term impact LMB P-inactivation can have in water body remediation efforts.

Although more uncommon, calcium and iron-based P-precipitates also deserve a spot for discussion. Calcium precipitates can include lime and gypsum, the latter of which is more commonly associated with improving pH buffering capacity while the latter may be used more commonly in industrial applications. For the purposes of surface water remediation, these products typically function as a P-precipitate better in high pH environments. Iron P-precipitates may generally include ferric sulfate and ferric chloride and require adequate oxygen to be effective at binding to P (see Iron trap description above).

P-inactivation would be one of few lake remediation techniques that has potential to provide long-term success (multiple years) while also targeting the root cause of nuisance growth in reservoir systems (P). Although this may seem like a “silver bullet” of sorts to primary productivity growth, it needs to be noted that P-inactivation primarily reduces the impact of in-lake P-loading and may have minimal impact on watershed inputs (unless P-interception via stream inputs were to be enacted). A full-scale P-budget would need to be conducted to fully address the P-load ratio between watershed inputs and in-lake inputs. This kind of assessment would go well beyond the data collected for the purpose of this report. Sediment P-fractioning data would be needed to determine labile vs. mobile forms of P and to fine-tune a P-inactivation rate. Costs associated with P-inactivation vary widely depending on the product used, rate determination, amount of pre-application sampling necessary, and labor needed. Many projects commonly exceed mid- to high- six figures but if properly conducted, the sustainability of the technique may be worth the expense.

Figure 38: A Phoslock application showing the cloud of precipitant and the specialized equipment commonly used (Photo credit: Derek Johnson).

Figure 39: A Phoslock application showing the cloud of precipitant suspended behind the application boat (Photo credit: Derek Johnson).

Biological techniques

Biologicals (bacteria & enzyme additions) – The use of bacterial or enzymatic additions for surface water applications is a relatively understudied area of Lake Management. The general goal behind their use varies depending on the product and vendor. Some products are meant to support the growth of bacterial species that will consume (decompose) organic material (i.e. muck) or provide a source of nutrient competition to algae growth. Some products claim to directly impact the chemical nature of nutrients or carbon, altering the processes involved in their cycling. Regardless, their successful use in achieving these goals is not well documented in literature. This may be because the processes that they are meant to influence are complex in nature with a large multitude of factors impacting their success or failure. For applications where the goal may be organic material decomposition, it is typically suggested to enhance the lake with oxygenation near the sediment layer to encourage aerobic decomposition vs. anaerobic (aerobic is a more efficient process).

Most biological products are readily available in granular, liquid, or “puck” form (in the case of some muck digesters) and are applied to surface waters in a similar capacity to aquatic herbicides and algaecides. Rates are determined through vendor suggestion and what is listed on the label (although some products may be applied under a notion of “apply as much as needed” suggesting there is no ceiling to application quantities). Most available products on the market do not go through the same rigorous testing process that herbicides and algaecides go through with the EPA and their long-term impact on the environment is currently unknown. Regardless, internal testing of muck degradation pellets by AQUA DOC did find an initial reduction of organic material when applied to a condensed 5-acre area of Hidden Harbour Lake near Toledo, OH. Although, testing in subsequent years did not see noteworthy results (Kwietniewski 2024). Additionally, when used on two small pond systems in Northeast Ohio and at heaviest rates suggested by the label, a nominal reduction in sediment quantity was found in these test ponds (Kwietniewski et al. 2018). In primary literature, Kindervater et al. found no change in bacterial composition when testing a vendor created muck digestion product on three lakes in Newaygo County, MI with no noted impact on organic matter decomposition either (Kindervater et al. 2022).

The use of bacterial additives and enzymes would not currently be suggested for Apple Valley Lake as a significant nutrient reduction or sediment reduction tool. This is due to the noted lack of consistent results with these products and lack of credible current third-party primary literature on their successful use. An argument can be made, however, to utilize these products as a maintenance tool once major projects have been completed (e.g. dredging, p-inactivation) to improve the longevity of these capital projects.

Mechanical techniques

Dredging – Sediment dredging involves the excavation of built-up organic material that accumulates at the bottom of lakes and reservoirs. Removal of this material deepens the lake, removes submersed plant growth media, and reduces internal nutrient concentrations (Cooke et al. 2005). In some instances, with shallow lakes or lakes with extensive shallow zones, Sediment-regenerated P can amount to a substantial portion of the total P-load (e.g. Linsley Pond, CT., Long Lake, Washington, Shagawa Lake, MN; Livingston and Boykin 1962, Welch et al. 1979, Larsen et al. 1981). In these type of systems, nutrient P-recycling may be reducible via export of nutrient rich sediments. Dredging is the only true way to “reverse” lake and reservoir succession by returning the basin to a previous deepened form. The technique itself can be accomplished through the draining of the water body in question and then removing sediment or through in-lake removal if draining is not possible or acceptable. When drawdown is possible, sediment may be dried prior to removal to allow for heavy equipment transport on the lakebed as well as allow for easier material removal. In-lake removal could require more specialized equipment including barges, hydraulic cutter heads or grab buckets, and piping for material transport. Costs associated with a dredging operation are highly variable but often extreme. This makes the use of the technique impractical for many lake associations who simply cannot afford the costs.

Dredging operations can negatively impact the local lake environment and awareness of the potential impacts should be noted. For in-lake dredging operations, there will be an expected increase in sediment turbidity beyond typical lake or reservoir conditions (Herbich and Brahme 1991). Depending on the scale of the operation, this turbidity could increase across the expanse of the system and could degrade water quality until the operation has been completed and settling occurs. This may happen even if silt curtains are constructed as part of the operation. Additionally, there can be noted impacts on non-target fauna and flora, particularly the macroinvertebrate population that resides within the benthos of the water body. A reduction in the macroinvertebrate community may reverberate throughout the food web, impacting higher trophic level organisms such as fish that prey upon benthic insects. Thankfully these negative consequences are usually temporary and benthic environmental stabilization typically can be expected within a few years of finishing the operation (Carline and Brynildson 1977). Dredging that follows drawdown may be more impactful on benthic fauna (Cooke et al. 2005).

In-lake dredging is a viable management technique on Apple Valley Lake and has been utilized at the northern section of the lake over the past three years. As a tool for sediment reduction, use of dredging will be needed as the lake experiences depth reduction from watershed sediment accumulation. Given the potential negative ramifications on the local benthic environment and water quality, it should be expected that the lake may experience a temporary regression in water quality and clarity. However, as mentioned above, environmental stabilization should be expected post-operation. It could be hypothesized that sediment disturbance during dredging could be a factor connected to the spring algae bloom of 2024 as disturbed sediment P could have become available for biological sequestering at the same time unusually warm spring temperatures were becoming prominent. However, this is merely a hypothesis as no information is available on water quality or nutrient changes pre- vs. post- dredging. Halting near-future dredging for a season may allow for observation of the impact the technique has been having on the lake in recent years. Regardless, dredging will need to be a component of future management decisions as the only currently effective way to reverse lake succession.

Discussion of Nutrient Management Techniques for Apple Valley Lake

Potential Management Options for 2025 and Beyond

As previously mentioned in this report, Apple Valley Lake was not impaired for its best categorical use as a recreational reservoir during the 2024 season. This simplifies a potential management direction for the community as intensive, short-term methods for primary productivity control can be argued as unnecessary at this time. Often lake management plans are deemed necessary for a lake community once conditions worsen to the point of direct impairment of the resource. Since this is not the case for Apple Valley Lake, long-term management options to reduce the impact of eutrophication, monitoring, and enactment of BMPs for sustainability should be investigated to maintain the reservoir's positive status. These last two items are discussed in the next chapter (VII). By working in a positive manner toward these three suggestions, nutrient reduction in Apple Valley Lake can be sustained and an extended timeline can be produced between future capital projects.

Of the five techniques listed in the assessment of viable in-lake nutrient control techniques above, only artificial circulation and bacterial/enzymatic additives would not be suggested for use in Apple Valley Lake unless specific management needs are demonstrated. For artificial circulation, there would need to be a desire to eliminate the hypolimnetic oxygen deficit in the lake which, although can be an issue for many water bodies, can be hypothesized as minimal concern for Apple Valley Lake's productivity values due to hypolimnetic withdrawal from the annual drawdown. In fact, as mentioned in its respective section above, the addition of artificial circulation via a BDA system may increase epilimnetic TP concentrations and may heighten the risk of future algae blooms. If removal of stratification was to become a future goal, additional reference conditions on the potential movement of P during mixing events should be collected before enactment to reduce risk. Bacterial additives are not suggested at this time if their intended use was to be utilized as a dredging replacement or impactful nutrient reducer on Apple Valley Lake. Again, as mentioned in its respective section above, this is due to limited primary literature case studies showcasing large-scale and temporal success of the products use vs. alternative methods. It could be suggested to utilize these products in a manner to maintain capital project success (e.g. dredging, P-inactivation) once those projects are completed. All management techniques reported above are summarized below in Table 13.

Table 13: Assessment of various management techniques for Apple Valley Lake to reduce in-lake nutrients.

Management Technique	Type	Details	Pros/Cons
Water Level Drawdown	Physical	Water release and refill can dilute nutrient enriched waters; sediment and biogeochemical alterations to bottom substrate can also impact P-concentrations in anoxic conditions.	Cost will be cheap to negligible (+), Ability to work on other aspects of lake while water is low (+), Risk to damage submersed plant community is high which works against potential future goals (-), Results will vary if incoming water is also nutrient enriched (-).
Artificial Circulation	Physical	Water circulation will prevent thermal stratification which will also prevent anoxic loss in the hypolimnion of dimictic reservoirs, deep water bodies can also make use of compensation point to reduce algae biomass.	Water circulation could have multiple positive effects on the lake beyond algae and nutrient control (+), Cost may be prohibitive (-), May increase cyanobacteria biomass in lake (-).
P-precipitants	Chemical	P-precipitants will sequester and precipitate biologically available P in the environment making it inert for algae growth. An additional quantity of product may be needed to reduce sediment derived P.	Directly combats the root cause of nuisance growth (P) with primary literature backing (+), Multiple years of success documented in some cases (+), Additional water quality data may be needed for proper dosing (-), costs may be high (-), Will

			decrease overall depth of lake(-).
Bacteria & Enzymes	Biological	Biological additions are marketed to reduce organic sediment concentrations in the lake or alter P-cycling processes in the lake.	Can be relatively cheap and easy to apply vs. other techniques listed (+), Not much literature to back up success of product (-), proprietary blends generate questions on what is in products (-).
Dredging	Mechanical	Direct removal of P-enriched sediment can reduce P-cycling into the lake which feeds cyanobacteria growth. Increasing water depth also allows for more incoming water to dilute the impact of P in-lake.	One of the only way to increase overall water depth and reverse succession (+), Long-lasting results typical so long as incoming water is low on sediment quantity and P (+), can be combined with drawdown (+), cost is typically massive (-), high amount of disturbance on lake during enactment (-).

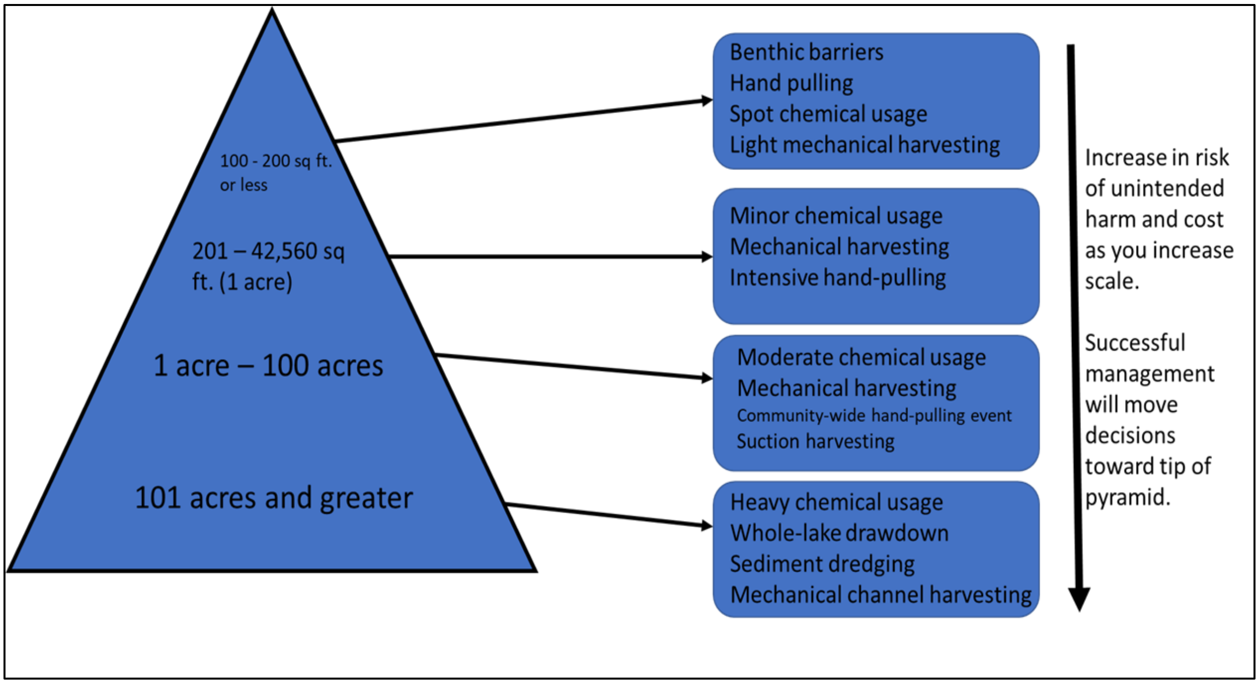


Figure 40: Diagram depicting how choices in management decisions can be altered in response to changes in target scale. Thinking in this manner may be one way to assist in making management choices. Note: pyramid includes vegetation management techniques but is conceptually important to algae or nutrient management as well.

VII. Beyond 2025: Long-Term Monitoring and Out-of-Lake Management

Introduction

Proper management of lakes and reservoirs requires adequate long-term data sets to properly define the water body in question, identify reference conditions, and develop realistic water quality thresholds. Without this information, management can become reliant on anecdotal observations from local stakeholders which, although important, can occasionally prove to be unreliable. Additionally, long-term data sets allow for a constant, critical reflection of management decisions. This elevated level of reflection over time supports dynamic planning and allows for lake managers to be dissuaded from the use of techniques that are proven inefficient on the system while supporting successful management practices with hard data. Long-term monitoring involves the consistent collection of relevant water quality information whether it be nutrient water samples, in-situ multi-parameter probe profiles, biological assessment studies, sediment analyses, and others. Although a generalized water quality monitoring program is adequate for most unimpaired bodies of water and for comparison of one system to another, individualized monitoring programs are preferred to assess lake or reservoir-specific issues or concerns.

Apple Valley Lake is a reservoir that benefits from local stakeholders who have a passion for collecting data and improving the lake's water quality. During the 2024 season, lake stakeholders accounted for all the presented historical data in this report. Although collection of some data may need to be standardized, continual collection of this information will be critical for ensuring Apple Valley Lake's management planning remains dynamic as described above. Included in this section is a review of how to construct a water quality monitoring program so that consistency in data collection can be achieved.

In addition to long-term monitoring of Apple Valley Lake, improving the sustainability and longevity of acceptable reservoir conditions warrant the suggestion to enact certain best management practices (BMPs) within the lake and watershed community. These BMPs can be thought of as behavioral changes that alter how the surrounding watershed is utilized which can reduce the impacts of cultural eutrophication over time. It is important to remember that water management goals require acceptable short-term management strategies to provide relief from a potential impaired use-status while simultaneously acting to pursue continual and realistic water quality threshold goals. Most of this report has thus far investigated only the in-lake solutions for nutrient management. This chapter is meant to provide the other side to holistic lake management: monitoring Apple Valley Lake and long-term watershed management.

Apple Valley Lake Monitoring

Monitoring programs that are used to collect data sets on lakes are broadly centered around the collection of physical, chemical, and biological parameters necessary for assessment of the water body. Within these categories are a large assortment of various pieces of information that need to be considered when attempting to complete the water quality monitoring puzzle. Many stakeholders mistakenly collect water quality information without knowledge of what they are collecting and why it is necessary to do so. This poses an issue as desired water quality information from the standpoint of drinking water from your kitchen sink will be far different from water quality information needed for recreational water body management purposes. Additionally, there is a need to understand the best categorical use of the water body being sampled. A drinking water reservoir for example would likely have more stringent acceptable water quality thresholds than a storm water retention basin. This is why it is important for thresholds to be determined based on the proper definition of the water body as well as with a determination of what may be considered typical data wise. These two points are examined through a simple observation of the primary uses of the water body in question (its best categorical use) in conjunction with a few years' worth (3 – 5) of monitoring data to begin determining trends in its data set. Although it may seem inefficient to need multiple years' worth of information to develop water quality goal thresholds, it is imperative to understand the typical water body conditions. Collecting a single year's worth of information during an unusual year for the lake may result in the incorrect assumption that the outlier year is typical of the system. This could lead to the creation of thresholds that are atypical of the water body and may drive poor management practices for the lake or reservoir. As more information is collected over time, thresholds can be altered and adjusted to reflect stronger data driven trends. It is also noteworthy to mention that this is meant to allow for comparison of the singular water body to itself overtime. Comparison of multiple water bodies would benefit from long-term, consistent data as well, but it can be useful to use a single year's worth of information when doing larger geographical analyses of different lakes and reservoirs for a given year.

Collecting and analyzing water quality information can be a daunting task for the average stakeholder who may lack the knowledge to understand how to interpret water quality data. This section will highlight important pieces of data to collect and attempt to simply explain their importance. Necessary tools to collect data are also described. Note that some of this information has been presented in Chapter III where physical and chemical data collected from Apple Valley Lake in 2024 was discussed.

In-situ multiprobe data

In-situ (collected within the water body) multiprobe data consists of information that is collected using a sampling sonde with probe(s) that can collect water quality information in real time. Most devices for water quality purposes have a sonde with a selection of desired probes that collect various parameters at once, cabling to drop the sonde at desired depths, and a readout interface. Many devices are handheld, but some can be attached to buoys for constant real-time data collection. This allows for quick and efficient data sampling and recording on a spatial scale (wherever in the lake or reservoir you want to sample) as well as vertical scale (at whatever depth you want to sample). In-situ multiprobes are an essential tool for the creation of depth profiles or the mapping of data from the surface of a body of water to the bottom. The ability to map this data allows a data collector or analyzer to watch for noticeable vertical alterations in collected data that can indicate the presence/absence of important physical, chemical, and biological changes in the water column. This can include temperature thresholds that define mixing characteristics and the likelihood for internal phosphorus release, heightened chlorophyll levels that may denote a below-surface algae bloom, and other characteristics depending on the probes installed on the sonde. It should be noted that some of the listed characteristics can be analyzed through collected water samples as well, but the use of a sonde provides near immediate value that increases efficiency and depth profile capability. Common multiparameter sonde data includes the following:

Temperature – physical characteristic that describes how hot or cold the water is. When collected as a depth profile, temperature trends can determine the location of the thermocline (if at all present), which allows one to determine if the body of water is experiencing thermal stratification. The presence of thermal stratification throughout the season allows for the estimation of the lake or reservoirs mixing regime (how many times does the lake turnover if at all). This is important when considering a stratified lake can alter benthic sediment chemistry and result in internal release of phosphorus (one of the leading nutrients that drive nuisance growth in lakes and reservoirs). This allows lake managers to determine if internal nutrient reduction is a necessary action vs external watershed reduction (or both). Temperature information is also important to consider for organism habitat requirements. The most notable example of this are the various species of fish that can live in a lake or reservoir environment which can be categorized by their thermal habitat requirements: warm-water, cool-water, and cold-water. Cold-water species such as trout for example, cannot typically survive in lakes or reservoirs that have thermal qualities that only support warm-water species. The thermal qualities of a lake or reservoir will change depending on the local climate as well as the thermal conditions of incoming water from the watershed. Water is most dense at 39.2°F (3.98°C) which allows for frozen water to become buoyant when ambient air temperatures reach freezing levels.

Dissolved oxygen (DO) – DO is one of the most critical pieces of information to collect on a lake or reservoir for its importance to the survival of gilled organisms as well as its potential to alter redox reactions (oxidation-reduction reactions). When collected as a depth profile, data collectors can observe whether the lake or reservoir has a hypoxic (low oxygen) condition or anoxic (no oxygen) condition. Oxygen loss is typically seen from the bottom of a water body and moves upward in the water column and anoxic conditions are one of the drivers for internal nutrient release from bottom sediments (oxygen loss can match thermal density changes). DO levels fluctuate based on the mixing regime of the lake or reservoir, amount of photosynthetic activity vs. respiration, and the flushing rate of the water body (particularly if oxygen rich water is entering the system). It should also be noted that a loss in DO should be expected at night when no photosynthetic activity is occurring usually resulting in the lowest DO concentrations occurring just before sunrise. Although DO concentration requirements vary from one organism to another, desired concentrations above 3.0 mg/L are often a minimum suggestion. Concentrations between 3.0 and 10.0 mg/L can be typical but again, will vary from one water body to another. DO can be reported in mg/L (direct concentration of DO) or as a percent saturation (amount of DO that the water is holding vs can hold based on temperature, colder water can hold more DO). Reporting the concentration (mg/L) is more common for threshold development.

pH – a water body's pH is the measured ratio of H^+ ions to OH^- ions. This ratio is related to a singular number that corresponds to a scale ranging from 0 to 14. Numbers below seven are acidic while numbers above seven are considered alkaline (basic). Seven itself is neutral. pH values that fall outside of acceptable ranges for aquatic organism survival may experience "dead lake" scenarios where biological life cannot be supported by the water body, but individual pH ranges can vary. Natural pH ranges for a body of water are highly dependent on the local geography surrounding the lake or reservoir, the amount of photosynthetic activity that can push pH to alkaline conditions, and acid deposition from rainwater or other sources among other factors. pH is also related to alkalinity or the buffering capacity of water (measured in $CaCO_3$ content) which affects how well a water body can resist pH changes. Lakes and reservoirs with low alkalinities may be more susceptible to acid rain or acidic deposition which is a common issue for mountain region lakes and reservoirs that exist in rocky geographical locations with little in pH buffering soils. Most lakes and reservoirs in Ohio do not need to be concerned with this as much of the state has rich, adequate soil for pH buffering.

Conductivity – conductivity is a measurement of the ease at which electrical current can pass through water, which is obtained by determining the quantity of ions present in the water at the point of sampling. It is a useful tool to give a rough account of water hardness as harder waters will express higher conductivity values. Perhaps more useful for many lake managers is its ability to demonstrate enhanced impact from inlet erosion materials that can severely impact conductivity levels for a short period of time especially from the addition of road salts during the winter. Conductivity is measured in µmho/cm or µs/cm (micromhos per centimeter and microSiemens per centimeter, respectively) and usually stays consistent throughout the year unless there is an influx in materials entering the water body.

Oxidation-reduction potential (ORP) – ORP describes whether chemical reactions are moving toward an oxidative state (positive higher values) or reduced state (negative lower values). Collected in millivolts (mV), ORP can estimate the likelihood of certain chemical reactions occurring and whether certain waste materials may be produced due to reaction changes in the water. This information typically coincides with DO levels and temperature readings to better determine the potential strength of internal phosphorus release. Very low ORP levels may indicate that anoxia has been present for some time and that high amounts of phosphorus release may have been occurring (which can then be confirmed with P sampling). Many lake managers also utilize ORP to track potential pollutants that may be hypothesized to be present in a water body if they are redox reactive. This may be more useful in wastewater discharge situations, however as prior knowledge or assumption of a pollutant being discharged needs to be known as ORP cannot determine what pollutant is present.

Chlorophyll α – chlorophyll α is one of the dominant pigments found in photosynthetic organisms. Collection of chlorophyll α data can be an excellent estimator to the quantity of algae growth at the sampling site. Collected as a depth profile, elevated quantities can also determine where built up algae growth is present as algal varieties such as cyanobacteria, can move up and down the water column to preferred depths for survival. Chlorophyll α is also one of the three (Chlorophyll α, Secchi transparency, and P concentrations) indicators to help describe a waterbodies productivity which is essential to defining excessive growth likelihoods and estimating lake or reservoir identity behaviors. Chlorophyll α levels that range between 8 – 10+ ug/L are more indicative of productive (more growth) systems that are pushing to elevated levels of eutrophy. Levels below eight start to show signs of less productivity (less growth) that may be considered mesotrophic or oligotrophic water body. Chlorophyll α is also commonly collected via water samples and is reported the same.

Water Sample Data

Many lake stakeholders hold the belief that collecting a sample of surface water in a bottle laying around their home is sufficient to analyze an incredible amount of information. Although the initiative of an individual who collects samples to analyze the water quality of a water body is commended, procedures for water sample collection can be more complicated. It is important to know what analysis needs to be conducted as some laboratories may require preservatives, darkened bottles, or other conditions to be met prior to conducting any lab tests. Additionally, how the sample is collected is equally as important as most surface water samples should be collected as a “grab sample” (at elbow depth) to reduce bias that may come from skimming material off the waters’ surface. Collecting samples beyond surface level may require the use of a specialized sampling device called a Kemmerer tube which allows for the sampler to collect water samples at various desired depths. Most lake stakeholders and even private firms do not have onsite laboratories to analyze water samples and as such, utilize third party labs to test and report water sample findings. It is important to follow the procedures given by these laboratories to ensure water samples arrive in an acceptable condition for analysis. Usually this entails storing water samples on ice or in coolers as well as shipping samples overnight if necessary. Sample bottles are typically provided by these labs as well. The following are commonly collected:

Nutrient Information (Phosphorus and Nitrogen) – Nutrient concentration data is incredibly important for the assessment of a lake or reservoir system. Phosphorus (which can be broken into organic and inorganic sampled varieties) is considered a limiting nutrient found in aquatic systems. This means that small quantities of added phosphorus can have a substantial impact on algae and macrophyte growth in a lake or reservoir system. Most stakeholders use total phosphorus (TP; ug/L; includes organic and inorganic varieties) concentrations for analysis purposes but collection of other varieties can be useful for a more integrated nutrient budget of the water body. TP is also one of the three (Chlorophyll α, Secchi transparency, and TP) indicators to help describe a waterbodies productivity which is essential to defining excessive growth likelihoods and estimating lake or reservoir identity behaviors. Levels above 20 ug/L are more indicative of productive (more growth) systems that are pushing to elevated levels of eutrophy. Levels below 20 start to show signs of less productivity (less growth) that may be considered mesotrophic or oligotrophic. Elevated concentrations of TP may correlate with internal loading, excessive runoff from the watershed, lack of adequate nutrient reduction best management practices by shoreline homeowners, and many other sources.

Although typically given a “back seat” to phosphorus, nitrogen can also function as a limiting nutrient that contributes to aquatic plant and algae growth. Also, similarly to phosphorus different species of nitrogen can be collected based off what is desired by the data collector. Total Kjeldahl nitrogen (TKN; mg/L) includes all organic forms that may be utilized by biological functioning as well as ammonia and is likely the most commonly collected by typical stakeholders to assess nitrogen quantities. Nitrate and Nitrite are collected as one unit and include inorganic and organic forms of nitrogen that can be used for biological processes. Ammonia is also commonly collected but more so to assess its potential as a fish toxicant. This is only typically an issue under anoxic conditions as ammonia will build up under exceptionally low ORP values where stratification is present. Nitrogen is not commonly used to define lake productivity like TP is, but excessive levels can contribute to greater macrophyte and algal growth.

E.coli/F. coliforms – E.coli and fecal coliform sampling is conducted when there exists concerns of elevated levels that may lead to human health complications. Collection of one over the other is simply a decision of how specific the collector wants to be as *E. coli* is a component of fecal coliforms. Regardless, the collection of *E. coli* or fecal coliform samples are typically reserved for high contact recreational use areas like beaches and other swim zones where exposure can result in illness. Most states have recommended standards that possess safe concentration thresholds with Ohio suggesting an *E. coli* threshold of 235 colony forming units (CFUs) as its risk threshold (ODH 2024). An advisory is posted over recreational zones if levels exceed this threshold until additional sampling suggests otherwise. *E. coli* and coliform levels fluctuate highly as much as hour to hour depending on a variety of conditions from heightened runoff potential to waterfowl presence. This means reoccurring samples are highly recommended throughout a recreational use season. Sampling of *E. coli* or coliforms occurs through standard “grab samples” (described above) and need to be delivered to a proper laboratory quickly (usually within 6 – 7 hours) for proper incubation of the sample to occur.

Microcystin (HAB monitoring) - Microcystin is a known toxin that is produced by the cyanobacteria *Microcystis.* Although not the only cyanobacteria to produce toxins, Microcystis may be considered one of the more common varieties. The sampling of its toxin is a general component of beach safety monitoring across Ohio. Elevated levels (beyond 8 µg/L) can be considered harmful to human health. All cyanobacteria have the potential to produce various toxicants that can impact liver function, neurological functions, or damage the skin. Sampling is typically conducted when a visual cyanobacteria bloom is noticed as toxin level is thought to increase with algal density. A visual bloom does not always indicate the presence of toxins however, as it is not fully understood why cyanobacteria produce these toxins nor what triggers their release. Microcystin and *E. coli* sampling together are a common component of contact recreation safety procedures and account for most beach or even lake/reservoir advisories. Sampling procedures for Ohio waterways is outlined in state’s HAB response strategies.

Other Pieces of Data

Since every lake and reservoir is different from one another, it may be critical to lake management goals to collect other pieces of data. What has been listed thus far includes some of the common water quality parameters for general water quality threshold development and lake or reservoir behavior identification. Further collected information can be related to direct goals including biological surveys for organism management, sediment surveys, and watershed data collection and mapping. Some of these procedures (i.e. sediment data and watershed mapping) have been covered in previous chapters.

Creating a Monitoring program for Apple Valley Lake

What should be sampled? - The creation of a monitoring program for Apple Valley Lake should include the collection of standard water quality information such as depth profiles for temperature, DO, pH, and ORP. Nutrient information should also be included for analysis and involve TP as well as TKN concentrations as “grab samples” at the surface and near the bottom of the sampling sites. Data involving human health concerns such as *E. coli* and microcystin concentrations shall continue to be collected in areas where contact recreation is common (and when a cyanobacteria bloom is noted with regards to microcystin per the 2020 State of Ohio Harmful Algal Bloom (HAB) Recreational Response protocol). This information should be the standard for monitoring purposes for typical water quality parameters. As management needs and concerns change, the addition of more sampling procedures may need to be included.

Who should monitor? – lake and reservoir monitoring can be conducted by a wide array of different individuals, groups, or agencies. Many lake associations may collect data internally but usually this is limited in scope and disorganized. Lake stakeholders may opt to hire a professional lake management company to monitor their waters, but this can prove to be costly which may limit the scope of what is feasible to collect as the cost becomes a burden to the association. Costs can be alleviated using a citizen’s monitoring program. Citizen’s monitoring incorporates the community into the active management of their lake or reservoir system. Typically, enthusiastic community members are brought together and trained in the procedures associated with data collection on their respective system. Once trained, they themselves are tasked with the collection of relevant information and in some cases, the analysis as well. Community monitoring programs save in monitoring costs by cutting out the middleman associated with data collection. Additionally, community engagement increases “lake-mindedness” allowing for more individuals to be educated on how their particular lake or reservoir functions. This may allow for greater community support once management decisions are formally decided as there will be a greater understanding of why those respective decisions were made. The added community engagement also allows for more frequent sampling dates as individuals typically live directly on the water body. This can allow for a better track of data trends over time, strengthening its assumptions. However, individuals must be well trained to correctly collect relevant information as improper collection procedures could produce biased or incorrect data. Consistency is also important for proper data analysis. With the presence of many enthusiastic individuals on Apple Valley Lake, there would be no problem with finding community members who would like to be involved. The use of professional companies or groups to monitor the lake until a citizen’s monitoring program can be developed is a feasible response. A template for a citizen monitoring training course is included in Appendix I of this report.

Where should monitoring occur? – Choosing a location or locations to sample varies from one system to another and depends on the goals of monitoring as well as what is being monitored. For example, if one was attempting to assess how in-lake nutrient concentrations were impacted by inlet additions, one may want to sample at the mouth of the inlet for normal flow nutrient concentrations as well as post-precipitation nutrient concentrations. Information regarding the inlet flow at these times would also be critical as there would be a hypothetical constant influx of incoming nutrients that should be reported as a rate. Another example could be assessing DO level alterations from a herbicide application. One may need to determine pre-application DO conditions and compare them to various post-application conditions to track changes and monitor for acceptable threshold levels. This would have to be conducted within the treatment zone. In both examples, the location, collected information, and timing of data collection is important to successfully accomplish the goals of monitoring. For general monitoring purposes however, sample at a) the deepest point of the water body as it will be the most data-inclusive and best represent the lake or reservoir and b) wherever the data collector believes there may be a sampling location necessary for the best possible monitoring of the individual system. In the case of Apple Valley Lake, which has a variable morphometry due to it being a reservoir and a long fetch, multiple locations will likely be needed to best collect relevant data. One location should be the deepest known point while the others can be spread out to other areas of concern where there may be importance in collected data. Location specific data such as those described in the examples above or for human health reasons should focus on the areas where the respective data is needed (e.g. beaches for contact safety sampling).

When should monitoring occur? – Data collection that has established direct goals should occur with the completion of said goals in mind. HAB monitoring with microcystin sampling should occur when a visual bloom is noticed for example. For general monitoring, however, consistency is needed for success. Many plans utilize a monitoring schedule that is different from one water body to the next but at a minimum, it may be suggested to monitor monthly. However, biweekly is better than monthly, and weekly is better than biweekly.

Developing realistic water quality thresholds

Once a monitoring program has been enacted and long-term data becomes available, the creation of individual water quality thresholds can be developed. It should be mentioned that the development of management thresholds can be arbitrary at times as differences for the uses for water, the agencies that manage and regulate water, and individual community perspectives can all lead to the development of different acceptable parameter thresholds based on their individual goals. It would be wise to try and unify these different threshold development pressures for both consistency and to avoid confusion. Proper thresholds should be realistic to the typical and acceptable conditions of the water body in question. This again, is why it is important to ensure adequate data over an acceptable span of time is collected as “typical” conditions can vary from year to year. Long-term data sets allow for the observation of trends that allow for the proper denotation of what may be considered “typical”. Once thresholds have been developed, management of the water body can be more streamlined to allow for the acquisition and distribution of resources to the improvement of those parameters that need it.

Long-term Watershed Management Concepts: BMPs

Along with long-term monitoring, sustainable management practices that go well beyond the 2025 season should be considered in order to maintain acceptable conditions while actively improving and/or maintaining water quality. Most of the techniques highlighted in this report can be considered In-lake solutions to reduce the nutrient concentrations of Apple Valley Lake. What many of these techniques do not accomplish however, is a reduction in watershed nutrient loading that becomes the basis for slowed anthropogenic eutrophication. In-lake nutrient reduction strategies have already been discussed in this report (P-inactivation, drawdown/flushing, aeration). However, whereas in-lake techniques may vary in success and may or may-not be suggested for differing reservoirs, the enactment of best management practices (BMPs) is typically suggested for all bodies of water to reduce nutrient impact over a long period of time. BMPs are actions that various stakeholders can take to reduce their individual impact footprint on a lake or reservoir and can be broken up into several distinct categories from shoreline homeowner BMPs to agricultural BMPs. Many BMPs reduce nutrient loading into a water body directly or slow down the path nutrients take to the water body. Table XXX lists many common BMPs that are utilized by different constituents to help alleviate nutrient loading into bodies of water.

Table 14: List of some common best management practices (BMPs) that can be enacted on Apple Valley Lake and its watershed.

Shoreline Homeowners	Construction	Agricultural	Other
Use reduced or no-P fertilizer	Use silt fencing on slopes where necessary	Ensure vegetated buffer strips are used to protect riverine systems	Allow for "greenways" to persist to sequester nutrients before they reach the lake
Ensure septic systems are up to date if applicable	Cover or stabilize barren soils	Enact fertilizer management practices	Follow wake zone rules to reduce erosion
Allow for a vegetated buffer strip to exist on your shoreline	Build sedimentation basins if necessary	Consider contour farming	Construct rain gardens to take in water before it reaches the lake
Consider using permeable surfaces when possible	Install swales in ditches	Enact crop rotation practices	
Conserve water usage as much as possible		Reduce livestock waste movement into moving waters	

Long-Term Watershed Management Concepts: Prevention

The cheapest and easiest way to ensure nuisance growth has as minimal of an impact on a body of water as possible is to prevent the nuisance from ever arriving in the first place. Although Apple Valley Lake is a private reservoir with restrictions on who has access to it, the presence of invasive species in surrounding waterbodies including Eurasian watermilfoil (*Myriophyllum spicatum*), curly-leaf pondweed (*Potemogeton crispus*), zebra mussels *(Dressenia polymorpha*), and others still warrant the need to discuss invasive species prevention. These invading organisms are not a historical component of the reservoir environment and can be introduced into Apple Valley Lake from a wide assortment of possible vectors (e.g. boat traffic, bait buckets, aquarium trade, inlet transport from upstream locations, etc.). Although it is difficult to determine if any of these invaders will be introduced, common prevention tactics will assist in avoiding the introduction of these unestablished invaders. Some states have established prevention tactics as regulations such as New York where it is unlawful to transport known invasive species and "reasonable precautions" need to be taken to prevent aquatic invasive species (AIS) spread (AIS; 6 NYCRR Part 576). Some communities also restrict invasive organism spread into their own systems by enforcing access to private recreational waterbodies and educating their communities on AIS (which Apple Valley Lake already does). The following are some additional considerations for AIS prevention:

- Clean, drain, and dry boats after use on any body of water. Especially if there is intent to move to another body of water.
- Pull aquatic plants off trailers when they exit the water body for the day.
- Adequately dispose of any bait that was brought onto the body of water. Dispose far offsite where there is little to no risk of introduction to a non-native environment.
- Clean fishing or boating gear that may have been exposed to potential invaders.
- Have a boat inspection program that ensures boats entering the system are clean of AIS and can turn away those that fail inspections.
- Put up signs to educate potential lake-users of the risks associated with AIS.

By enacting preventative measures to inhibit invasion by non-native species, the costs associated with potential management can be severely reduced (Figure 43; Ahmed et al. 2022). This in conjunction with local awareness of AIS, early detection through observations and monitoring, and rapid response to new invasions can improve the efficacy and reduce the cost to contain or even eradicate potential future invaders.

Enactment of prevention techniques have resulted in the creation of inspection and wash stations at public launch points in lakes across the United States (e.g. Tenmile Lake, OR, Otsego Lake, NY, Lake Mead, AZ). These stations may collect a fee from an operator who conducts the inspection and can clean boats if necessary. In some instances, these operators are given the power to turn away inspection failing boats (Otsego Lake; Horvath 2008). The fee can offset the cost associated with enacting the preventative technique (averages $30,000 per year at Otsego Lake, 2008 values). Heated power washers can be utilized where applicable and where temperatures of 60°C are possible and suggested to result in 100% mortality of invasive plants, mussels, and various insects (Mohit et al. 2021). Wash stations and inspectors positioned at public locations could be a means to reduce new incoming AIS into Apple Valley Lake although the costs for construction and maintenance may be high.

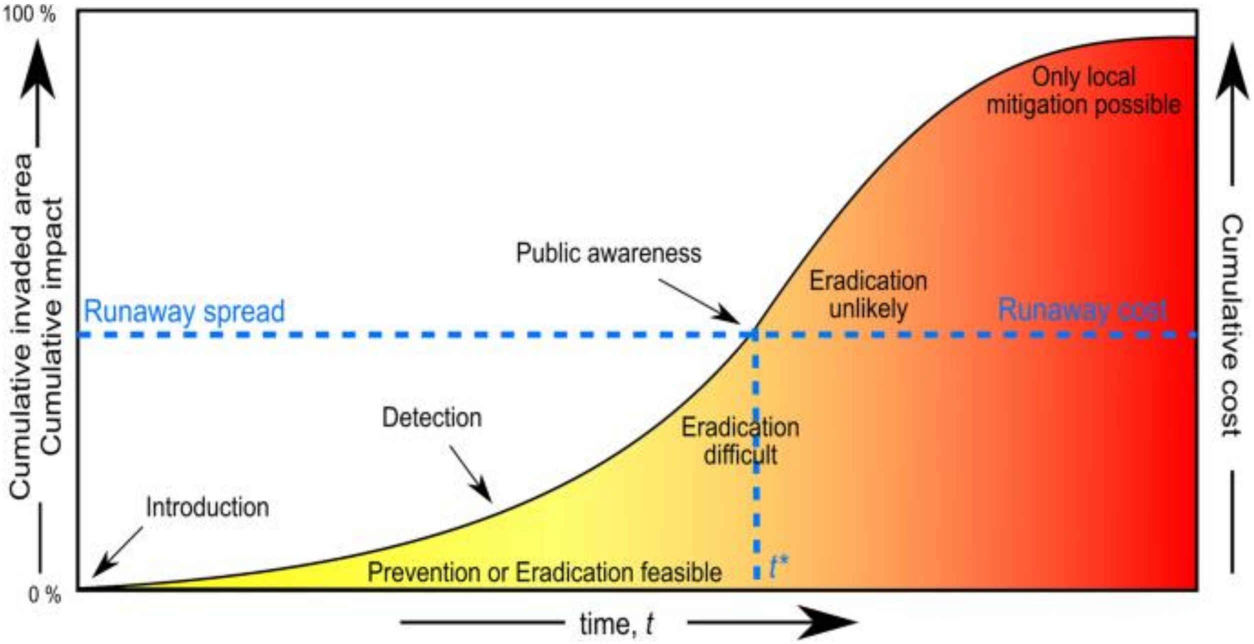


Figure 41: Generalized invasion curve depicting the relationship between costs, feasibility of eradication, and area of impact of an invader over time (Ahmed et al. 2022).

VIII. Lake Monitoring and Sustainability Plan (LMSP)

Directives

With the reservoir's first noted major algae bloom in recent years coinciding with an observed reduction of submerged aquatic vegetation (SAV) during the 2024 season, stakeholder concerns regarding the sustainability of Apple Valley Lake and its stable state are understandable. However, information collected during the 2024 season does not suggest the need for aggressive in-lake management strategies as the lake showcased natural recovery in the form of reduced water column chlorophyll α and a late increase in macrophyte growth. As such, Apple Valley Lake was not impaired for its best categorical use during the 2024 season. Due to this, actions that improve the sustainability of the resource with an updated monitoring program are suggested as the primary action items going into the 2025 season. This is contrary to many lakes and reservoirs in Ohio that are eutrophic in nature and require more immediate and aggressive implemented management strategies. Therefore, a "Lake Monitoring and Sustainability Plan" seems more appropriate for Apple Valley Lake than a traditional "Lake Management Plan". The information and procedures presented in this section of the "Apple Valley Lake State of the Lake Report and Monitoring/Sustainability Plan" (referred to as the LMSP) are meant to act as a guide to assist the local lake community with these goals and to reduce the likelihood of an impaired status in future years. For the purpose of this plan, "impaired" is defined by the inability of Apple Valley Lake to provide its best categorical activities as a contact-recreation water body. Based on the noted concern above and the information presented within this report, it is suggested that the following be priorities for a dynamic approach to sustaining Apple Valley Lake's condition (in order and described in more detail below):

1) An overhaul of Apple Valley Lake's current water quality monitoring program to generate additional reference conditions, monitor the health of the system, and have a necessary tool to gauge management success should future management decisions be enacted (**primary item to start in 2025 and beyond**).
    a. Water quality monitoring described in detail in Chapter VII of the State of the Lake Report.
2) Work with watershed constituents and groups to assist in the enactment of watershed best management practices (BMPs) to help reduce watershed nutrient inputs, namely phosphorus (P; **primary item to start in 2025 and beyond**).
    a. BMPs described in Chapter VII of the State of the Lake Report.
3) Consider incorporating in-lake P-reducing techniques to supplement watershed BMPs especially if a trend of increasing P values and movement of productivity index values toward eutrophic conditions (high productivity) are confirmed through lake monitoring in subsequent years (**secondary item for future consideration**).

As the primary governing body of Apple Valley Lake, The Apple Valley Property Owner's Association (AVPOA) should become the final decision maker for any management directives that involve the reservoir and these priorities. However, given the scale of the reservoir a strong community influence in the overall decision-making process should be expected and all respective stakeholder groups and organizations should be involved in the process. There are multiple individuals within the local Apple Valley Lake area who show a level of passion and capability to assist with the goals and direction of this management plan. These individuals (who may be referred to as "local champions") should work in a positive and collaborative nature with the primary decision-making body, other lake constituents, as well as relevant government officials (e.g. ODNR, EPA, local non-profit entities) to ensure the overall goal of social sustainable well-being of Apple Valley Lake and its community are achieved.

Understanding the 3-legged Stool of Lake Management

For any positive management direction to occur in Apple Valley Lake decisions must be made that incorporate the lake's environment, social components, and financial capabilities (Figure 42). These three components work like the legs on a 3-legged stool whereas, the instability or failure of one component will cause the complete collapse of the whole stool (successful lake management). It is important to consider all three (3) of these components when making a sound management decision. If a lake management technique cannot be supported by the environment of the lake due to bathymetry, chemical, physical, and biological factors, or other biogeochemical components, then those techniques may not be suitable for enactment. If a lake management technique is not socially acceptable to the community at large due to community philosophy or inherent risk, then those techniques may not be suitable for enactment. If the costs of management techniques are greatly out of reach budgetarily, then those techniques may not be suitable for enactment. Time must be taken through community hearings and meetings to establish a community identity and ensure these principles involved with the 3-legged stool are grounded so that the overall LMSP has the highest potential for success.

Introduction

This section of the LMSP is meant to highlight information from 2024 data collection as well as historical data to describe the current condition of Apple Valley Lake and help to develop reference conditions to build off. As this is one of the first plans of its kind for Apple Valley Lake, and water quality data regarding reference conditions are limited, it is imperative that comprehensive monitoring continue into the foreseeable future and this plan be updated on an annual basis as new information is collected (Priority 1 above). This way this plan can become a dynamic component of future management decisions and change as new information and perspectives appear. The groundwork for a citizens monitoring training program is included with “Appendix K” of this report. Additionally, a glossary of terms that may be helpful for those reading through this document are available in “Appendix J”.

2024 Relevant Monitoring Information Summarized

To characterize Apple Valley Lake and identify key components of its behavior for future management purposes, key chemical, physical, and biological properties of the lake were assessed through four visits on June 20, July 19, August 22, and October 2, 2024, and compiled with historical data collected by local stakeholders. Data collected on sampling dates consisted of in-situ chemical and physical depth profiles, nutrient grab samples, and a lake mapping survey during the August sampling date. This, compiled with additional in-situ data collected by local stakeholders (DO profile information, nutrient data, and Secchi transparency) allowed for a comprehensive look at Apple Valley Lake throughout the 2024 use-season with some historical context.

Collected data from the 2024 season identified Apple Valley Lake as a heavily stratified, mesotrophic system with occasional eutrophic or oligotrophic productivity values at given times. The stratified designation is based off thermal and oxygen patterns noted throughout the lake season where a distinct thermocline was noted at every sampling date with an anoxic hypolimnion below it. The mesotrophic productivity designation is derived from phosphorus, Secchi transparency, and chlorophyll α data that, when calculated through Carlson Trophic Status Index (Carlson 1977), showcased mesotrophic designation dominance in Secchi transparency, mesotrophic to eutrophic phosphorus concentrations, and chlorophyll α derived mesotrophic to oligotrophic values. Nutrient concentrations were not notably different from historical values (2024 mean 0.035 mg/L with historical data showing most samples below 0.05 mg/L) however, it should be noted that historical total phosphorus (TP) values were collected and analyzed utilizing a method with a much less stringent detectable limits than 2024 collected data making fine comparison difficult. Submersed aquatic vegetation (SAV) mapping did showcase the presence of SAV in select locations around the lake but this only amounted to approximately 6.8% of the surface area of the entire reservoir. Additionally, within the noted 6.8%, only 17.3% of the water column was occupied with SAV. This suggests that SAV growth in Apple Valley Lake encompassed a low percentage of the suggested littoral zone (area where plants can grow) and was low within the water column. Investigatory rake sampling within zones with noted SAV growth that included naiad (*Najas*) and pondweed (*Potamogeton*) species which was to be expected due to their ability to tolerate water level drawdowns.

It is hypothesized that the lack of SAV in Apple Valley Lake during the 2024 sampling season may involve the early-season algae bloom limiting nutrient availability and restricting the littoral zone causing plant growth to be retarded later into the season. Additionally, the low-laying plant growth may be attributed to naiads which typically grow in the lake in the later months and does not encompass a large quantity of the water column due to its short, “bushy” appearance. As there is little pre-algae bloom sampling data available, information supporting this hypothesis is minimal beyond a noted increase in SAV later in the lake season post-algae bloom (August) and confirmation of naiad growth with rake tosses. However, observing SAV growth patterns into 2025 can confirm if plant growth continues to recover as it appeared to at the end of 2024.

2024 Management Overview Summarized

During the 2024 season, dredging of the northern-most section of the lake was being conducted in the spring to alleviate sedimentation from the primary inlet. This operation was put on hold by the time sampling occurred in June. Shoreline herbicide applications were also conducted throughout the season by AQUA DOC: Lake and Pond Management to shoreline homeowners who wished to purchase the service privately. Applications occurred on June 3, July 16, and August 13, 2024, and incorporated less than 2% of the total lake area. No large-scale management strategies (whole - lake) were implemented other than the annual lake winter water level drawdown.

Apple Valley Lake Monitoring Suggested Standard Operating Procedure (SOP)

The following information is the suggested standard operating procedure (SOP) for water quality monitoring in Apple Valley Lake. Chapter VII, in the main body of the State of the Lake Report describes water quality monitoring in great detail and specifics on sampling procedures for each of the points listed below can be found there. As lake monitoring is a dynamic component of holistic lake management, the suggested SOP below should also be dynamic to accommodate any additional sampling that may need to occur if lake conditions change (e.g. collect microcystin data during a confirmed HAB, fisheries data if fish concerns develop, etc.). With this in mind, the following suggestions are organized with annual, continual water quality data being listed as “CRITICAL” and supplemental data for specifics regarding 2024 concerns or potential future concerns listed as “SUPPLEMENTAL”. The information presented here assists with priority one listed under the directives of this plan.

1) ***Collect relevant depth profile information at the deepest known point of the lake for maximum vertical information (CRITICAL).***
    a. At the deepest known point of the lake, in-situ profile information including temperature, dissolved oxygen (DO), pH, and chlorophyll α should be collected at least every 2.0 ft from surface to bottom (or as deep as possible beyond the thermocline) to identify stratification behaviors, DO loss, and algae bloom locations (if a bloom is occurring).

b. Collection of in-situ profile data in 2024 showcased matching spatial data patterns across the lake. This means profile data beyond the deepest point may be unnecessary but encouraged for thoroughness. Follow the locations presented in Figure 9 (Chapter III) for repeatability if this is the case.

c. As a substitute for handheld devices, a buoy system can also be implemented at the deepest point of the lake. A buoy system with telematic capabilities would be able to provide immediate data availability displayed on a hub accessible from a personal computer (no need to send someone out in the field) but at an elevated cost with limitations on vertical data availability (i.e. you would only receive data where probes were placed in the water column). Despite this limitation, daily accessible data is a substantial benefit over monthly or biweekly profile collection as the amount of consistent information is typically greater than what can be achieved with a handheld device.

d. TP (below), surface chlorophyll α, and Secchi transparency (below) should be converted into/ analyzed as Carlson's TSI per methods in Chapter III of the State of the Lake Report.

2) ***Collect relevant depth profile information should be supplemented with nutrient water grab samples (CRITICAL).***

a. Nutrient data (total phosphorus; TP and nitrogen species; total Kjeldahl nitrogen [TKN] suggested) should supplement depth profile information at the deepest point of the lake. A grab sample should be collected at the surface to estimate epilimnion nutrient concentrations as well as in the hypolimnion (bottom; at least 2.0 ft above the absolute bottom). A Kemmerer or Van Dorn sampling device will be needed to accomplish this.

b. As 2024 nutrient data varied spatially, it may be suggested to collect TP and TKN information in the same locations showcased in Figure 20 (Chapter III) to observe how nutrient data changes as one travels from the inlet to the dam. Hypolimnetic sampling would be unnecessary beyond the deep point.

c. Grab samples will need to be delivered to a certified laboratory for analysis. This may mean shipping of samples will need to occur. If this is the case, it is important to properly prepare the sample for shipping by properly labelling the water sample per lab procedures and cooling the sample which can be accomplished by adding an activated cold pack to the package just prior to shipping.

d. TP, surface chlorophyll α, and Secchi transparency (below) should be converted into Carlson's TSI per methods in Chapter III of the State of the Lake Report.

3) ***Collect Secchi transparency at locations surface nutrient data is collected (CRITICAL).***

a. Collect Secchi transparency at the same locations as surface TP/TKN sampling as Secchi transparency displayed spatial variability during 2024 sampling.

   b. TP, surface chlorophyll α, and Secchi transparency should be converted into/ analyzed as Carlson's TSI per methods in Chapter III of the State of the Lake Report.

4) ***Collect E. coli samples at beach/primary recreational location on a minimum monthly basis to ensure contact recreation safety (CRITICAL).***
   a. Utilizing grab sample procedures (Chapter VII) collect *E.coli* samples at least monthly to confirm concentrations are below suggested Ohio Health Department thresholds (235 colony forming units; CFUs; ODH 2024). Samples should be collected at high contact recreational use areas (beaches, swim zones, etc.)
   b. Should concentrations exceed the threshold listed above, a notice of elevated human health risk should be made to the community at large for the area sampled and closure of the area suggested. Repeated sampling should occur daily or bidaily until concentrations are below the risk threshold. Once this has been confirmed, the elevated risk notice should be lifted.

5) ***If a confirmed HAB occurs, microcystin toxin sampling should be prioritized in the area of the bloom to determine risk to contact recreation (CRITICAL; SITUATIONAL).***
   a. Community members should be educated on identification of HABs ("Appendix K"). If one is confirmed, a microcystin assay water sample should be collected to assess human health risk via grab sample (Chapter VII). Samples displaying a concentration above 8.0 µg/L should be considered unsafe for contact recreational activities.
   b. When a confirmed HAB is present, primary contact recreation areas where algae mass is present should be immediately shut down until microcystin samples demonstrate safe toxin concentrations. Short-term management strategies such as algaecide usage may become necessary to lower algae biomass. Once biomass is reduced, sampling should be redone to confirm toxin reduction.

6) ***Vegetation surveying can occur again in 2025 to compare the progress of submersed aquatic vegetation (SAV) growth to that of 2024 (SUPPLEMENTAL).***
   a. 2024 stakeholder concerns included a noted decrease in SAV in Apple Valley Lake. SAV survey work conducted in 2024 noted 6.8% of the lake's surface area contained SAV with plant recovery seeming to occur later in the season. Should the community want to monitor SAV growth into 2025, a repeat of methodology utilized in 2024 into 2025 would be suggested (Chapter IV).

All the data and information collected following these procedures should be stored and analyzed together so that trends and patterns can be constructed into sound reference conditions. Once these reference conditions are established, water quality thresholds can be developed to assist in defining the lake as impaired or not in the future. Table 15 represents estimated costs that could be expected for the purchasing/use of equipment mentioned in the SOP above. Table 16 showcases estimated costs for laboratory services mentioned in the SOP above.

Apple Valley Lake Best Management Practices (BMPs)

BMPs were discussed in Chapter VII of the State of the Lake Report above. As mentioned within that chapter, enactment of lake BMPs are suggested for all lakes and reservoirs regardless of impairment status. They can be thought of as behaviors and actions that individuals can take to reduce their individual impact on the reservoir and its environment and improve its sustainability. These actions are categorized by the constituents or groups they are meant to impact (lake homeowner, agriculture, construction, etc.) and typically involve either a) slowing the velocity of water as it makes its way toward Apple Valley Lake and/or b) reducing the quantity of pollutants (typically P) that are carried into Apple Valley Lake. For lake homeowner BMPs, the Apple Valley Property Owners Association (AVPOA) may be able to construct bylaws or rules that support the enactment of these actions to help reduce cultural eutrophication (process of regressed lake sustainability due to human induced activities) from immediate lake homeowners. However, for watershed BMPs (agricultural, construction beyond AVPOA property, etc.) cohesive relationships with local townships, watershed non-profits, soil and water conservation organizations within the Apple Valley Lake watershed (Figure 4) will likely be necessary for BMP enactment. As presented in Chapter II of the State of the Lake Report, a substantial amount of the land used within the Apple Valley Lake watershed is cultivated crops and pasture/hay (Figures 4 and 5). Because of this, priority should be given to enactment of agricultural BMPs to increase the potential positive impact on Apple Valley Lake. Continued efforts in BMP enactment assists with priority two in the directives of this plan. A table of common BMPs for different constituent groups was provided with Table 14 in Chapter VII. As these should be implemented perpetually throughout the life of the lake and require the cooperation of multiple stakeholders and properties beyond those in control of the AVPOA, exact procedures would be difficult to produce as a SOP (like with monitoring). However, some suggestions are provided below.

At the time of this report, Ohio Governor Mike DeWine and the Ohio Department of Agriculture have released and expanded upon the state’s H2Ohio program which aims to reduce nutrient runoff from agricultural sources in the state (State of Ohio 2023). Since 2019, this program has helped to reduce an estimated 317,000 lbs of P from entering Lake Erie from 1.4 million acres of land. Although this program is dominantly aimed at reducing P into Lake Erie, the program does extend throughout the state with Knox County already having 16,000 acres enrolled in the program (Splain 2024). Encouraging farmers to join this incentive program, if possible, would be an excellent way to support agricultural BMPs and potentially reduce P loads into Apple Valley Lake through direct nutrient reduction. In addition to this statewide effort, more localized programing may be available or developed with the Knox County Soil and Water Conservation District. As the watershed extends throughout Knox County, a hand-in-hand relationship with their soil and water conservation group would likely allow for a greater ability to reach watershed farmers. Program development custom tailored to Knox farming families (or organizations) to enact BMPs that are funded through a shared mutual agreement by Apple Valley Lake, the Soil and Water Conservation District, and the farmers themselves may be more easily adoptable as community improvement programs. Specifics on the ability to adopt such programming would need to involve all parties but typically are not difficult due to aligning goals.

Apple Valley Lake In-lake Nutrient Reduction

In-lake nutrient reduction techniques that can be applicable to Apple Valley Lake were discussed in greater detail in Chapter VI of the State of the Lake Report above. Although the lake can be primarily categorized as mesotrophic based on productivity index information (Chapter III) and didn't experience impairment due to primary productivity (aquatic plants and algae). Eutrophication or stable state changes may alter this status in the future and result in necessary in-lake nutrient reduction techniques to maintain its designated use as a contact recreation reservoir. Although an extreme change in the productivity of Apple Valley Lake is not expected into 2025, preparedness can be key for successful management of the resource well into the future. As such, an important component of the LMSP should be awareness and consideration of in-lake P-reduction techniques. As Apple Valley Lake conducts a substantial water level drawdown every fall with nutrient rich, bottom waters being released from the system, one may suggest that P-concentrations are already currently managed. However, with eutrophication potentially increasing nutrient concentrations over time additional measures may need to be taken. If monitoring were to suggest this to be the case and productivity indexes demonstrate an increase toward a eutrophic (high productivity; enriched TP, lower transparency, heightened chlorophyll α designation, P-inactivation may be a direction that should be considered. As noted in Chapter VI, P-inactivation would be an intensive capital project and would require an extensive budget as well as time for proper planning. However, this technique directly reduces P concentrations in waterbodies and would directly reduce all primary production in the lake. Generating a P-budget that goes beyond the means of the information of this report would be suggested if finances allow however, targeting a water column TP range of 20 – 30 µg/L would be a good starting point for sustainable reduction if it were necessary. Lanthanum products would be the preferred product due to the lower impact on the lake's pH, but alum can be substituted to save on costs.

Timeline

Due to the nature of the work to be conducted on Apple Valley Lake, an exact timeline to complete the various goals associated with this plan cannot be exactly determined. Rather, it would be suggested to start incorporating suggested monitoring actions at the start of the 2025 lake season (April/May) and continue until it ends (October/November) annually. The same can be suggested for the enactment of BMPs within the lake and its watershed. Both of these items will be ongoing perpetually as a component of lake monitoring and maintaining lake sustainability. As Apple Valley Lake changes, reconstruction of this plan should occur to account for concerns noted by lake stakeholders coinciding with annually collected monitoring data. This way, a strategic response can be more easily planned, written, and enacted to reduce the potential for the lake to become impaired in the future. Should the lake become impaired for its categorical use, management should include the use of short-term techniques to remedy the impaired status while long-term solutions are enacted to return the stable state of the lake to an acceptable condition. It should be noted that monitoring, BMP enactment, and in-lake nutrient reduction work cohesively to reduce the potential for developing an impaired status.

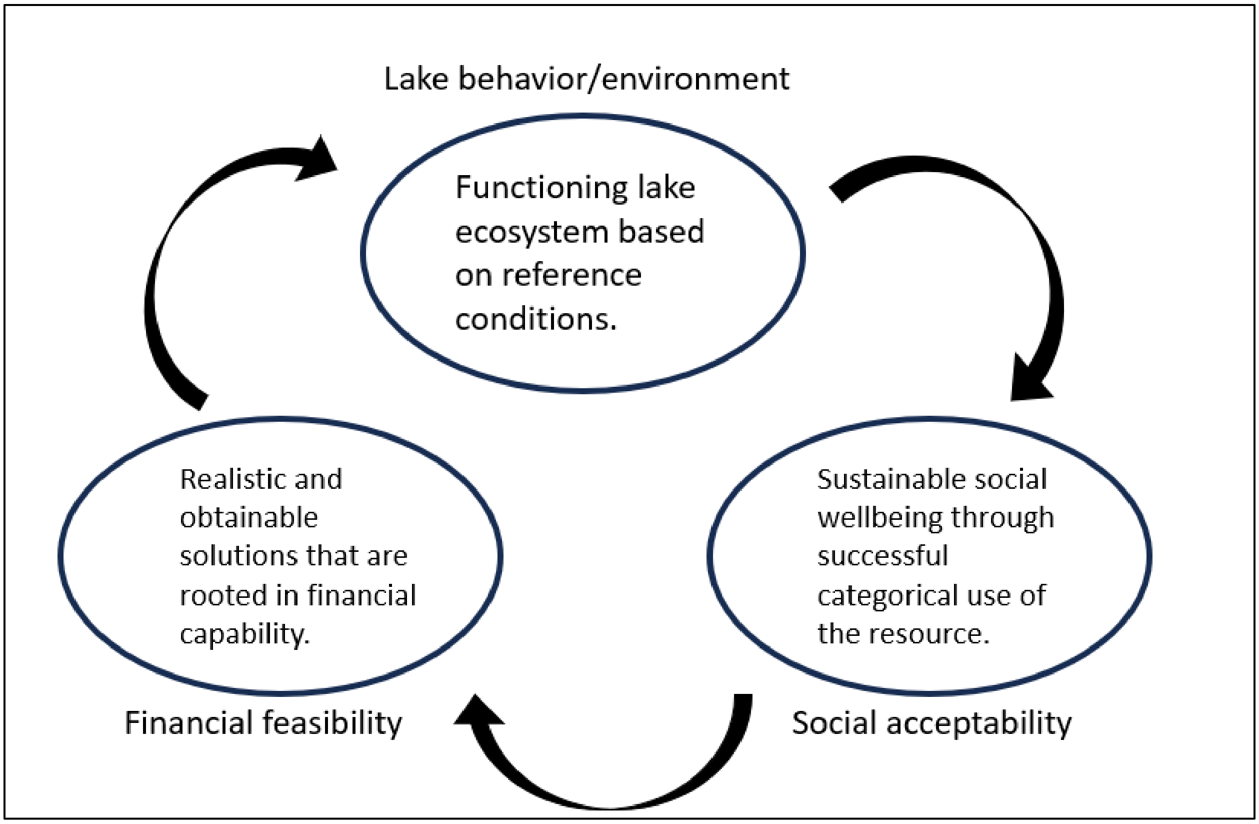


Figure 42: Three-legged stool paradigm showcasing the need for an understanding of lake behavior, social acceptance, and financial feasibility on the success of a wholistic management plan.

Table 15: Cost ranges for water quality equipment and items mentioned in this plan. Please note that cost estimations are subject to change and represent approximate values from 2024.

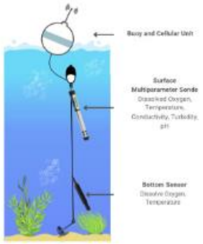
Equipment	***Estimated cost***	***Image***	***A few considerations***
Multiprobe In-situ sonde (EXO1 by YSI)	$7,000 - $10,000 (depending on number of sensors and cable length; Quote needs to be requested by manufacturer)		Will need at least 75’ cabling for proper sampling. Temperature, DO, Chlorophyll α (total algae), pH should be minimum needed sensors.
LakeTech, Inc. Buoy System with telemetry capabilities	$12,000 - $25,000 (depending on number of sondes, cable length, etc.)		Services for maintenance, installation, and rental available through AQUA DOC if desired.
Kemmerer Water Sampler or equivalent (Wildco suggested)	$300 - $1,000 (based on model)		Will need at least 75’ rope for hypominion sampling. Make sure messenger is included with purchase.
Secchi Disk	AVPOA already owns (individuals can purchase one from $20 - $50)		N/A
High density polyurethane sampling bottles	Usually free from labs samples are being sent to (inquire with certified lab)		Do nutrient samples require acid preservation methods? If so, ensure acid is in bottles on pick up.

Table 16: Cost ranges for laboratory services mentioned in this plan. Please note that cost estimations are subject to change and represent approximate values from 2024.

Lab service/unit*	***Estimated cost***	***Potential labs****	***A few considerations***
Total phosphorus (TP; mg/L or µg/L))	$20 - $60 per sample depending on lab	SePRO - Whittakers NC BioSolutions – Chagrin Falls, OH	Minimum detection threshold needs to be at least 0.01 mg/L. 28 day holding period allowed if acid preserved.
Total Kjeldahl nitrogen (TKN; mg/L)	$20 - $60 per sample depending on lab	SePRO - Whittakers NC BioSolutions – Chagrin Falls, OH	Minimum detection threshold needs to be at least 1.0 mg/L. 28 day holding period if acid preserved.
E. coli (CFUs)	$15 - $30 per sample depending on lab	*Local lab suggested due to fast delivery needed.*	Need to be delivered on ice within 6 – 7 hours of collection (see individual lab for details)
Microcystin (µg/L; ELISA)	$200 - $250 per sample depending on lab	EnviroScience – Stow, OH	N/A

Please note that this only represents those services noted in this report. Water sample collection can include an extensive number of potential samples to be analyzed. Consult with your local laboratory for a pricing sheet on the variety of services and bottle types for additional water samples.

**** Local labs are plentiful. When choosing a lab, please make sure they utilize standard methodology or EPA approved methodology, and report analyzed results in the metric provided in the table for "apples to apples" comparison.***

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Appendix A: Summary of soil types from soils report (Soil Survey Staff 2024)

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
BoA	Bogart silt loam, 0 to 2 percent slopes	51.8	0.4%
BoB	Bogart silt loam, 2 to 6 percent slopes	60.1	0.5%
BrC	Brownsville channery silt loam, 6 to 12 percent slopes	20.2	0.2%
BrD	Brownsville channery silt loam, 12 to 18 percent slopes	198.6	1.7%
BsE	Brownsville-Westmoreland complex, 18 to 25 percent slopes	516.8	4.4%
BsF	Brownsville-Westmoreland complex, 25 to 40 percent slopes	133.4	1.1%
ChB	Chili gravelly loam, 2 to 6 percent slopes	12.1	0.1%
ChC	Chili gravelly loam, 6 to 12 percent slopes	19.4	0.2%
ChD	Chili gravelly loam, 12 to 18 percent slopes	30.5	0.3%
ChE	Chili gravelly loam, 18 to 25 percent slopes	8.3	0.1%
CmA	Chili silt loam, 0 to 2 percent slopes	20.2	0.2%
CmB	Chili silt loam, 2 to 6 percent slopes	110.8	0.9%
CnC	Chili-Homewood silt loams, 6 to 12 percent slopes	109.3	0.9%
CnD	Chili-Homewood silt loams, 12 to 18 percent slopes	74.3	0.6%
CvB	Coshocton silt loam, 2 to 6 percent slopes	1.6	0.0%
FcA	Fitchville silt loam, 0 to 2 percent slopes	61.6	0.5%
FcB	Fitchville silt loam, 2 to 6 percent slopes	111.3	0.9%
GhB	Gilpin silt loam, 3 to 8 percent slopes	402.7	3.4%
GhC	Gilpin silt loam, 8 to 15 percent slopes	543.1	4.6%
GnA	Glenford silt loam, 0 to 2 percent slopes	10.2	0.1%
GnB	Glenford silt loam, 2 to 6 percent slopes	257.5	2.2%

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
GnC	Glenford silt loam, 6 to 12 percent slopes	13.2	0.1%
GrB	Gresham silt loam, 2 to 6 percent slopes	61.4	0.5%
Ho	Holly silt loam, frequently flooded	32.4	0.3%
HwB	Homewood silt loam, 2 to 6 percent slopes	980.2	8.3%
HwC	Homewood silt loam, 6 to 12 percent slopes	1,260.7	10.7%
HwD2	Homewood silt loam, 12 to 18 percent slopes, eroded	359.9	3.0%
HwE2	Homewood silt loam, 18 to 25 percent slopes, eroded	8.1	0.1%
JmA	Jimtown silt loam, 0 to 2 percent slopes	26.8	0.2%
JmB	Jimtown silt loam, 2 to 6 percent slopes	4.0	0.0%
LvB	Loudonville silt loam, 2 to 6 percent slopes	663.5	5.6%
LvC	Loudonville silt loam, 6 to 12 percent slopes	1,381.3	11.7%
LvD	Loudonville silt loam, 12 to 18 percent slopes	1,203.7	10.2%
LvE	Loudonville silt loam, 18 to 25 percent slopes	165.7	1.4%
Ly	Luray silty clay loam	1.2	0.0%
Or	Orrville silt loam, 0 to 3 percent slopes, occasionally flooded	896.3	7.6%
Pg	Pits, gravel	2.2	0.0%
Se	Sebring silt loam	10.0	0.1%
TvB	Titusville silt loam, 2 to 6 percent slopes	714.1	6.0%
TvC	Titusville silt loam, 6 to 12 percent slopes	178.6	1.5%
Ud	Udorthents, loamy	5.1	0.0%
W	Water	493.8	4.2%
WeD	Westmoreland silt loam, 15 to 25 percent slopes	592.8	5.0%
Totals for Area of Interest		**11,808.7**	**100.0%**

Appendix B: Deep point depth profile data collected throughout the 2024 lake season.

Date	*Depth (ft)*	*Temperature (°F)*	*Dissolved Oxygen (DO; mg/L)*	*Conductivity*	*pH*	*ORP*	*Chl. a (ug/L)*	*Phycocyan*
6/20/2024	0	81.9	11.87	239.2	9.25	88.3	3.69	0.19
6/20/2024	2	81.6	12.03	238.5	9.27	85.8	3.68	0.16
6/20/2024	4	80.6	12.32	235.4	9.3	84.5	7.75	0.29
6/20/2024	6	79.8	12.41	233	9.31	83.9	9.16	0.36
6/20/2024	8	79	11.86	232.5	9.25	86.3	14.47	0.52
6/20/2024	10	77.2	11.08	230.1	9.2	88.8	18.6	0.72
6/20/2024	12	75.5	8.6	230.5	8.91	102	19.52	0.94
6/20/2024	14	71.5	2.23	236.1	7.97	138.6	13.4	1.06
6/20/2024	16	69.2	0	238.7	7.62	145.5	8.13	0.8
6/20/2024	18	64.3	0	234.1	7.42	85.2	5.55	0.61
6/20/2024	20	61.4	0	227.7	7.34	-3.6	3.7	0.52
6/20/2024	22	58.7	0	220.7	7.28	-10.4	2.71	0.47
6/20/2024	24	56.4	0	215.4	7.23	17.8	2.57	0.43
6/20/2024	26	55.2	0	211.8	7.2	22.1	1.99	0.41
6/20/2024	28	53.9	0	209	7.17	6.7	1.6	0.34
6/20/2024	30	52.6	0	205	7.14	23.3	1.22	0.32
6/20/2024	32	52.1	0	203.4	7.12	28.4	1.11	0.32
6/20/2024	34	51.3	0	201.5	7.09	36.3	0.92	0.29
6/20/2024	36	50.5	0	200.5	7.07	38.9	0.94	0.3
6/20/2024	38	50	0	198.7	7.06	44.5	0.79	0.29
6/20/2024	40	49	0	197.6	7.06	47.7	0.71	0.29
6/20/2024	42	48.8	0	197.5	7.05	51.1	0.67	0.28
6/20/2024	44	48.5	0	197.3	7.04	52.8	0.75	0.3
6/20/2024	46	48.2	0	196.9	7.03	53.8	0.61	0.28
6/20/2024	48	48.1	0	196.7	7.03	54.3	0.58	0.28
6/20/2024	50	48	0	196.7	7.03	54	0.5	0.28
6/20/2024	52	48	0	196.3	7.02	54.2	0.45	0.29
6/20/2024	54	47.9	0	196.2	7.03	53.6	0.4	0.29
6/20/2024	56	47.8	0	196.2	7.03	49.7	0.44	0.31
6/20/2024	58	47.8	0	196.1	7.03	53	0.4	0.29
6/20/2024	60	47.8	0	196.1	7.03	53.7	0.36	0.29
7/19/2024	0	81.7	9.05	261.3	8.64	10.5	0.77	0.22
7/19/2024	2	81.3	9.18	259.9	8.67	11.1	1.34	0.22
7/19/2024	4	80.3	9.36	257.3	8.67	14.2	2.06	0.32
7/19/2024	6	80	9.2	256.3	8.63	17.8	2.66	0.45
7/19/2024	8	79.9	8.94	256	8.6	21.7	2.79	0.46
7/19/2024	10	79.8	8.7	256.2	8.55	25.1	2.9	0.49

7/19/2024	12	79.7	8.61	256.1	8.53	26.9	2.94	0.5
7/19/2024	14	79.6	8.49	256	8.51	29.5	3.18	0.49
7/19/2024	16	79.6	8.45	255.8	8.5	31.7	3.17	0.48
7/19/2024	18	78.6	6.31	254.8	7.84	45.1	3.18	0.53
7/19/2024	20	71.3	0	245.6	7.34	-227.4	1.85	0.67
7/19/2024	22	68.6	0	244.3	7.4	-247.5	1.83	0.64
7/19/2024	24	60.6	0	233.2	7.43	-258	1.45	0.45
7/19/2024	26	56.2	0	221.4	7.39	-246.9	1.2	0.35
7/19/2024	28	53.8	0	213.9	7.37	-236	0.99	0.29
7/19/2024	30	52.5	0	208.9	7.35	-214.5	0.77	0.27
7/19/2024	32	51.2	0	204.7	7.31	-187.2	0.62	0.25
7/19/2024	34	50	0	202.2	7.25	-178.4	0.49	0.25
7/19/2024	36	49.6	0	201.5	7.23	-183.4	0.37	0.25
7/19/2024	38	49.4	0	202.2	7.12	-205.3	0.39	0.24
7/19/2024	40	49	0	202.1	7.08	-211.9	0.38	0.26
7/19/2024	42	48.8	0	202.5	7.06	-220.9	0.36	0.25
7/19/2024	44	48.6	0	202.3	7.04	-221.4	0.27	0.25
7/19/2024	46	48.5	0	201.6	7.04	-221	0.31	0.24
7/19/2024	48	48.4	0	201.7	7.04	-222.1	0.29	0.26
7/19/2024	50	48.3	0	202.2	7.03	-224.1	0.31	0.26
7/19/2024	52	48.3	0	202.1	7.03	-226.4	0.29	0.25
7/19/2024	54	48.3	0	202.5	7.03	-227.6	0.27	0.24
7/19/2024	56	48.2	0	203	7.02	-229.2	0.35	0.26
7/19/2024	58	48.2	0	203.1	7.01	-230.6	0.36	0.26
7/19/2024	60	48.1	0	203.6	7	-232.5	0.35	0.26
8/22/2024	0	75.3	8.68	258	8.34	124.7	1.35	0.48
8/22/2024	2	75.3	8.64	258	8.33	119.2	1.55	0.47
8/22/2024	4	75.1	8.73	257.9	8.34	117	2.55	0.61
8/22/2024	6	75	8.71	257.8	8.33	116.4	2.64	0.74
8/22/2024	8	74.8	8.5	258	8.26	117.8	2.88	0.8
8/22/2024	10	74.6	8.32	257.9	8.22	118.2	2.8	0.78
8/22/2024	12	74.5	7.97	258.2	8.13	121	2.71	0.76
8/22/2024	14	74.5	7.84	258.2	8.11	121.5	2.6	0.77
8/22/2024	16	74.3	7.55	258.6	8.03	123.7	2.65	0.78
8/22/2024	18	74.3	7.48	258.6	8.02	123.9	3	0.75
8/22/2024	20	74	7.19	259	7.94	126.5	2.61	0.75
8/22/2024	22	73.6	7.22	258.6	8.03	123.6	2.57	0.69
8/22/2024	24	70.6	3	273.1	7.48	-10	1.9	0.43
8/22/2024	26	64.7	0	285.4	7.35	-228	0.94	0.15
8/22/2024	28	58.8	0	288.2	7.37	-245	0.93	0.18
8/22/2024	30	57	0	288.9	7.37	-247.7	0.79	0.23

8/22/2024	32	53.1	0	288.6	7.33	-256.9	0.65	0.25
8/22/2024	34	51.9	0	288.5	7.3	-243.8	0.62	0.25
8/22/2024	36	51	0	288.3	7.25	-241.3	0.54	0.24
8/22/2024	38	50.1	0	289.7	7.14	-237	0.42	0.23
8/22/2024	40	49.7	0	291	7.1	-237.2	0.37	0.22
8/22/2024	42	49.3	0	292.5	7.06	-238.1	0.38	0.24
8/22/2024	44	49	0	294.5	7.05	-238.7	0.34	0.23
8/22/2024	46	48.8	0	295.8	7.02	-239.8	0.28	0.24
8/22/2024	48	48.7	0	295.9	7.02	-240.7	0.29	0.22
8/22/2024	50	48.6	0	296.3	7.01	-241.4	0.33	0.22
8/22/2024	52	48.5	0	296.5	7.01	-242.2	0.32	0.24
8/22/2024	54	48.5	0	296.8	7	-242.8	0.29	0.22
8/22/2024	56	48.4	0	297.3	7	-243.7	0.29	0.23
8/22/2024	58	48.4	0	297.7	6.99	-244.5	0.29	0.23
8/22/2024	60	48.4	0	298.6	6.99	-245.9	0.28	0.28
10/2/2024	0	70.8	7.24	267.5	8	138.1	2.83	0.3
10/2/2024	2	70.8	7.23	267.5	8	137.7	2.85	0.31
10/2/2024	4	70.8	7.22	267.5	8	137.1	2.93	0.33
10/2/2024	6	70.8	7.13	267.6	7.98	137.2	3.03	0.35
10/2/2024	8	70.8	7.05	267.7	7.95	137	2.99	0.33
10/2/2024	10	70.8	6.96	267.7	7.94	137.4	2.99	0.3
10/2/2024	12	70.8	6.92	267.7	7.94	137.7	3.29	0.34
10/2/2024	14	70.8	6.9	267.7	7.94	137.5	3.19	0.33
10/2/2024	16	70.8	6.87	267.8	7.93	137.4	3.47	0.32
10/2/2024	18	70.8	6.86	267.8	7.93	137.2	3.33	0.33
10/2/2024	20	70.7	6.73	267.9	7.9	138	3.39	0.31
10/2/2024	22	70.7	6.74	267.8	7.91	137.4	3.28	0.33
10/2/2024	24	70.7	6.75	267.8	7.91	137.1	3.42	0.33
10/2/2024	26	70.5	1.86	267.7	7.59	150.5	2.39	0.3
10/2/2024	28	64.5	0	293.9	7.27	-213	0.59	0.13
10/2/2024	30	59.3	0	296.6	7.31	-246.9	0.61	0.11
10/2/2024	32	55.8	0	291.1	7.28	-254.5	0.48	0.14
10/2/2024	34	53.6	0	294.1	7.25	-257.4	0.41	0.15
10/2/2024	36	52.4	0	291.8	7.24	-261.6	0.38	0.17
10/2/2024	38	51.5	0	293.4	7.22	-262.3	0.37	0.17
10/2/2024	40	50.7	0	294.7	7.18	-262.3	0.37	0.2
10/2/2024	42	50.3	0	295.8	7.17	-263.7	0.29	0.19
10/2/2024	44	50	0	299.3	7.14	-264.5	0.46	0.22
10/2/2024	46	49.8	0	300.4	7.13	-264.7	0.44	0.21
10/2/2024	48	49.3	0	298.4	7.13	-264.9	0.35	0.2
10/2/2024	50	49.2	0	299	7.12	-264.5	0.25	0.2

10/2/2024	52	49	0	300.6	7.1	-264.3	0.21	0.21
10/2/2024	54	48.9	0	300.9	7.09	-264.3	0.2	0.21
10/2/2024	56	48.7	0	302.7	7.08	-264.5	0.24	0.2
10/2/2024	58	48.7	0	303.5	7.07	-264.4	0.26	0.21
10/2/2024	60	48.6	0	307.4	6.89	-251.9	2.71	0.73

Appendix C: Site 1 depth profile data collected throughout the 2024 lake season.

Date	*Depth (ft)*	*Temperature (°F)*	*Dissolved Oxygen (DO; mg/L)*	*Conductivity*	*pH*	*ORP*	*Chl. a (ug/L)*	*Phycocyan*
6/20/2024	0	83.1	11.77	245.2	9.25	57.7	2.54	0.1
6/20/2024	2	82.9	11.83	244	9.26	57.9	4.11	0.13
6/20/2024	4	81.6	12.13	240.9	9.27	59.2	5.03	0.19
6/20/2024	6	81.2	12.02	239.9	9.27	60.2	9.49	0.36
6/20/2024	8	78.2	12.01	231.7	9.28	61.9	14.56	0.58
6/20/2024	10	77.2	10.98	231.3	9.19	66.5	19.1	0.79
6/20/2024	12	75.1	7.62	231.9	8.85	78.7	19.91	0.94
6/20/2024	14	72.5	3.5	236.6	8.14	102.9	12.01	0.93
6/20/2024	16	69.6	0	239	7.75	112.1	9.95	0.91
6/20/2024	18	67.7	0	237.6	7.7	-15.3	6.77	0.7
6/20/2024	20	65.8	0	236.4	7.64	-111.2	5.95	0.67
6/20/2024	22	59.6	0	222.8	7.46	-110.2	2.62	0.4
6/20/2024	24	56.6	0	216.6	7.41	-66.1	2.58	0.46
6/20/2024	26	54.1	0	210.6	7.36	-44.5	1.46	0.35
6/20/2024	28	52.7	0	208.1	7.33	-28.5	1.16	0.32
6/20/2024	30	51.7	0	204.7	7.31	-17.8	1	0.3
6/20/2024	32	50.2	0	201.2	7.28	-12	0.81	0.32
6/20/2024	34	49.3	0	199.5	7.25	-7.1	0.63	0.28
6/20/2024	36	49.1	0	199.1	7.24	-3.2	0.57	0.29
6/20/2024	38	48.6	0	198.5	7.23	0.2	0.53	0.29
6/20/2024	40	48.2	0	197.5	7.22	0.2	0.44	0.29
6/20/2024	42	48.2	0	197.6	7.21	-8.7	0.43	0.29
6/20/2024	44	48	0	197	7.18	-8	0.49	0.3
7/19/2024	0	80.1	8.74	257.7	8.58	38.5	1.25	0.29
7/19/2024	2	80.1	8.81	257.8	8.58	35.2	1.47	0.32
7/19/2024	4	80.1	8.8	257.5	8.57	36.4	2.07	0.38
7/19/2024	6	79.9	8.73	257	8.56	38	2.61	0.46
7/19/2024	8	79.9	8.73	257	8.56	38.8	2.58	0.49
7/19/2024	10	79.7	8.54	256.4	8.53	41.2	2.8	0.52
7/19/2024	12	79.5	8.37	255.7	8.48	44.4	2.7	0.49
7/19/2024	14	79.2	8.03	255.4	8.42	47.1	2.72	0.49

7/19/2024	16	79.1	7.68	255.3	8.31	52.4	2.91	0.5
7/19/2024	18	76.4	0.66	250.5	7.33	74.2	2.46	0.53
7/19/2024	20	71.6	0	246.2	7.35	-224.3	1.72	0.6
7/19/2024	22	65.8	0	242.4	7.45	-252	1.64	0.55
7/19/2024	24	60.6	0	232.4	7.31	-244.1	1.44	0.44
7/19/2024	26	57.5	0	224.8	7.14	-229.6	1.22	0.4
7/19/2024	28	54.7	0	217	7.11	-222.7	0.92	0.3
7/19/2024	30	53	0	213	7.09	-221	0.8	0.28
7/19/2024	32	52.3	0	210.1	7.07	-214.9	0.64	0.27
7/19/2024	34	51.1	0	207.9	7.05	-216.7	0.54	0.26
7/19/2024	36	50.9	0	207.7	7.04	-218.5	0.54	0.27
7/19/2024	38	50.5	0	207.1	7.03	-219.9	0.55	0.27
7/19/2024	40	50.2	0	206.4	7.03	-220.3	0.47	0.27
7/19/2024	42	49.3	0	205	6.99	-221	0.36	0.25
7/19/2024	44	49.1	0	204.3	6.99	-220.6	0.32	0.26
8/22/2024	0	76.1	8.24	260	8.08	47.7	0.95	0.46
8/22/2024	2	75.9	8.08	259.5	8.11	48.1	1.25	0.5
8/22/2024	4	75.7	8.07	259.6	8.12	50	2.72	0.75
8/22/2024	6	75.2	8.06	259	8.13	53.5	2.92	0.91
8/22/2024	8	74.7	8.04	259	8.13	55.5	2.84	0.87
8/22/2024	10	74.6	8.02	258.9	8.13	57.4	2.95	0.85
8/22/2024	12	74.6	8	258.9	8.12	59.3	2.94	0.86
8/22/2024	14	74.3	7.7	259.1	8.01	62.7	2.7	0.85
8/22/2024	16	74.1	7.35	259	7.94	64.7	2.85	0.87
8/22/2024	18	74.1	7.28	259.1	7.91	65.3	2.77	0.83
8/22/2024	20	74.1	7.16	259.1	7.91	65.8	2.6	0.82
8/22/2024	22	73.9	7.07	259.1	7.9	66.6	2.62	0.85
8/22/2024	24	66.8	6.9	259.7	7.86	68.7	2.5	0.81
8/22/2024	26	60.3	1.7	284.4	7.41	-204.9	0.85	0.17
8/22/2024	28	58.3	0.03	287.9	7.37	-232.5	0.83	0.15
8/22/2024	30	55.7	0	289.8	7.37	-242.2	0.83	0.19
8/22/2024	32	53	0	289.7	7.35	-245.7	0.75	0.21
8/22/2024	34	52.1	0	291.1	7.32	-249.1	0.7	0.23
8/22/2024	36	51	0	291	7.32	-252.6	0.63	0.24
8/22/2024	38	50.5	0	292.4	7.27	-252.3	0.67	0.25
8/22/2024	40	50.1	0	295.7	7.24	-252.7	0.57	0.25
8/22/2024	42	49.7	0	294.2	7.24	-253.9	0.54	0.24
8/22/2024	44	49.6	0	294.4	7.21	-253.1	0.5	0.23
10/2/2024	0	70.8	6.81	268.4	7.79	10.7	2.95	0.3
10/2/2024	2	70.9	6.45	268.5	7.8	11.9	2.72	0.25
10/2/2024	4	70.9	6.43	268.5	7.8	12.9	3.1	0.3

10/2/2024	6	70.9	6.38	268.5	7.79	13.9	3.51	0.34
10/2/2024	8	70.8	6.33	268.4	7.79	14.8	3.24	0.3
10/2/2024	10	70.8	6.24	268.5	7.78	16.4	3.31	0.31
10/2/2024	12	70.8	6.19	268.5	7.77	17.8	3.45	0.29
10/2/2024	14	70.8	6.09	268.5	7.75	18.7	3.57	0.31
10/2/2024	16	70.8	6.02	268.5	7.74	20	3.39	0.29
10/2/2024	18	70.8	5.94	268.5	7.73	21.1	3.57	0.31
10/2/2024	20	70.7	5.99	268.4	7.75	22.3	3.86	0.33
10/2/2024	22	70.7	6.16	268.5	7.77	23.1	3.72	0.32
10/2/2024	24	70.4	4.61	270.2	7.62	26.5	3.04	0.29
10/2/2024	26	65.8	0	289.1	7.38	-179.6	1.1	0.2
10/2/2024	28	62.1	0	292.4	7.36	-210.2	0.66	0.15
10/2/2024	30	59.3	0	296.6	7.32	-218.1	1	0.17
10/2/2024	32	57.1	0	298.4	7.32	-223.6	0.51	0.12
10/2/2024	34	55.6	0	298.5	7.3	-225.5	0.68	0.14
10/2/2024	36	53.4	0	299.1	7.26	-227.9	0.46	0.14
10/2/2024	38	51.7	0	300.2	7.23	-230.9	0.31	0.16
10/2/2024	40	50.7	0	302.6	7.19	-233.7	0.29	0.15
10/2/2024	42	49.7	0	303.5	7.17	-236.6	0.25	0.17
10/2/2024	44	49.4	0	303.3	7.16	-238.9	0.26	0.17

Appendix D: Site 2 depth profile data collected throughout the 2024 lake season.

Date	*Depth (ft)*	*Temperature (°F)*	*Dissolved Oxygen (DO; mg/L)*	*Conductivity*	*pH*	*ORP*	*Chl. a (ug/L)*	*Phycocyan*
6/20/2024	0	83.9	11.89	247.2	9.25	44.5	3.59	0.16
6/20/2024	2	83.6	12.02	246.8	9.25	46.3	3.6	0.15
6/20/2024	4	82.8	12.23	244.3	9.27	47.6	8.53	0.3
6/20/2024	6	82.2	12.4	243.4	9.28	49.2	9.34	0.36
6/20/2024	8	81.5	12.41	244	9.26	51.8	10.6	0.37
6/20/2024	10	78.1	10.61	236.6	9.16	57.5	17.75	0.67
6/20/2024	12	75.8	8.5	232.7	8.96	66.1	21.13	0.9
6/20/2024	14	74.2	5.78	234.6	8.51	81.8	14.1	0.75
6/20/2024	16	71.8	0	243.1	7.69	101.4	10.29	0.64
6/20/2024	18	70	0	241.3	7.64	93.4	7.97	0.68
6/20/2024	20	64.9	0	236.2	7.55	-197.4	5.94	0.64
6/20/2024	22	57.7	0	221.6	7.42	-192.8	2.38	0.37
6/20/2024	24	53.8	0	210.8	7.35	-156.8	1.45	0.33
6/20/2024	26	52.4	0	208	7.32	-136	0.89	0.27
7/19/2024	0	79.8	7.98	259	8.34	80.5	1.45	0.35

7/19/2024	2	79.8	7.99	259.1	8.34	81	1.67	0.37
7/19/2024	4	79.6	7.97	258.6	8.34	82.8	2.77	0.5
7/19/2024	6	79.5	7.85	258	8.31	85.7	3.04	0.54
7/19/2024	8	79.3	7.6	257.4	8.24	89.3	3.12	0.6
7/19/2024	10	79.3	7.27	257.5	8.16	93.8	3.28	0.61
7/19/2024	12	79.2	7.24	257.9	8.13	96	3.12	0.6
7/19/2024	14	79	6.95	257.7	8.05	99.9	3.17	0.64
7/19/2024	16	78.9	6.89	257.6	8.06	100.8	2.8	0.62
7/19/2024	18	76	0.31	251.3	7.29	-7.4	2.58	0.59
7/19/2024	20	68.5	0	244.8	7.42	-237.3	1.58	0.53
7/19/2024	22	63.8	0	241.8	7.42	-251.5	1.41	0.41
7/19/2024	24	59	0	232.9	7.39	-253	1.17	0.34
7/19/2024	26	56.3	0	225.7	7.3	-248.2	1.04	0.34
8/22/2024	0	76.3	7.48	261.2	7.96	70.3	1.75	0.48
8/22/2024	2	76.3	7.45	261.4	7.97	70.4	2.61	0.56
8/22/2024	4	75	7.57	260	8	71.3	3.25	0.81
8/22/2024	6	74.8	7.55	260	7.99	73	3.17	0.92
8/22/2024	8	74.5	7.35	259.9	7.96	75.2	3.15	0.92
8/22/2024	10	74.5	7.23	259.9	7.92	77.7	3.02	0.91
8/22/2024	12	74.1	6.59	259.8	7.78	81.8	2.52	0.9
8/22/2024	14	74	6.32	259.8	7.75	82.8	2.48	0.89
8/22/2024	16	74	6.18	259.9	7.74	83.7	2.48	0.86
8/22/2024	18	73.9	6.07	260	7.73	84.2	2.48	0.85
8/22/2024	20	73.6	4.6	262.4	7.54	88.8	2.03	0.69
8/22/2024	22	72.1	1.12	268	7.34	94	1.62	0.4
8/22/2024	24	70.5	0.1	274.2	7.33	-144	1.35	0.35
10/2/2024	0	70.9	6.41	269.8	7.8	7.5	3.23	0.28
10/2/2024	2	71.1	6.39	269.8	7.8	8.5	3.49	0.31
10/2/2024	4	70.9	6.37	269.9	7.8	8.8	4.14	0.31
10/2/2024	6	70.9	6.36	269.9	7.79	10.2	4.51	0.31
10/2/2024	8	70.8	6.3	267.7	7.78	11.7	4.17	0.31
10/2/2024	10	70.7	6.26	269.7	7.78	12.7	4.26	0.3
10/2/2024	12	70.7	6.23	269.6	7.77	13.7	4.28	0.31
10/2/2024	14	70.7	6.21	269.4	7.77	13.9	3.99	0.29
10/2/2024	16	70.7	6.09	269.7	7.75	15.3	3.75	0.28
10/2/2024	18	70.6	5.88	270	7.73	14.9	4	0.28
10/2/2024	20	70.6	5.83	270.1	7.72	15.8	4.29	0.29
10/2/2024	22	70.4	5.78	270.1	7.72	16.3	4.44	0.33
10/2/2024	24	68.9	0.57	279.7	7.43	-111	2.18	0.28
10/2/2024	26	68.2	0	285.4	7.37	-175	1.71	0.28

Appendix E: Water column TP values collected throughout 2024 lake season.

Location ID	*Depth*	*Test*	*Lab Method*	*Date*	*Unit*	*Value*
Deep Surface 1	Grab	TP	SM 4500P-B5,E	6/20/2024	mg/L	0.01
Deep Surface 2	Grab	TKN	Hach 10242	6/20/2024	mg/L	1
Deep Bottom 3	60 ft.	TP	SM 4500P-B5,E	6/20/2024	mg/L	0.04
Deep Bottom 4	60 ft.	TKN	Hach 10242	6/20/2024	mg/L	2
Site 1	Grab	TP	SM 4500P-B5,E	6/20/2024	mg/L	0.04
Site 2	Grab	TP	SM 4500P-B5,E	6/20/2024	mg/L	0.02
Site 3	Grab	TP	SM 4500P-B5,E	6/20/2024	mg/L	0.04
Inlet	Grab	TP	SM 4500P-B5,E	6/20/2024	mg/L	0.05
Deep Surface 1	Grab	TP	SM 4500P-B5,E	7/19/2024	mg/L	0.03
Deep Surface 2	Grab	TKN	Hach 10242	7/19/2024	mg/L	<1
Deep Bottom 3	60 ft.	TP	SM 4500P-B5,E	7/19/2024	mg/L	0.07
Deep Bottom 4	60 ft.	TKN	Hach 10242	7/19/2024	mg/L	2
Site 1	Grab	TP	SM 4500P-B5,E	7/19/2024	mg/L	BDL
Site 2	Grab	TP	SM 4500P-B5,E	7/19/2024	mg/L	BDL
Site 3	Grab	TP	SM 4500P-B5,E	7/19/2024	mg/L	0.14
Inlet	Grab	TP	SM 4500P-B5,E	7/19/2024	mg/L	0.02
Deep Surface 1	Grab	TP	SM 4500P-B5,E	8/22/2024	mg/L	0.03
Deep Surface 2	Grab	TKN	Hach 10242	8/22/2024	mg/L	<1
Deep Bottom 3	60 ft.	TP	SM 4500P-B5,E	8/22/2024	mg/L	0.10
Deep Bottom 4	60 ft.	TKN	Hach 10242	8/22/2024	mg/L	3
Site 1	Grab	TP	SM 4500P-B5,E	8/22/2024	mg/L	0.03
Site 2	Grab	TP	SM 4500P-B5,E	8/22/2024	mg/L	0.05
Site 3	Grab	TP	SM 4500P-B5,E	8/22/2024	mg/L	0.03
Inlet	Grab	TP	SM 4500P-B5,E	8/22/2024	mg/L	0.05
Deep Surface 1	Grab	TP	SM 4500P-B5,E	10/2/2024	mg/L	0.02
Deep Surface 2	Grab	TKN	Hach 10242	10/2/2024	mg/L	<1
Deep Bottom 3	60 ft.	TP	SM 4500P-B5,E	10/2/2024	mg/L	0.13
Deep Bottom 4	60 ft.	TKN	Hach 10242	10/2/2024	mg/L	3

Site 1	Grab	TP	SM 4500P-B5,E	10/2/2024	mg/L	0.01
Site 2	Grab	TP	SM 4500P-B5,E	10/2/2024	mg/L	BDL
Site 3	Grab	TP	SM 4500P-B5,E	10/2/2024	mg/L	0.01
Inlet	Grab	TP	SM 4500P-B5,E	10/2/2024	mg/L	0.02

Appendix F: Carlson's TSI values collected throughout the 2024 lake season.

Date	SD (ft.)	SD (m conversion)	TSI (SD)
6/20/2024	3.25	0.984848485	42.9956
6/20/2024	3.25	0.984848485	42.9956
6/20/2024	3.25	0.984848485	42.9956
6/20/2024	3	0.909090909	44.15037
7/19/2024	4.5	1.363636364	38.30075
7/19/2024	3.75	1.136363636	40.93109
7/19/2024	3.5	1.060606061	41.92645
7/19/2024	2	0.606060606	50
8/22/2024	3.75	1.136363636	40.93109
8/22/2024	3.75	1.136363636	40.93109
8/22/2024	3.5	1.060606061	41.92645
8/22/2024	2	0.606060606	50
10/2/2024	5.5	1.666666667	35.40568
10/2/2024	5.1	1.545454545	36.49503
10/2/2024	5	1.515151515	36.78072
10/2/2024	3.75	1.136363636	40.93109

Date	TP (ug/L)	TSI TP
6/20/2024	10	37.36966
6/20/2024	40	57.36966
6/20/2024	20	47.36966
6/20/2024	40	57.36966
6/20/2024	50	60.58894
7/19/2024	30	53.21928
7/19/2024	140	75.44321
7/19/2024	20	47.36966
8/22/2024	30	53.21928
8/22/2024	30	53.21928
8/22/2024	50	60.58894

8/22/2024	30	53.21928
8/22/2024	50	60.58894
10/2/2024	20	47.36966
10/2/2024	10	37.36966
10/2/2024	10	37.36966
10/2/2024	20	47.36966

Date	Chl a	TSI Chl a
6/20/2024	3.69	44.24718
6/20/2024	2.54	37.115
6/20/2024	3.59	43.80838
7/19/2024	0.77	0
7/19/2024	1.25	13.49768
7/19/2024	1.45	19.91179
8/22/2024	1.35	16.94229
8/22/2024	0.95	0
8/22/2024	1.75	26.78405
10/2/2024	2.83	39.4601
10/2/2024	2.95	40.29563
10/2/2024	3.23	42.00374

Appendix G: Historical DO and temperature data provided by the Apple Valley Fish Club.

Date	Depth	Temperature	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Sat.)
7/10/2019	2		8.7	
7/10/2019	4		8.8	
7/10/2019	6		8.8	
7/10/2019	8		8.8	
7/10/2019	10		8.7	
7/10/2019	12		8.4	
7/10/2019	14		5.2	
7/10/2019	16		3.1	
7/10/2019	18		0.9	
7/10/2019	20		0.3	
7/10/2019	22		0.2	
7/10/2019	24		0.1	
7/10/2019	26		0.1	
7/10/2019	28		0.1	
7/10/2019	30		0.1	

8/6/2020	2		7.4	
8/6/2020	4		7.55	
8/6/2020	6		7.67	
8/6/2020	8		7.76	
8/6/2020	10		7.8	
8/6/2020	12		7.8	
8/6/2020	14		7.76	
8/6/2020	16		7.72	
8/6/2020	18		6.6	
8/6/2020	20		3.5	
8/6/2020	22		2.71	
8/6/2020	24		1.39	
8/6/2020	26		1.67	
8/6/2020	28		0.4	
10/26/2020	2	59.4		82.3
10/26/2020	4	59.4		81.1
10/26/2020	6	59.4		80.4
10/26/2020	8	59.4		80
10/26/2020	10	59.4		79.5
10/26/2020	12	59.4		79.3
10/26/2020	14	59.4		78.4
10/26/2020	16	59.4		78.6
10/26/2020	18	59.4		78.6
10/26/2020	20	59.3		78.3
10/26/2020	22	59.3		78.8
10/26/2020	24	59.3		78.5
10/26/2020	26	59.3		75.6
10/26/2020	28	59.2		74.4
10/26/2020	30	59.1		71.5
10/26/2020	32	58.3		63.5
10/26/2020	34	58.7		63
6/15/2021	2		8	
6/15/2021	4		8	
6/15/2021	6		8.1	
6/15/2021	8		8.1	
6/15/2021	10		8.1	
6/15/2021	12		7.9	
6/15/2021	14		8	
6/15/2021	16		7.4	
6/15/2021	18		7.1	
6/15/2021	20		7	

6/15/2021	22		6.7	
6/15/2021	24		6.3	
6/15/2021	26		6.3	
6/15/2021	28		6.3	
6/15/2021	30		5.1	
6/15/2021	32		4.7	
6/15/2021	34		3.7	
6/15/2021	36		3.9	
7/13/2021	2	78.4	9.1	
7/13/2021	4	78.4	9.1	
7/13/2021	6	78.4	9.2	
7/13/2021	8	78.4	9.1	
7/13/2021	10	78.4	9.1	
7/13/2021	12	78.3	9.1	
7/13/2021	14	78	8.2	
7/13/2021	16	76.6	7.5	
7/13/2021	18	74.6	5.9	
7/13/2021	20	73.5	5.4	
7/13/2021	22	71.8	4.9	
7/13/2021	24	72	4.1	
7/13/2021	26	74.3	4.2	
7/13/2021	28	74	4.2	
7/13/2021	30	75	4.2	
8/10/2021	2			
8/10/2021	4	79.5	8.1	
8/10/2021	6	79.5	8.1	
8/10/2021	8	79.5	8.1	
8/10/2021	10	79.5	8.1	
8/10/2021	12	79.5	8.1	
8/10/2021	14	79.5	8.1	
8/10/2021	16	79	6.1	
8/10/2021	18	76.9	4	
8/10/2021	20	73.8	2.4	
8/10/2021	22	70.5	1.8	
8/10/2021	24	63.5	1.6	
8/10/2021	26	58.8	1.5	
8/10/2021	28	55.5	1.2	
8/10/2021	30	53.9	1.1	
9/14/2021	2	76.1	8.8	110
9/14/2021	4	75.9	8.8	110
9/14/2021	6	75.7	8.7	109

9/14/2021	8	75.5	8.6	107
9/14/2021	10	76	8.6	108
9/14/2021	12	75.5	8.6	107
9/14/2021	14	75.5	8.4	104
9/14/2021	16	75.4	8.4	104
9/14/2021	18	75.3	8.2	102
9/14/2021	20	75.3	8.2	102
9/14/2021	22	75	7.8	95
9/14/2021	24	74.9	7.5	93
9/14/2021	26	74.7	7	85
9/14/2021	28	74.5	6.9	84
9/14/2021	30	74.4	6.6	81
10/12/2021	2	70.7	9.4	111
10/12/2021	4	70.7	9.5	112
10/12/2021	6	70.7	9.5	111
10/12/2021	8	70.6	9.6	112
10/12/2021	10	70.6	9.4	112
10/12/2021	12	70.5	9.6	112
10/12/2021	14	70.6	9.4	112
10/12/2021	16	70.5	9.5	110
10/12/2021	18	70.5	9.5	110
10/12/2021	20	70.4	9.3	109
10/12/2021	22	70.5	9.4	109
10/12/2021	24	70.5	9.1	107
10/12/2021	26	70	7.8	83
10/12/2021	28	67.2	4.2	48
5/10/2022	2	61	9.8	102
5/10/2022	4	60.9	9.8	102
5/10/2022	6	60.9	9.8	102
5/10/2022	8	60.8	9.8	104
5/10/2022	10	60.5	9.8	101
5/10/2022	12	58.3	10.2	103
5/10/2022	14	57.5	10	102
5/10/2022	16	57.2	10	100
5/10/2022	18	56.3	10	99
5/10/2022	20	55.5	9.8	95
5/10/2022	22	55.5	9.5	93
5/10/2022	24	55.3	9.3	91
5/10/2022	26	55.4	9.3	91
5/10/2022	28	55.1	9.3	90
5/10/2022	30	53.3	9.2	88

6/14/2022	2			
6/14/2022	4	75.3	8.7	108
6/14/2022	6	74.5	8.7	106
6/14/2022	8	74.6	8.6	106
6/14/2022	10	74.5	8.3	104
6/14/2022	12	74.2	8.1	99
6/14/2022	14	72	6.6	80
6/14/2022	16	70.7	6	70
6/14/2022	18	68.6	4.8	55
6/14/2022	20	66	4.1	45
6/14/2022	22	63.5	3.9	41
6/14/2022	24	61.2	3.8	39
6/14/2022	26	59	3.7	38
6/14/2022	28	56.5	3.7	37
6/14/2022	30	55.6	3.7	36
7/12/2022	2			
7/12/2022	4	79.9	6.2	80
7/12/2022	6	79.4	6.3	81
7/12/2022	8	79.4	6.2	79
7/12/2022	10	79.2	6	77
7/12/2022	12	79.1	5.8	75
7/12/2022	14	78.7	5.9	74
7/12/2022	16	79.1	4.9	68
7/12/2022	18	75.6	3.6	44
7/12/2022	20	70.3	2.3	26
7/12/2022	22	66.7	1.9	21
7/12/2022	24	69.1	1.5	17
7/12/2022	26	59.9	1.3	15
7/12/2022	28	56.1	1.3	13
7/12/2022	30	55.9	1.1	11
8/9/2022	2	81.3	4.8	62
8/9/2022	4	81.3	4.7	61
8/9/2022	6	81.3	4.7	60
8/9/2022	8	81.3	4.6	59
8/9/2022	10	81.3	4.6	59
8/9/2022	12	81.3	4.5	58
8/9/2022	14	81.2	4.4	57
8/9/2022	16	79.6	3.7	45
8/9/2022	18	76.9	1.6	18
8/9/2022	20	75.6	1	11
8/9/2022	22	71.6	0.7	8

8/9/2022	24	67	0.5	6
8/9/2022	26	59	0.4	4
8/9/2022	28	55.2	0.4	4
8/9/2022	30	53.4	0.4	3
9/13/2022	2			
9/13/2022	4	74.6	6.2	76
9/13/2022	6	74.6	6.2	75
9/13/2022	8	74.6	6.1	75
9/13/2022	10	74.6	6.1	74
9/13/2022	12	74.6	6	74
9/13/2022	14	74.6	6	73
9/13/2022	16	74.6	5.9	73
9/13/2022	18	74.6	5.9	73
9/13/2022	20	74.6	5.9	73
9/13/2022	22	74.6	5.2	65
9/13/2022	24	72.1	1.5	14
9/13/2022	26	66	0.6	6
9/13/2022	28	63.8	0.3	3
9/13/2022	30	59	0.4	4
10/11/2022	2			
10/11/2022	4	61.3	8.4	86.3
10/11/2022	6	61.2	8.4	85
10/11/2022	8	61.2	8.3	84
10/11/2022	10	61.1	8.2	83.6
10/11/2022	12	61.1	8.1	82.4
10/11/2022	14	61.1	7.9	80.3
10/11/2022	16	61	7.8	78.9
10/11/2022	18	60.9	7.7	77.8
10/11/2022	20	60.7	6.9	69.6
10/11/2022	22	60.6	6.6	66.7
10/11/2022	24	60.5	6.2	62.8
10/11/2022	26	60.4	6	60.6
10/11/2022	28	60.1	5.9	59.6
10/11/2022	30	60	6.2	62.8
10/11/2022	32	60	1.3	10
4/11/2023	2			
4/11/2023	4	53.4	12.9	120
4/11/2023	6	52	13.1	120
4/11/2023	8	51.4	13.3	121.4
4/11/2023	10	50.7	13.3	118
4/11/2023	12	50.4	12.8	114

4/11/2023	14	50.1	12.6	111.3
4/11/2023	16	49.5	12.1	105.5
4/11/2023	18	48.8	11.49	99.9
4/11/2023	20	48.5	11	95
4/11/2023	22	48.5	10.25	87.8
4/11/2023	24	47.7	10	91.5
4/11/2023	26	48.1	10.4	90.4
4/11/2023	28	47.6	9.84	84.5
4/11/2023	30	47.2	9.44	81.9
4/11/2023	32			
5/9/2023	2			
5/9/2023	4	59	10.2	101
5/9/2023	6	58.5	10.3	101
5/9/2023	8	58	10.3	101
5/9/2023	10	57.7	10.3	100.6
5/9/2023	12	56.2	10.5	100.4
5/9/2023	14	56.2	10.5	98.6
5/9/2023	16	56.2	10.5	97.6
5/9/2023	18	52.9	10.3	95.3
5/9/2023	20	52.5	9.9	90.5
5/9/2023	22	52.4	9.5	87.2
5/9/2023	24	52.5	9.4	86
5/9/2023	26	52.3	9.2	83.6
5/9/2023	28	51.9	8.8	79.6
5/9/2023	30	52	8.4	75
5/9/2023	32			
6/20/2023	2			
6/20/2023	4	71.5	8.7	94.6
6/20/2023	6	70.5	8.7	99.7
6/20/2023	8	71.4	8.8	100.3
6/20/2023	10	71	8.7	98.8
6/20/2023	12	70.2	8.6	97
6/20/2023	14	69.6	8.5	94.9
6/20/2023	16	68.4	8	87.6
6/20/2023	18	67.3	7.2	78.1
6/20/2023	20	66	6.47	66.1
6/20/2023	22	60.5	5.7	45
6/20/2023	24	59.4	3.57	40.1
6/20/2023	26	56.7	1.65	15.8
6/20/2023	28	55.1	0.74	6.5
6/20/2023	30			

6/20/2023	32			
7/18/2023	2			
7/18/2023	4	80.1	8.25	103.3
7/18/2023	6	80	8.34	104.2
7/18/2023	8	79.9	8.43	104.9
7/18/2023	10	79.9	8.44	105.2
7/18/2023	12	79.8	8.43	104.7
7/18/2023	14	79.8	7.66	100.8
7/18/2023	16	74.4	5.6	50
7/18/2023	18	71.5	3.05	35.3
7/18/2023	20	68.8	1.79	15
7/18/2023	22	64.2	1.21	10.2
7/18/2023	24	60.2	0.78	6.9
7/18/2023	26	57.2	0.63	5.9
7/18/2023	28	55.3	0.55	5.1
7/18/2023	30	54	0.49	4.4
7/18/2023	32			
8/8/2023	2			
8/8/2023	4	78.3	7.83	93.5
8/8/2023	6	78.1	7.61	93
8/8/2023	8	78.1	7.73	94.5
8/8/2023	10	78	7.6	93.1
8/8/2023	12	78.1	7.68	94
8/8/2023	14	78	7.59	92.5
8/8/2023	16	77.4	6.88	87.4
8/8/2023	18	77.5	5.69	70.5
8/8/2023	20	76.6	3.06	35
8/8/2023	22	76	2.1	24.5
8/8/2023	24	72	1.65	19.1
8/8/2023	26	63.1	1.6	16.4
8/8/2023	28	59.8	1.44	14
8/8/2023	30	56.3	1.33	12.5
8/8/2023	32			
9/19/2023	2			
9/19/2023	4	71.5	7.3	83
9/19/2023	6	71.3	7.25	82.7
9/19/2023	8	71.2	7.2	81.8
9/19/2023	10	71.2	7.06	81.9
9/19/2023	12	71.2	7	80
9/19/2023	14	71.2	7.03	79.9
9/19/2023	16	71.1	7	79.6

9/19/2023	18	71.1	6.95	79.2
9/19/2023	20	71	6.74	77.7
9/19/2023	22	71	6.7	75.1
9/19/2023	24	70.9	6.8	76.4
9/19/2023	26	67	4.15	41
9/19/2023	28	59.7	3.9	38.5
9/19/2023	30	56.2	3.85	34.5
9/19/2023	32			
10/6/2023	2			
10/6/2023	4	71	9.89	115.9
10/6/2023	6	70.9	9.9	115
10/6/2023	8	70.9	9.95	115.5
10/6/2023	10	70.9	9.9	116
10/6/2023	12	70.9	9.84	115.5
10/6/2023	14	70.8	9.8	115.5
10/6/2023	16	70.7	9.42	110.5
10/6/2023	18	69.1	7.1	81.3
10/6/2023	20	69	6.3	70.1
10/6/2023	22	68.6	5.6	62.1
10/6/2023	24	68	3.88	42.7
10/6/2023	26	66.4	2.8	30.4
10/6/2023	28	65	2.2	23
10/6/2023	30	62	1.7	19
10/6/2023	32			
5/14/2024	2			
5/14/2024	4	66.7	12.9	145
5/14/2024	6	66.7	12.9	146
5/14/2024	8	66.7	12.9	145
5/14/2024	10	65.8	12.06	132
5/14/2024	12	64.9	11.5	126
5/14/2024	14	63.1	9.6	103
5/14/2024	16	60.9	8.4	86.8
5/14/2024	18	55.5	5.85	59.5
5/14/2024	20	55.9	5.25	52.7
5/14/2024	22	55.5	4.65	45
5/14/2024	24	54.2	4.5	43.6
5/14/2024	26	52.8	3.7	35.5
5/14/2024	28	51.8	3.7	34.5
5/14/2024	30	52.8	3.5	32.5
5/14/2024	32			
6/11/2024	2	72	9.3	110

6/11/2024	4	71	9.2	109
6/11/2024	6	71	9.1	107
6/11/2024	8	71	9	106
6/11/2024	10	71	9	106
6/11/2024	12	71	9	106
6/11/2024	14	71	8.4	99
6/11/2024	16	69	1.7	22
6/11/2024	18	62	0.2	2
6/11/2024	20	64	0.1	1.1
6/11/2024	22	58	0.9	0.7
6/11/2024	24			
6/11/2024	26			
6/11/2024	28			
6/11/2024	30			
6/11/2024	32			

Appendix H: Historical data provided by the AVPOA. Note: Temperature was reported in Celsius and Fahrenheit interchangeably at times.

Date	Location	Secchi (m)	Temp	Conductivity	Dissolved Oxygen (mg/L)	TSI (SD)
7/13/2021	Bennett Park	0.58	78.4		8.5	67.8
8/10/2021	Bennett Park	0.84	80.5		7.3	62.5
9/14/2021	Bennett Park	0.28	75.8		9.0	78.4
10/12/2021	Bennett Park	0.84	71.1		8.5	62.5
6/14/2022	Bennett Park	1.07	77.2		7.7	59.1
7/12/2022	Bennett Park	0.94	81.7		6.9	60.9
9/13/2022	Bennett Park	1.17	23.5		8.8	57.8
10/11/2022	Bennett Park	1.17	58.0		9.4	57.8
4/11/2023	Bennett Park	1.52	59.0		12.2	53.9
5/9/2023	Bennett Park	2.06	64.9		12.9	49.6
6/20/2023	Bennett Park	1.50	71.7		8.7	54.2
7/18/2023	Bennett Park	2.01	80.6		2.7	50.0
8/8/2023	Bennett Park	1.19	78.6		5.9	57.4
9/19/2023	Bennett Park	1.37	69.5		6.7	55.4
10/6/2023	Bennett Park	1.30	70.6		8.2	56.3
5/14/2024	Bennett Park	1.52	58.4		11.7	53.9
6/11/2024	Bennett Park	1.52	73.0		7.0	53.9
8/13/2024	Bennett Park	2.44	79.0		9.0	47.1
7/9/2024	Cove 1	1.02	82.0		7.0	59.8
7/12/2022	Cove1 Sutton Beach	1.50	78.6		6.8	54.2
5/24/2018	GCN	1.98	25.2		7.1	50.1

6/14/2022	GCS	1.17	75.4		8.5	57.8
10/19/2017	Gordon's Cove	1.98	19.2		6.2	50.1
6/15/1986	L1	1.55	24	216	9	53.7
8/15/1986	L1	1.32	25.0	215	10.0	56.0
6/15/1997	L1	1.35	22.0	176	10.0	55.7
8/15/1997	L1	1.30	23.0	185	9.0	56.3
6/22/2000	L1	1.17	24.0	205	8.0	57.8
8/31/2000	L1	1.47	26.0	220	9.0	54.4
8/2/2001	L1	0.91	26.0	250	8.0	61.3
5/11/2002	L1	1.02	14.0	180	9.0	59.8
5/29/2002	L1	1.70	19.0			52.3
6/14/2002	L1	1.07	23.0	250	12.0	59.1
6/26/2002	L1	1.52	24.0	250	9.0	53.9
8/7/2002	L1	0.66	24.0		8.0	66.0
8/28/2002	L1	1.22	24.0	240	10.0	57.1
9/30/2002	L1	1.04	19.0	215	10.0	59.4
10/11/2002	L1	1.35	18.0	200	9.0	55.7
5/16/2003	L1	0.76	16.0	200	10.0	63.9
5/30/2003	L1	0.97	21.0	220	11.0	60.5
6/6/2003	L1	1.52	18.0	210	10.0	53.9
6/27/2003	L1	0.91	24.0		10.0	61.3
7/15/2003	L1	0.79	23.0	215	8.0	63.4
7/23/2003	L1	0.91	26.0	232	10.0	61.3
10/20/2003	L1	1.19	12.0	184	9.0	57.4
5/9/2004	L1	1.37	16.0	190	13.0	55.4
7/13/2004	L1	1.04	28.0	235	12.0	59.4
8/25/2004	L1	1.22	25.0	220	12.0	57.1
9/24/2004	L1	1.37	22.0	215	11.0	55.4
5/20/2005	L1	1.12	16.0	188	12.0	58.4
9/8/2005	L1	0.81	24.0	218	10.0	63.0
6/5/2006	L1	1.22	19.0	192	11.0	57.1
6/30/2006	L1	0.71	25.0	240	13.0	64.9
7/19/2006	L1	0.94	27.0	212	14.0	60.9
8/29/2006	L1	0.91	26.0	230	8.0	61.3
5/14/2007	L1	1.47	18.0	190	11.0	54.4
5/30/2007	L1	1.02	26.0	260	12.0	59.8
6/18/2007	L1	1.27	27.0	270	11.0	56.6
7/16/2007	L1	0.86	25.0	243	10.0	62.1
7/31/2007	L1	0.91	25.0	220	10.0	61.3
8/2/2007	L1	1.52	26.0	220	10.0	53.9
9/10/2007	L1	0.94	25.0	237	7.0	60.9

9/24/2007	L1	0.61	24.0	220	7.0	67.1
10/10/2007	L1	0.89	23.0	235	7.0	61.7
5/13/2008	L1	1.40	15.0	177	10.0	55.2
6/13/2008	L1	0.91	32.0	255	7.0	61.3
6/23/2008	L1	0.91	23.0	250		61.3
7/29/2008	L1	0.91	26.0	222	8.0	61.3
5/19/2009	L1	1.14	17.0	209	10.0	58.1
6/23/2009	L1	0.91	26.0	265	8.0	61.3
7/16/2009	L1	0.91	24.0	263	9.0	61.3
7/25/2009	L1	1.22	26.0	225	7.0	57.1
8/17/2009	L1	0.71	28.0	225	9.0	64.9
9/17/2009	L1	0.61	52.0	240	10.0	67.1
11/9/2009	L1	1.22	24.0	130	12.0	57.1
5/26/2010	L1	1.32	21.0	296	11.0	56.0
6/25/2010	L1	0.71	24.0	251	13.0	64.9
8/25/2010	L1	0.66	23.0	260	12.0	66.0
8/30/2010	L1	0.69	23.0	270	10.0	65.4
10/19/2010	L1	1.07	14.0	212	0.0	59.1
6/6/2011	L1	1.24	26.0	250	10.0	56.8
6/28/2011	L1	0.91	26.0	248	10.0	61.3
7/27/2011	L1	0.89	28.0	255	10.0	61.7
8/25/2011	L1	0.89	26.0	255	5.0	61.7
10/29/2011	L1	1.19	12.0	190	10.0	57.4
5/22/2012	L1	1.27	19.3	220	9.5	56.6
6/25/2012	L1	0.91	27.0	248	6.5	61.3
8/15/2012	L1	0.91	24.7	240	8.3	61.3
8/15/2012	L1	0.91	24.4	240	8.3	61.3
9/28/2012	L1	0.91	18.1	220	9.0	61.3
5/31/2013	L1	1.12	22.7	258	9.1	58.4
6/24/2013	L1	0.84	27.0	260	10.0	62.5
7/25/2013	L1	1.09	24.3	230	9.5	58.7
8/26/2013	L1	1.14	26.2	245	11.1	58.1
9/18/2013	L1	1.04	24.0	222	9.9	59.4
5/28/2014	L1	1.35	23.2	212	9.8	55.7
6/30/2014	L1	1.02	26.1	220	12.2	59.8
7/30/2014	L1	0.86	22.9	230	12.2	62.1
9/29/2014	L1	1.09	22.0	122	220.0	58.7
5/12/2015	L1	0.84	24.1			62.5
6/24/2015	L1	1.37	27.0			55.4
7/24/2015	L1	0.81	25.0			63.0
8/21/2015	L1	0.58	25.5	245		67.8

9/23/2015	L1	0.79	24.0	235	8.5	63.4
10/20/2015	L1	1.12	14.3		9.6	58.4
5/19/2016	L1	1.40	15.0		10.8	55.2
6/27/2016	L1	1.12	26.9		7.9	58.4
7/26/2016	L1	0.89	28.6		7.7	61.7
8/24/2016	L1	0.89	27.3		10.2	61.7
9/20/2016	L1	0.89	25.0		7.6	61.7
10/11/2016	L1	1.07	18.3		7.7	59.1
8/16/2017	L1	1.22	27.0		12.0	57.1
9/28/2017	L1	0.64	24.0		6.2	66.6
10/19/2017	L1	1.37	17.4		10.2	55.4
5/24/2018	L1	0.84	23.6		6.7	62.5
6/14/2018	L1	1.52	26.5		8.0	53.9
7/18/2018	L1	0.66	29.3		5.9	66.0
9/27/2018	L1	1.17	22.7		6.6	57.8
5/22/2019	L1	0.99	62.0		8.9	60.1
8/12/2019	L1	0.84	77.7		7.7	62.5
10/9/2019	L1	1.02	65.6		9.5	59.8
10/15/2019	L1	1.12	61.6		8.9	58.4
8/6/2020	L1	1.14	77.5		8.7	58.1
9/22/2020	L1	1.55	67.1		8.9	53.7
10/26/2020	L1	1.35	56.6			55.7
6/15/2021	L1	0.94	73.0		6.0	60.9
7/13/2021	L1	1.17	78.0		8.9	57.8
8/10/2021	L1	0.89	78.9		7.8	61.7
9/14/2021	L1	1.30	74.5		9.0	56.3
10/12/2021	L1	1.04	70.8		9.5	59.4
5/10/2022	L1	0.99	60.2		9.3	60.1
6/14/2022	L1	1.27	72.5		8.4	56.6
7/12/2022	L1	0.84	78.8		5.1	62.5
8/9/2022	L1	0.79	80.7		4.4	63.4
9/13/2022	L1	0.84	22.7 c		8.1	62.5
10/11/2022	L1	1.07	59.1		9.2	59.1
4/11/2023	L1	1.04	53.4		11.3	59.4
5/9/2023	L1	1.02	55.4		10.1	59.8
6/20/2023	L1	1.14	71.5		8.3	58.1
7/18/2023	L1	0.74	79.2		8.2	64.4
8/8/2023	L1	0.61	76.5		7.3	67.1
9/19/2023	L1	0.94	68.5		8.4	60.9
10/6/2023	L1	0.84	70.3		9.1	62.5
5/14/2024	L1	0.72	63.7		12.5	64.7

6/11/2024	L1	0.53	69.6		8.2	69.1
7/9/2024	L1	0.86	80.0		9.7	62.1
8/13/2024	L1	0.76	77.0		8.2	63.9
6/25/2012	L10	1.83	26.0	230	8.1	51.3
7/26/2016	L10	1.73	29.6		8.9	52.1
7/13/2021	L10	1.60	78.4		7.8	53.2
9/14/2021	L10	1.65	76.2		8.8	52.8
5/10/2022	L10	1.75	61.2		9.5	51.9
5/9/2023	L10	1.36	58.1		10.2	55.6
6/20/2023	L10	1.50	76.6		8.3	54.2
5/14/2024	L10	0.65	67.3		12.8	66.3
8/15/1986	L2	1.17	26.0	207	10.0	57.8
6/15/1997	L2	1.07	22.0	171	9.0	59.1
8/15/1997	L2	1.14	24.0	181	9.0	58.1
6/22/2000	L2	1.27	25.0	205	9.0	56.6
8/31/2000	L2	0.66	24.0	220	8.0	66.0
8/2/2001	L2	1.52	27.0	225	8.0	53.9
5/11/2002	L2	1.24	14.0	180	9.0	56.8
5/29/2002	L2	2.59	19.0			46.3
6/14/2002	L2	2.03	23.0	240	11.0	49.8
6/26/2002	L2	1.91	24.0	230	9.0	50.7
8/7/2002	L2	1.22	26.0		8.0	57.1
8/28/2002	L2	1.65	25.0	210	10.0	52.8
9/30/2002	L2	1.60	22.0	210	10.0	53.2
10/11/2002	L2	1.83	19.0	200	8.0	51.3
5/16/2003	L2	1.70	19.0	201	11.0	52.3
5/30/2003	L2	1.78	20.0	212	11.0	51.7
6/6/2003	L2	1.63	19.0	208	10.0	53.0
6/27/2003	L2	1.22	22.0		10.0	57.1
7/15/2003	L2	1.22	16.0	210	9.0	57.1
7/23/2003	L2	0.91	23.0	230	9.0	61.3
8/12/2003	L2	1.27		220	11.0	56.6
8/12/2003	L2	0.91		270	9.0	61.3
10/20/2003	L2	1.57	15.0	190	8.0	53.4
5/9/2004	L2	1.37	17.0	190	13.0	55.4
7/13/2004	L2	1.40	28.0	224	12.0	55.2
8/25/2004	L2	1.22	25.0	214	12.0	57.1
9/24/2004	L2	1.60	23.0	205	12.0	53.2
5/20/2005	L2	1.45	16.0	179	12.0	54.7
9/8/2005	L2	1.57	25.0	218	9.0	53.4
6/5/2006	L2	1.78	22.0	220	11.0	51.7

6/30/2006	L2	1.45	26.0	220	15.0	54.7
7/19/2006	L2	1.12	27.0	212	13.0	58.4
8/29/2006	L2	1.19	26.0	220	8.0	57.4
5/14/2007	L2	1.83	19.0	189	12.0	51.3
5/30/2007	L2	1.65	25.0	235	12.0	52.8
6/18/2007	L2	1.88	27.0	235	11.0	50.9
7/16/2007	L2	1.32	25.0	208	12.0	56.0
7/31/2007	L2	1.22	27.0	200	9.0	57.1
8/2/2007	L2	1.52	27.0	210	9.0	53.9
9/10/2007	L2	1.30	26.0	220	8.0	56.3
9/24/2007	L2	1.32	26.0	210	8.0	56.0
10/10/2007	L2	1.40	24.0	220	9.0	55.2
5/13/2008	L2	1.88	18.0	179	10.0	50.9
6/13/2008	L2	1.22	33.0	240	7.0	57.1
6/23/2008	L2	1.22	25.0	222		57.1
7/29/2008	L2	1.27	27.0	215	8.0	56.6
5/19/2009	L2	2.16	18.0	203	10.0	48.9
6/23/2009	L2	2.08	26.0	250	9.0	49.4
7/16/2009	L2	1.37	25.0	245	10.0	55.4
7/25/2009	L2	1.22	27.0	215	9.0	57.1
8/17/2009	L2	1.42	26.0	210	8.0	54.9
9/17/2009	L2	1.52	23.0	235	7.0	53.9
11/9/2009	L2	1.52	22.0	170	10.0	53.9
5/26/2010	L2	2.11	21.0	248	12.0	49.2
6/25/2010	L2	1.07	24.0	245	12.0	59.1
8/25/2010	L2	0.91	24.0	255	10.0	61.3
8/30/2010	L2	1.19	24.0	253	9.0	57.4
10/19/2010	L2	1.17	14.0	220	0.0	57.8
6/6/2011	L2	1.93	26.0	205	10.0	50.5
6/28/2011	L2	1.52	26.0	238	10.0	53.9
7/27/2011	L2	1.37	29.0	249	11.0	55.4
8/25/2011	L2	0.97	27.0	245	7.0	60.5
10/29/2011	L2	1.55	13.0	190	8.0	53.7
5/22/2012	L2	1.60	20.5	216	12.0	53.2
6/25/2012	L2	1.12	28.0	230	7.6	58.4
8/15/2012	L2	1.27	25.3	242	7.2	56.6
8/15/2012	L2	1.27	25.3	242	7.2	56.6
9/28/2012	L2	1.14	18.8	220	8.1	58.1
5/31/2013	L2	1.57	22.0	239	9.9	53.4
6/24/2013	L2	1.52	27.0	250	10.6	53.9
7/25/2013	L2	1.57	25.5	240	8.2	53.4

8/26/2013	L2	1.40	26.0	240	11.2	55.2
9/18/2013	L2	1.09	24.0	220	8.3	58.7
5/28/2014	L2	2.13	23.0	210	10.0	49.1
6/30/2014	L2	1.63	26.3	220	11.5	53.0
7/30/2014	L2	1.19	23.6	215	10.8	57.4
9/29/2014	L2	1.42	21.0	130	210.0	54.9
10/13/2014	L2	1.40	19.3	213	8.0	55.2
5/12/2015	L2	1.52	24.8			53.9
6/24/2015	L2	1.60	27.0			53.2
7/24/2015	L2	0.94	25.0			60.9
8/21/2015	L2	1.17	26.1	237	8.7	57.8
9/23/2015	L2	1.50	27.0	230	7.7	54.2
10/20/2015	L2	1.55	15.2		8.8	53.7
5/19/2016	L2	2.34	16.4		10.8	47.8
6/27/2016	L2	2.95	26.9		7.6	44.4
7/26/2016	L2	1.68	29.6		9.0	52.5
8/24/2016	L2	1.66	27.3		9.7	52.7
9/20/2016	L2	1.98	25.9		7.2	50.1
10/11/2016	L2	1.57	20.0		6.7	53.4
8/16/2017	L2	1.78	27.0		12.1	51.7
9/28/2017	L2	1.12	23.9		8.0	58.4
10/19/2017	L2	1.45	19.1		8.8	54.7
5/24/2018	L2	1.88	25.3		7.6	50.9
6/14/2018	L2	2.13	26.9		8.3	49.1
7/18/2018	L2	1.88	30.4		8.4	50.9
9/27/2018	L2	1.47	24.4		6.4	54.4
5/22/2019	L2	2.21	64.0		9.7	48.6
8/12/2019	L2	1.65	79.6		8.3	52.8
10/9/2019	L2	1.14	69.2		8.2	58.1
10/15/2019	L2	1.30	65.4		7.8	56.3
8/6/2020	L2	1.52	79.3		8.0	53.9
9/22/2020	L2	1.75	69.5		8.7	51.9
10/26/2020	L2	1.88	59.3			50.9
6/15/2021	L2	0.99	75.4		7.4	60.1
7/13/2021	L2	1.70	78.4		8.9	52.3
8/10/2021	L2	1.27	79.8		7.9	56.6
9/14/2021	L2	1.96	76.1		8.8	50.3
10/12/2021	L2	1.55	71.0		9.3	53.7
5/10/2022	L2	1.65	61.1		9.6	52.8
6/14/2022	L2	1.17	72.5		8.4	57.8
7/12/2022	L2	1.02	79.4		5.9	59.8

8/9/2022	L2	1.07	81.4		4.5	59.1
9/13/2022	L2	1.12	23.8 c		7.1	58.4
10/11/2022	L2	1.55	61.4		8.7	53.7
4/11/2023	L2	1.37	53.7		12.5	55.4
5/9/2023	L2	1.32	57.8		10.1	56.0
6/20/2023	L2	1.57	71.5		8.1	53.4
7/18/2023	L2	0.99	80.2		8.1	60.1
8/8/2023	L2	0.97	78.4		7.7	60.5
9/19/2023	L2	1.45	71.3		7.2	54.7
10/6/2023	L2	1.18	71.4		9.3	57.6
5/14/2024	L2	0.84	67.1		13.0	62.5
6/11/2024	L2	0.79	71.0		9.4	63.4
7/9/2024	L2	1.07	81.0		7.7	59.1
8/13/2024	L2	0.89	78.0		7.4	61.7
6/22/2000	L3	1.35	24.0	205	8.0	55.7
8/31/2000	L3	1.68	25.0	200	9.0	52.5
8/2/2001	L3	1.73	27.0	210	8.0	52.1
5/11/2002	L3	1.27	14.0	190	9.0	56.6
5/29/2002	L3	2.74	19.0			45.4
6/14/2002	L3	2.03	24.0	240	11.0	49.8
6/26/2002	L3	2.36	26.0	220	7.0	47.6
8/7/2002	L3	1.37	26.0		8.0	55.4
8/28/2002	L3	1.70	25.0	210	10.0	52.3
9/30/2002	L3	2.03	21.0	210	9.0	49.8
10/11/2002	L3	1.83	19.0	200	8.0	51.3
5/16/2003	L3	1.68	18.0	200	11.0	52.5
5/30/2003	L3	1.78	20.0	213	11.0	51.7
6/6/2003	L3	2.13	18.0	201	10.0	49.1
6/27/2003	L3	1.35	25.0		10.0	55.7
7/15/2003	L3	1.45	15.0	216	8.0	54.7
7/23/2003	L3	1.22	24.0	232	9.0	57.1
8/12/2003	L3	1.37		220	11.0	55.4
10/20/2003	L3	1.73	15.0	190	7.0	52.1
5/9/2004	L3	1.30	16.0	190	13.0	56.3
7/13/2004	L3	1.55	28.0	225	11.0	53.7
8/25/2004	L3	1.22	24.0	212	12.0	57.1
9/24/2004	L3	1.65	23.0	205	12.0	52.8
5/20/2005	L3	1.65	16.0	178	12.0	52.8
9/8/2005	L3	1.57	25.0	217	9.0	53.4
6/5/2006	L3	1.83	22.0	220	11.0	51.3
6/30/2006	L3	1.68	26.0	220	14.0	52.5

7/19/2006	L3	1.09	28.0	212	13.0	58.7
8/29/2006	L3	1.32	26.0	220	8.0	56.0
5/14/2007	L3	2.03	20.0	190	11.0	49.8
5/30/2007	L3	1.75	25.0	230	12.0	51.9
6/18/2007	L3	2.11	26.0	235	11.0	49.2
7/16/2007	L3	1.52	26.0	208	13.0	53.9
7/31/2007	L3	1.52	26.0	200	10.0	53.9
8/2/2007	L3	1.52	27.0	210	10.0	53.9
9/10/2007	L3	1.42	26.0	219	8.0	54.9
9/24/2007	L3	1.42	26.0	210	8.0	54.9
10/10/2007	L3	1.52	24.0	218	9.0	53.9
5/13/2008	L3	2.24	18.0	177	10.0	48.4
6/13/2008	L3	1.22	36.0	235	6.0	57.1
6/23/2008	L3	1.83	25.0	219		51.3
7/29/2008	L3	1.60	28.0	210	7.0	53.2
5/19/2009	L3	2.13	18.0	206	10.0	49.1
6/23/2009	L3	2.36	27.0	250	9.0	47.6
7/16/2009	L3	1.37	25.0	245	11.0	55.4
7/25/2009	L3	1.14	27.0	210	9.0	58.1
8/17/2009	L3	1.22	26.0	210	8.0	57.1
9/17/2009	L3	1.73	23.0	240	8.0	52.1
11/9/2009	L3	1.73	22.0	170	10.0	52.1
5/26/2010	L3	2.06	21.0	245	11.0	49.6
6/25/2010	L3	1.22	24.0	245	12.0	57.1
8/25/2010	L3	1.17	24.0	250	9.0	57.8
8/30/2010	L3	1.32	24.0	250	9.0	56.0
10/19/2010	L3	1.40	16.0	220	0.0	55.2
6/6/2011	L3	2.31	26.0	205	10.0	47.9
6/28/2011	L3	1.52	25.0	232	10.0	53.9
7/27/2011	L3	1.55	29.0	250	10.0	53.7
8/25/2011	L3	1.27	26.0	240	7.0	56.6
10/29/2011	L3	1.55	13.0	190	7.0	53.7
5/22/2012	L3	1.80	21.1	219	11.8	51.5
6/25/2012	L3	1.24	27.0	230	6.9	56.8
8/15/2012	L3	1.45	25.4	240	7.2	54.7
8/15/2012	L3	1.45	25.4	240	7.2	54.7
9/28/2012	L3	1.42	19.5	218	8.1	54.9
5/31/2013	L3	1.91	21.8	238	9.9	50.7
6/24/2013	L3	1.68	27.0	250	10.8	52.5
7/25/2013	L3	1.68	25.6	240	8.2	52.5
8/26/2013	L3	1.42	25.8	240	11.3	54.9

9/18/2013	L3	1.12	24.5	220	8.2	58.4
5/28/2014	L3	2.21	22.9	208	9.9	48.6
6/30/2014	L3	1.60	26.2	220	11.5	53.2
7/30/2014	L3	1.30	23.6	215	9.2	56.3
9/29/2014	L3	1.40	21.0	133	210.0	55.2
10/13/2014	L3	1.50	19.4	215	8.1	54.2
5/12/2015	L3	1.68	22.0			52.5
6/24/2015	L3	1.83	27.0			51.3
7/24/2015	L3	1.17	26.0			57.8
8/21/2015	L3	1.22	26.1	235	8.3	57.1
9/23/2015	L3	1.65	28.0	225	8.2	52.8
10/20/2015	L3	1.57	15.3		8.4	53.4
5/19/2016	L3	2.41	16.4		10.8	47.3
6/27/2016	L3	3.66	27.0		8.3	41.3
7/26/2016	L3	2.13	29.7		9.1	49.1
8/24/2016	L3	2.11	27.7		8.9	49.2
9/20/2016	L3	1.75	25.9		7.8	51.9
10/11/2016	L3	1.42	20.1		6.5	54.9
8/16/2017	L3	1.70	27.1		12.5	52.3
9/28/2017	L3	1.17	24.1		9.1	57.8
10/19/2017	L3	1.70	19.0		8.1	52.3
5/24/2018	L3	2.31	25.6		7.6	47.9
6/14/2018	L3	2.31	26.8		8.1	47.9
7/18/2018	L3	1.96	30.4		8.4	50.3
9/27/2018	L3	1.57	24.4		5.6	53.4
5/22/2019	L3	2.03	64.0		9.6	49.8
8/12/2019	L3	1.65	79.6		8.3	52.8
10/9/2019	L3	1.37	69.3		7.9	55.4
10/15/2019	L3	1.40	65.4		7.3	55.2
8/6/2020	L3	1.93	78.8		7.3	50.5
9/22/2020	L3	1.96	69.5		8.7	50.3
10/26/2020	L3	1.93	59.4			50.5
6/15/2021	L3	1.73	76.5		7.9	52.1
7/13/2021	L3	1.91	78.4		9.1	50.7
8/10/2021	L3	1.50	79.5		8.1	54.2
9/14/2021	L3	2.03	76.1		8.8	49.8
10/12/2021	L3	1.60	70.7		9.4	53.2
5/10/2022	L3	2.03	60.9		9.7	49.8
6/14/2022	L3	1.22	75.2		8.4	57.1
7/12/2022	L3	1.27	79.6		6.0	56.6
8/9/2022	L3	1.14	81.3		4.8	58.1

9/13/2022	L3	1.35	23.7 c		6.8	55.7
10/11/2022	L3	1.52	61.4		8.5	53.9
4/11/2023	L3	1.35	53.9		12.8	55.7
5/9/2023	L3	1.55	59.1		10.6	53.7
6/20/2023	L3	1.68	71.5		8.5	52.5
7/18/2023	L3	1.12	80.1		8.1	58.4
8/8/2023	L3	1.07	78.4		7.9	59.1
9/19/2023	L3	1.55	71.5		7.4	53.7
10/6/2023	L3	1.42	71.0		9.7	54.9
5/14/2024	L3	0.74	66.8		12.9	64.4
7/9/2024	L3	1.17	81.0		8.6	57.8
8/13/2024	L3	1.19	79.0		8.1	57.4
6/22/2000	L4	1.45	24.0	200	9.0	54.7
8/2/2001	L4	1.80	27.0	225	8.0	51.5
5/11/2002	L4	1.63	14.0	180	10.0	53.0
5/29/2002	L4	3.05	19.0			43.9
6/14/2002	L4	2.34	24.0	240	11.0	47.8
6/26/2002	L4	2.90	27.0	220	8.0	44.7
8/7/2002	L4	1.78	26.0		8.0	51.7
8/28/2002	L4	1.88	26.0	210	9.0	50.9
9/30/2002	L4	2.34	19.0	210	8.0	47.8
10/11/2002	L4	2.29	19.0	200	8.0	48.1
5/16/2003	L4	1.85	19.0	200	11.0	51.1
5/30/2003	L4	1.91	20.0	215	11.0	50.7
6/6/2003	L4	1.98	19.0	205	10.0	50.1
6/27/2003	L4	1.83	24.0		10.0	51.3
7/15/2003	L4	1.68	17.0	210	9.0	52.5
7/23/2003	L4	1.27	24.0	230	9.0	56.6
8/12/2003	L4	1.37		218	11.0	55.4
9/29/2003	L4	1.60	19.0		7.0	53.2
10/20/2003	L4	1.88	15.0	190	6.0	50.9
5/9/2004	L4	1.37	16.0	190	13.0	55.4
7/13/2004	L4	1.57	28.0	223	11.0	53.4
8/25/2004	L4	1.22	24.0	211	13.0	57.1
9/24/2004	L4	1.65	23.0	205	12.0	52.8
5/20/2005	L4	1.52	17.0	179	12.0	53.9
9/8/2005	L4	1.78	25.0	213	9.0	51.7
6/5/2006	L4	2.21	22.0	220	11.0	48.6
6/30/2006	L4	1.83	26.0	220	14.0	51.3
7/19/2006	L4	1.14	28.0	212	14.0	58.1
8/29/2006	L4	1.57	26.0	215	8.0	53.4

5/14/2007	L4	2.06	20.0	193	11.0	49.6
5/30/2007	L4	1.88	25.0	225	12.0	50.9
6/18/2007	L4	2.16	27.0	235	11.0	48.9
7/16/2007	L4	1.57	26.0	206	11.0	53.4
7/31/2007	L4	1.52	28.0	201	11.0	53.9
8/2/2007	L4	1.52	26.0	210	9.0	53.9
9/10/2007	L4	1.37	26.0	216	8.0	55.4
9/24/2007	L4	1.52	26.0	212	9.0	53.9
10/10/2007	L4	1.73	24.0	215	9.0	52.1
5/13/2008	L4	1.88	18.0	177	10.0	50.9
6/13/2008	L4	1.98	38.0	230	6.0	50.1
6/23/2008	L4	1.83	25.0	215		51.3
7/29/2008	L4	1.52	27.0	210	8.0	53.9
5/19/2009	L4	2.06	18.0	209	11.0	49.6
6/23/2009	L4	2.72	27.0	250	9.0	45.6
7/16/2009	L4	1.37	25.0	245	11.0	55.4
7/25/2009	L4	1.14	27.0	200	9.0	58.1
8/17/2009	L4	1.37	26.0	210	8.0	55.4
9/17/2009	L4	1.50	23.0	240	8.0	54.2
11/9/2009	L4	1.63	22.0	170	8.0	53.0
5/26/2010	L4	2.39	21.0	244	11.0	47.4
6/25/2010	L4	1.22	24.0	245	12.0	57.1
8/25/2010	L4	1.42	24.0	251	9.0	54.9
8/30/2010	L4	1.42	24.0	250	9.0	54.9
10/19/2010	L4	1.52	14.0	220	0.0	53.9
6/6/2011	L4	2.57	26.0	210	10.0	46.4
6/28/2011	L4	1.22	25.0	230	11.0	57.1
7/27/2011	L4	1.85	29.0	250	10.0	51.1
8/25/2011	L4	1.40	26.0	235	8.0	55.2
10/29/2011	L4	1.68	13.0	190	7.0	52.5
5/22/2012	L4	1.93	21.5	220	11.6	50.5
6/25/2012	L4	1.07	35.0	230	7.3	59.1
8/15/2012	L4	1.55	25.4	240	7.1	53.7
8/15/2012	L4	1.55	25.4	240	7.1	53.7
9/28/2012	L4	1.75	19.5	216	7.8	51.9
5/31/2013	L4	1.80	21.7	235	10.0	51.5
6/24/2013	L4	1.73	27.0	250	10.4	52.1
7/25/2013	L4	1.91	25.9	240	10.5	50.7
8/26/2013	L4	1.63	26.3	240	11.1	53.0
9/18/2013	L4	1.19	24.5	220	7.8	57.4
5/28/2014	L4	2.18	22.9	207	10.0	48.7

6/30/2014	L4	1.60	26.0	220	10.7	53.2
7/30/2014	L4	1.24	23.7	212	10.2	56.8
9/29/2014	L4	1.45	21.0	129	210.0	54.7
10/13/2014	L4	1.50	20.1	213	9.3	54.2
5/12/2015	L4	1.85	21.3			51.1
6/24/2015	L4	1.93	27.0			50.5
7/24/2015	L4	1.17	27.0			57.8
8/21/2015	L4	1.35	25.9	235	7.4	55.7
9/23/2015	L4	1.68	28.0	225	8.4	52.5
10/20/2015	L4	1.63	15.3		8.5	53.0
5/19/2016	L4	2.67	17.1		11.0	45.8
6/27/2016	L4	3.86	27.2		8.3	40.5
7/26/2016	L4	1.83	29.5		9.0	51.3
8/24/2016	L4	2.13	25.6		8.5	49.1
9/20/2016	L4	1.91	26.2		7.9	50.7
10/11/2016	L4	1.63	20.4		6.6	53.0
8/16/2017	L4	1.75	26.9		12.5	51.9
9/28/2017	L4	1.32	24.4		9.3	56.0
10/19/2017	L4	1.88	19.1		6.8	50.9
5/24/2018	L4	2.57	25.8		7.4	46.4
6/14/2018	L4	2.74	26.8		7.8	45.4
7/18/2018	L4	2.39	30.4		8.4	47.4
9/27/2018	L4	1.91	24.3		4.4	50.7
5/22/2019	L4	2.29	65.0		9.8	48.1
8/12/2019	L4	2.08	79.6		8.4	49.4
10/9/2019	L4	1.52	69.6		7.9	53.9
10/15/2019	L4	1.83	65.6		7.2	51.3
8/6/2020	L4	2.26	79.1		7.8	48.2
9/22/2020	L4	1.96	69.4		8.6	50.3
10/26/2020	L4	1.91	59.5			50.7
6/15/2021	L4	1.96	76.7		7.9	50.3
7/13/2021	L4	2.36	78.3		8.9	47.6
8/10/2021	L4	1.60	79.3		7.9	53.2
9/14/2021	L4	1.96	75.8		8.6	50.3
10/12/2021	L4	1.85	70.3		9.3	51.1
5/10/2022	L4	1.96	60.5		9.8	50.3
6/14/2022	L4	1.24	75.5		8.3	56.8
7/12/2022	L4	1.35	79.8		6.8	55.7
8/9/2022	L4	1.27	81.1		5.3	56.6
9/13/2022	L4	1.60	23.6 c		6.4	53.2
10/11/2022	L4	1.80	61.0		8.0	51.5

4/11/2023	L4	1.50	52.8		13.2	54.2
5/9/2023	L4	1.73	59.3		10.7	52.1
6/20/2023	L4	1.88	71.6		8.3	50.9
7/18/2023	L4	1.14	77.8		7.5	58.1
8/8/2023	L4	1.13	78.3		7.7	58.2
9/19/2023	L4	1.55	71.8		7.4	53.7
10/6/2023	L4	1.52	70.6		9.6	53.9
5/14/2024	L4	0.72	66.7		12.5	64.7
6/11/2024	L4	0.91	72.0		9.7	61.3
7/9/2024	L4	1.17	81.0		8.7	57.8
8/13/2024	L4	1.12	79.0		8.3	58.4
8/15/1986	**L5**	**1.14**	**26.0**	**204**	**10.0**	**58.1**
6/15/1997	L5	1.02	20.0	166	10.0	59.8
8/15/1997	L5	1.14	23.0	181	9.0	58.1
6/22/2000	L5	1.35	24.0	205	8.0	55.7
8/31/2000	L5	2.34	25.0	190	9.0	47.8
8/2/2001	L5	2.06	27.0	210	8.0	49.6
5/11/2002	L5	1.55	13.0	185	9.0	53.7
5/29/2002	L5	3.05	19.0			43.9
6/14/2002	L5	2.44	25.0	240	11.0	47.1
6/26/2002	L5	2.95	27.0	220	6.0	44.4
8/7/2002	L5	2.06	26.0		8.0	49.6
8/28/2002	L5	1.65	26.0	210	9.0	52.8
9/30/2002	L5	2.24	21.0	205	9.0	48.4
10/11/2002	L5	2.29	19.0	200	8.0	48.1
5/16/2003	L5	1.93	18.0	201	11.0	50.5
5/30/2003	L5	1.88	20.0	216	11.0	50.9
6/6/2003	L5	1.83	18.0	201	10.0	51.3
6/27/2003	L5	1.96	24.0		10.0	50.3
7/15/2003	L5	1.52	16.0	210	9.0	53.9
7/23/2003	L5	1.47	24.0	230	9.0	54.4
8/12/2003	L5	1.37		218	11.0	55.4
9/29/2003	L5	1.83	19.0		10.0	51.3
10/20/2003	L5	1.88	15.0	190	7.0	50.9
5/9/2004	L5	1.37	16.0	188	13.0	55.4
7/13/2004	L5	1.65	28.0	222	11.0	52.8
8/25/2004	L5	1.22	24.0	207	13.0	57.1
9/24/2004	L5	1.73	23.0	205	12.0	52.1
5/20/2005	L5	1.60	17.0	179	12.0	53.2
9/8/2005	L5	1.91	24.0	210	10.0	50.7
6/5/2006	L5	2.26	22.0	220	11.0	48.2

6/30/2006	L5	1.83	26.0	220	13.0	51.3
7/19/2006	L5	0.99	28.0	212	19.0	60.1
8/29/2006	L5	1.47	26.0	215	8.0	54.4
5/14/2007	L5	1.24	24.0	203	9.0	56.8
5/14/2007	L5	2.34	20.0	193	11.0	47.8
5/30/2007	L5	2.46	25.0	220	12.0	47.0
6/18/2007	L5	2.21	27.0	235	11.0	48.6
7/16/2007	L5	1.83	27.0	209	11.0	51.3
7/31/2007	L5	1.55	27.0	202	10.0	53.7
8/2/2007	L5	1.83	27.0	205	10.0	51.3
9/10/2007	L5	1.55	26.0	215	8.0	53.7
9/24/2007	L5	1.96	26.0	212	9.0	50.3
10/10/2007	L5	1.93	24.0	215	9.0	50.5
5/13/2008	L5	2.29	18.0	178	10.0	48.1
6/13/2008	L5	1.98	36.0	231	6.0	50.1
6/23/2008	L5	1.65	25.0	215		52.8
7/29/2008	L5	1.45	27.0	205	8.0	54.7
5/19/2009	L5	2.03	18.0	209	11.0	49.8
6/23/2009	L5	2.67	27.0	250	9.0	45.8
7/16/2009	L5	1.83	25.0	245	11.0	51.3
7/25/2009	L5	1.14	27.0	200	9.0	58.1
8/17/2009	L5	1.52	26.0	210	8.0	53.9
9/17/2009	L5	1.55	24.0	235	9.0	53.7
11/9/2009	L5	1.73	22.0	172	9.0	52.1
5/26/2010	L5	2.44	21.0	242	11.0	47.1
6/25/2010	L5	1.42	24.0	245	12.0	54.9
8/25/2010	L5	1.40	24.0	250	10.0	55.2
8/30/2010	L5	1.27	24.0	250	9.0	56.6
10/19/2010	L5	1.57	16.0	220	0.0	53.4
6/6/2011	L5	2.51	26.0	205	10.0	46.7
6/28/2011	L5	1.47	25.0	290	10.0	54.4
7/27/2011	L5	2.11	29.0	248	10.0	49.2
8/25/2011	L5	1.60	26.0	240	7.0	53.2
10/29/2011	L5	1.73	14.0	190	7.0	52.1
5/22/2012	L5	2.06	21.9	220	11.4	49.6
6/25/2012	L5	1.47	34.0	230	6.8	54.4
8/15/2012	L5	1.45	25.6	240	7.2	54.7
8/15/2012	L5	1.45	25.6	240	7.2	54.7
9/28/2012	L5	1.68	19.3	210	7.7	52.5
5/31/2013	L5	2.18	21.7	230	9.8	48.7
6/24/2013	L5	1.91	27.0	25.5	10.8	50.7

7/25/2013	L5	1.80	25.8	240	8.8	51.5
8/26/2013	L5	1.65	26.1	240	10.6	52.8
9/18/2013	L5	1.22	24.5	220	8.3	57.1
5/28/2014	L5	2.21	23.0	209	9.9	48.6
6/30/2014	L5	1.85	26.0	220	10.5	51.1
7/30/2014	L5	1.37	23.8	212	10.5	55.4
9/29/2014	L5	1.57	21.0	130	215.0	53.4
10/13/2014	L5	1.40	20.1	212	9.6	55.2
5/12/2015	L5	1.60	20.8			53.2
6/24/2015	L5	1.98	27.0			50.1
7/24/2015	L5	1.17	26.0			57.8
8/21/2015	L5	1.19	25.9	231	7.4	57.4
9/23/2015	L5	1.75	28.0	228	8.7	51.9
10/20/2015	L5	1.80	15.4		8.7	51.5
5/19/2016	L5	2.64	17.1		10.9	46.0
6/27/2016	L5	4.17	27.1		8.4	39.4
7/26/2016	L5	1.98	29.6		8.9	50.1
8/24/2016	L5	2.54	27.6		8.6	46.6
9/20/2016	L5	1.91	26.4		7.9	50.7
10/11/2016	L5	1.73	20.4		6.8	52.1
8/16/2017	L5	1.96	27.1		12.7	50.3
9/28/2017	L5	1.45	24.8		9.2	54.7
5/24/2018	L5	2.59	25.8		7.4	46.3
6/14/2018	L5	3.18	27.1		8.0	43.3
7/18/2018	L5	2.24	30.3		8.5	48.4
9/27/2018	L5	2.06	24.5		4.3	49.6
10/19/2018	L5	1.88	19.0		7.2	50.9
5/22/2019	L5	2.18	65.0		9.8	48.7
8/12/2019	L5	1.93	83.0		8.6	50.5
10/9/2019	L5	1.57	69.7		8.4	53.4
10/15/2019	L5	1.65	65.5		7.2	52.8
8/6/2020	L5	2.34	78.6		7.9	47.8
9/22/2020	L5	1.91	69.4		8.5	50.7
10/26/2020	L5	2.08	59.3			49.4
6/15/2021	L5	2.03	77.1		7.7	49.8
7/13/2021	L5	2.03	78.2		8.9	49.8
8/10/2021	L5	1.60	79.2		8.1	53.2
9/14/2021	L5	1.91	75.6		8.7	50.7
10/12/2021	L5	1.45	70.2		9.1	54.7
5/10/2022	L5	2.21	59.8		9.6	48.6
6/14/2022	L5	1.24	76.3		8.5	56.8

7/12/2022	L5	1.42	79.5		7.0	54.9
8/9/2022	L5	1.37	80.9		5.4	55.4
9/13/2022	L5	1.68	23.4 c		6.3	52.5
10/11/2022	L5	1.88	61.0		7.6	50.9
4/11/2023	L5	1.70	53.2		12.9	52.3
5/9/2023	L5	1.83	60.5		10.3	51.3
6/20/2023	L5	1.68	71.1		8.5	52.5
7/18/2023	L5	1.24	79.7		7.8	56.8
8/8/2023	L5	1.13	78.4		7.8	58.2
9/19/2023	L5	1.60	72.0		7.6	53.2
10/6/2023	L5	1.47	70.2		9.4	54.4
5/14/2024	L5	0.75	56.3		12.5	64.2
6/11/2024	L5	0.76	72.0		9.4	63.9
6/20/2024	L5	0.99				60.1
7/9/2024	L5	1.35	80.0		8.7	55.7
7/19/2024	L5	1.37				55.5
8/13/2024	L5	1.14	79.0		7.9	58.1
8/22/2024	L5	1.14				58.1
10/2/2024	L5	1.67				52.6
6/22/2000	L6	1.50	24.0	204	8.0	54.2
8/31/2000	L6	2.13	25.0	180	9.0	49.1
8/2/2001	L6	1.30	26.0	210	8.0	56.3
5/11/2002	L6	1.70	14.0	185	9.0	52.3
5/29/2002	L6	2.74	19.0			45.4
6/14/2002	L6	2.24	24.0	240	10.0	48.4
6/26/2002	L6	2.21	27.0	220	6.0	48.6
8/7/2002	L6	1.85	26.0		8.0	51.1
8/28/2002	L6	1.60	26.0	210	9.0	53.2
9/30/2002	L6	2.13	21.0	205	9.0	49.1
10/11/2002	L6	2.18	19.0	200	8.0	48.7
5/16/2003	L6	1.60	18.0	200	12.0	53.2
5/30/2003	L6	1.98	20.0	212	10.0	50.1
6/6/2003	L6	1.83	19.0	202	10.0	51.3
6/27/2003	L6	1.83	24.0		10.0	51.3
7/15/2003	L6	1.52	16.0	230	9.0	53.9
7/23/2003	L6	1.12	24.0	230	10.0	58.4
8/12/2003	L6	1.37		219	11.0	55.4
9/29/2003	L6	1.22	19.0		9.0	57.1
10/20/2003	L6	1.70	15.0	190	7.0	52.3
5/9/2004	L6	1.37	16.0	189	13.0	55.4
7/13/2004	L6	1.73	28.0	222	11.0	52.1

8/25/2004	L6	1.22	24.0	205	11.0	57.1
9/24/2004	L6	1.70	23.0	205	11.0	52.3
5/20/2005	L6	1.45	17.0	180	11.0	54.7
9/8/2005	L6	1.35	24.0	212	9.0	55.7
6/5/2006	L6	1.80	22.0	220	10.0	51.5
6/30/2006	L6	1.85	26.0	230	13.0	51.1
6/30/2006	L6	1.17	28.0	212	13.0	57.8
8/29/2006	L6	1.47	29.0	215	8.0	54.4
5/14/2007	L6	1.78	21.0	194	10.0	51.7
5/30/2007	L6	2.08	25.0	220	11.0	49.4
6/18/2007	L6	1.98	27.0	235	11.0	50.1
7/16/2007	L6	1.88	27.0	205	11.0	50.9
7/31/2007	L6	1.52	27.0	202	10.0	53.9
8/2/2007	L6	1.52	27.0	205	10.0	53.9
9/10/2007	L6	1.30	26.0	217	8.0	56.3
9/24/2007	L6	1.63	26.0	212	8.0	53.0
10/10/2007	L6	1.63	24.0	215	8.0	53.0
5/13/2008	L6	1.75	18.0	179	10.0	51.9
6/13/2008	L6	1.98	34.0	230	6.0	50.1
6/23/2008	L6	1.68	25.0	215		52.5
7/29/2008	L6	1.52	27.0	202	8.0	53.9
5/19/2009	L6	2.03	18.0	210	11.0	49.8
6/23/2009	L6	2.11	26.0	252	9.0	49.2
7/16/2009	L6	1.22	22.0	245	10.0	57.1
7/25/2009	L6	1.22	27.0	200	9.0	57.1
8/17/2009	L6	1.40	27.0	208	8.0	55.2
9/17/2009	L6	1.60	24.0	235	9.0	53.2
11/9/2009	L6	1.91	22.0	175	9.0	50.7
5/26/2010	L6	2.44	21.0	241	11.0	47.1
6/25/2010	L6	1.22	24.0	245	12.0	57.1
8/25/2010	L6	1.30	24.0	250	9.0	56.3
8/30/2010	L6	1.50	24.0	250	9.0	54.2
10/19/2010	L6	1.22	16.0	220	0.0	57.1
6/6/2011	L6	2.06	26.0	210	10.0	49.6
6/28/2011	L6	1.83	25.0	235	10.0	51.3
7/27/2011	L6	1.96	29.0	249	10.0	50.3
8/25/2011	L6	1.50	26.0	240	7.0	54.2
10/29/2011	L6	1.63	13.0	190	8.0	53.0
5/22/2012	L6	1.91	22.2	222	10.9	50.7
6/25/2012	L6	1.04	35.0	225	7.5	59.4
8/15/2012	L6	1.63	25.7	240	7.6	53.0

8/15/2012	L6	1.63	25.7	240	7.6	53.0
9/28/2012	L6	1.47	19.3	212	8.0	54.4
5/31/2013	L6	1.68	21.0	230	9.9	52.5
6/24/2013	L6	1.83	27.0	250	10.2	51.3
7/25/2013	L6	1.70	25.7	240	9.0	52.3
8/26/2013	L6	1.65	26.1	240	10.7	52.8
9/18/2013	L6	0.99	25.0	220	8.7	60.1
5/28/2014	L6	2.11	22.8	205	10.1	49.2
6/30/2014	L6	1.73	25.7	220	9.9	52.1
7/30/2014	L6	1.22	23.8	210	10.3	57.1
9/29/2014	L6	1.37	22.0	132	210.0	55.4
10/13/2014	L6	1.32	19.9	212	9.7	56.0
5/12/2015	L6	1.60	20.6			53.2
6/24/2015	L6	1.73	27.0			52.1
7/24/2015	L6	1.14	25.0			58.1
8/21/2015	L6	1.35	25.5	230	7.0	55.7
9/23/2015	L6	1.57	28.0	225	8.5	53.4
10/20/2015	L6	1.65	15.3		8.3	52.8
5/19/2016	L6	2.64	17.3		10.7	46.0
6/27/2016	L6	3.56	27.0		8.6	41.7
7/26/2016	L6	1.88	29.8		9.2	50.9
8/24/2016	L6	2.01	27.4		8.4	50.0
9/20/2016	L6	1.91	26.3		7.9	50.7
10/11/2016	L6	1.63	20.2		6.8	53.0
8/16/2017	L6	1.91	27.5		12.3	50.7
9/28/2017	L6	1.30	25.1		8.5	56.3
10/19/2017	L6	1.85	19.0		7.0	51.1
5/24/2018	L6	2.41	26.2		7.3	47.3
6/14/2018	L6	3.38	26.7		7.9	42.4
7/18/2018	L6	2.26	30.5		8.7	48.2
9/27/2018	L6	1.73	24.4		4.5	52.1
5/22/2019	L6	2.13	65.0		9.8	49.1
8/12/2019	L6	1.83	80.0		8.6	51.3
10/9/2019	L6	1.40	69.6		8.6	55.2
10/15/2019	L6	1.78	65.4		7.4	51.7
8/6/2020	L6	2.13	79.2		8.1	49.1
9/22/2020	L6	2.06	69.2		8.5	49.6
10/26/2020	L6	2.01	59.3			50.0
6/15/2021	L6	1.80	77.3		7.5	51.5
7/13/2021	L6	1.78	78.2		8.9	51.7
8/10/2021	L6	1.52	79.1		8.2	53.9

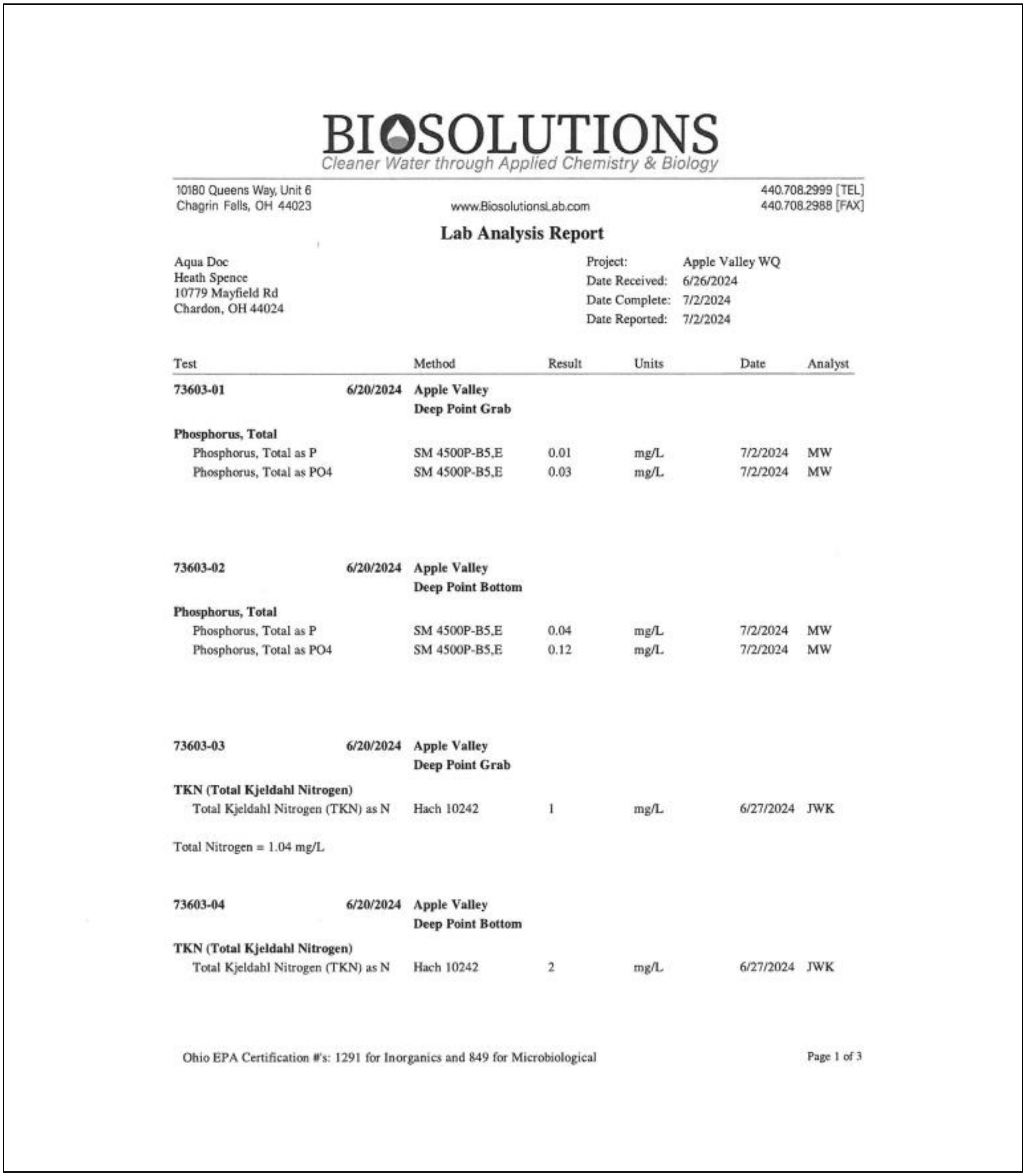
9/14/2021	L6	1.93	75.4		8.5	50.5
10/12/2021	L6	1.73	69.8		9.2	52.1
5/10/2022	L6	2.08	60.1		9.6	49.4
6/14/2022	L6	1.28	75.6		8.4	56.4
7/12/2022	L6	1.24	79.4		5.9	56.8
8/9/2022	L6	1.37	80.7		5.4	55.4
9/13/2022	L6	1.35	23.3 c		6.1	55.7
10/11/2022	L6	1.60	61.1		7.8	53.2
4/11/2023	L6	1.57	53.1		12.9	53.4
5/9/2023	L6	1.80	61.2		9.9	51.5
6/20/2023	L6	1.80	71.7		8.7	51.5
7/18/2023	L6	1.24	79.5		8.0	56.8
8/8/2023	L6	1.17	78.3		7.9	57.8
9/19/2023	L6	1.52	71.9		7.6	53.9
10/6/2023	L6	1.42	69.9		9.0	54.9
5/14/2024	L6	0.81	56.3		12.5	63.0
6/11/2024	L6	0.94	72.0		9.9	60.9
7/9/2024	L6	1.22	80.0		9.8	57.1
8/13/2024	L6	1.12	79.0		8.4	58.4
8/31/2000	L7	1.83	25.0	220	8.0	51.3
8/2/2001	L7	1.22	27.0	210	8.0	57.1
5/16/2003	L7	1.37	18.0	200	11.0	55.4
6/25/2012	L7	1.14	36.0	230	6.9	58.1
5/19/2016	L7	2.34	17.7		10.7	47.8
8/16/2017	L7	2.06	27.6		12.2	49.6
7/18/2018	L7	2.11	30.4		9.8	49.2
10/15/2019	L7	1.60	65.6		7.4	53.2
10/26/2020	L7	1.78	58.8			51.7
8/10/2021	L7	1.51	79.2		8.1	54.0
10/11/2022	L7	1.52	60.9		8.1	53.9
7/18/2023	L7	1.14	79.4		8.0	58.1
10/6/2023	L7	1.44	70.0		9.0	54.8
6/25/2012	L8	1.12	29.0	225	6.5	58.4
8/12/2019	L8	1.98	80.3		8.4	50.1
8/6/2020	L8	2.08	78.8		7.6	49.4
6/15/2021	L8	1.70	76.5		7.8	52.3
8/9/2022	L8	1.17	81.2		5.1	57.8
8/8/2023	L8	1.13	78.3		7.4	58.2
8/13/2024	L8	1.07	79.0		8.1	59.1
6/25/2012	L9	1.19	36.0	230	7.0	57.4
9/27/2018	L9	1.78	24.3		4.1	51.7

10/9/2019	L9	1.52	68.0		7.9	53.9
9/22/2020	L9	1.93	69.4		8.5	50.5
9/13/2022	L9	1.55	23.6 c		6.7	53.7
9/19/2023	L9	1.65	71.6		7.1	52.8
6/22/2000	LJ1	0.94	22.0	205	8.0	60.9
8/31/2000	LJ1	0.94	22.0	240	9.0	60.9
8/2/2001	LJ1	0.86	25.0	275	8.0	62.1
5/11/2002	LJ1	1.27	10.0	195	10.0	56.6
5/29/2002	LJ1	1.14	21.0			58.1
6/14/2002	LJ1	0.91	19.0	260	11.0	61.3
10/11/2002	LJ1	1.04	15.0	255	9.0	59.4
6/6/2003	LJ1	0.91	16.0	215	11.0	61.3
6/27/2003	LJ1	0.91	23.0		10.0	61.3
7/15/2003	LJ1	0.51	15.0	220	9.0	69.8
8/12/2003	LJ1	0.91		270	9.0	61.3
5/9/2004	LJ1	0.97	16.0	190	13.0	60.5
7/13/2004	LJ1	0.64	23.0	280	8.0	66.6
8/25/2004	LJ1	0.91	23.0	230	10.0	61.3
9/24/2004	LJ1	1.04	18.0	240	12.0	59.4
5/20/2005	LJ1	1.17	13.0	192	11.0	57.8
9/8/2005	LJ1	1.09	18.0	242	10.0	58.7
9/8/2005	LJ1	1.09	18.0	242	9.0	58.7
6/5/2006	LJ1	0.81	15.0	165	11.0	63.0
6/30/2006	LJ1	0.81	21.0	265	11.0	63.0
7/19/2006	LJ1	0.61	20.0	210	10.0	67.1
8/29/2006	LJ1	0.64	23.0	240	8.0	66.6
5/14/2007	LJ1	1.32	14.0	224	12.0	56.0
5/30/2007	LJ1	0.13	23.0	290	12.0	89.8
7/16/2007	LJ1	0.76	19.0	295	11.0	63.9
7/31/2007	LJ1	0.61	24.0	305	10.0	67.1
8/2/2007	LJ1	0.91	24.0	330	7.0	61.3
9/10/2007	LJ1	0.97	22.0	278	9.0	60.5
9/24/2007	LJ1	0.99	21.0	255	7.0	60.1
10/10/2007	LJ1	1.02	21.0	275	8.0	59.8
5/13/2008	LJ1	1.14	13.0	150	11.0	58.1
6/23/2008	LJ1	0.64	20.0	260		66.6
7/29/2008	LJ1	0.89	19.0	280	7.0	61.7
5/19/2009	LJ1	1.17	14.0	230	11.0	57.8
6/23/2009	LJ1	0.69	25.0	340	9.0	65.4
7/16/2009	LJ1	0.61	23.0	303	9.0	67.1
7/25/2009	LJ1	1.02	23.0	255	6.0	59.8

8/17/2009	LJ1	0.53	27.0	250	13.0	69.1
9/17/2009	LJ1	0.76	18.0	280	10.0	63.9
5/26/2010	LJ1	0.61	20.0	280	9.0	67.1
5/26/2010	LJ1	0.61	20.0	280	9.0	67.1
6/25/2010	LJ1	0.71	17.0	260	9.0	64.9
8/25/2010	LJ1	0.64	21.0	315	14.0	66.6
8/30/2010	LJ1	0.81	22.0	300	10.0	63.0
10/19/2010	LJ1	1.04	8.0	260	0.0	59.4
6/6/2011	LJ1	0.81	22.0	255	10.0	63.0
6/28/2011	LJ1	0.61	27.0	300	11.0	67.1
7/27/2011	LJ1	0.76	26.0	300	7.0	63.9
8/25/2011	LJ1	0.81	24.0	295	6.0	63.0
10/29/2011	LJ1	1.37	7.0	210	13.0	55.4
5/22/2012	LJ1	0.99	16.9	270	8.9	60.1
6/25/2012	LJ1	0.89	36.0	320	6.2	61.7
8/15/2012	LJ1	0.97	20.7	300	7.7	60.5
8/15/2012	LJ1	0.97	20.7	300	7.7	60.5
9/28/2012	LJ1	0.91	14.5	250	10.6	61.3
5/31/2013	LJ1	0.64	20.2	303	9.0	66.6
6/24/2013	LJ1	0.69	28.0	280	9.2	65.4
7/25/2013	LJ1	1.40	17.1	210	11.3	55.2
8/26/2013	LJ1	0.94	20.0	315	10.7	60.9
9/18/2013	LJ1	0.66	17.0	280	8.3	66.0
5/28/2014	LJ1	0.91	17.8	230	9.9	61.3
6/30/2014	LJ1	0.66	18.2	200	10.8	66.0
7/30/2014	LJ1	0.69	20.5	280	14.0	65.4
9/29/2014	LJ1	0.97	17.1	151	290.0	60.5
10/13/2014	LJ1	1.14	16.2	285	10.2	58.1
5/12/2015	LJ1	1.22	25.5			57.1
6/24/2015	LJ1	0.97	21.0			60.5
7/24/2015	LJ1	0.61	24.0			67.1
8/21/2015	LJ1	0.58	23.8	265	9.0	67.8
9/23/2015	LJ1	0.84	19.0	260	8.5	62.5
10/20/2015	LJ1	1.24	11.6		10.9	56.8
5/19/2016	LJ1	0.91	14.6		10.7	61.3
6/27/2016	LJ1	0.81	21.7		7.3	63.0
8/24/2016	LJ1	0.84	25.9		10.5	62.5
9/20/2016	LJ1	0.76	24.0		7.0	63.9
10/11/2016	LJ1	0.76	16.3		8.2	63.9
7/26/2016	LM1	0.66	28.7		6.6	66.0
8/16/2017	LM1	0.94	26.2		11.0	60.9

9/28/2017	LM1	0.66	23.8		8.1	66.0
10/19/2017	LM1	0.94	15.4		12.5	60.9
5/24/2018	LM1	0.58	21.9		6.7	67.8
6/14/2018	LM1	0.91	25.4		7.7	61.3
7/18/2018	LM1	0.74	28.8		7.2	64.4
9/27/2018	LM1	0.66	17.4			66.0
5/22/2019	LM1	0.99	61.0		8.3	60.1
8/12/2019	LM1	1.02	74.0		7.9	59.8
10/9/2019	LM1	1.02	62.0		9.3	59.8
10/15/2019	LM1	0.97	58.1		8.8	60.5
8/6/2020	LM1	0.97	75.0		7.5	60.5
9/22/2020	LM1	1.07	63.1		8.7	59.1
10/26/2020	LM1	0.56	51.8			68.4
7/13/2021	LM1	0.76	69.9		8.2	63.9
8/10/2021	LM1	0.86	77.3		7.5	62.1
9/14/2021	LM1	0.91	73.6		9.0	61.3
10/12/2021	LM1	0.94	69.4		9.0	60.9
5/10/2022	LM1	0.84	55.8		9.3	62.5
6/14/2022	LM1	1.02	72.5		8.3	59.8
7/12/2022	LM1	0.61	78.0		6.7	67.1
8/9/2022	LM1	0.56	79.0		3.8	68.4
9/13/2022	LM1	0.71	21.9 c		7.6	64.9
10/11/2022	LM1	0.94	56.0		8.8	60.9
4/11/2023	LM1	0.91	52.0		10.9	61.3
5/9/2023	LM1	0.64	56.5		8.8	66.6
6/20/2023	LM1	0.89	69.2		7.8	61.7
7/18/2023	LM1	0.61	76.8		8.1	67.1
8/8/2023	LM1	0.61	74.5		7.1	67.1
9/19/2023	LM1	0.76	63.3		8.7	63.9
10/6/2023	LM1	0.74	68.6		8.4	64.4
5/14/2024	LM1	0.61	65.3		9.3	67.1
6/11/2024	LM1	0.71	67.1		8.4	64.9
7/9/2024	LM1	0.66	79.0		9.3	66.0
8/13/2024	LM1	0.66	75.0		8.2	66.0
6/11/2024	SGC	0.64	71.0		9.7	66.6

Appendix I: Laboratory data sheets for nutrient analysis.



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Lab Analysis Report

Aqua Doc
Heath Spence
10779 Mayfield Rd
Chardon, OH 44024

Project: Apple Valley WQ
Date Received: 6/26/2024
Date Complete: 7/2/2024
Date Reported: 7/2/2024

Test		Method	Result	Units	Date	Analyst
73603-01	**6/20/2024**	**Apple Valley** **Deep Point Grab**				
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	0.01	mg/L	7/2/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	0.03	mg/L	7/2/2024	MW
73603-02	**6/20/2024**	**Apple Valley** **Deep Point Bottom**				
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	0.04	mg/L	7/2/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	0.12	mg/L	7/2/2024	MW
73603-03	**6/20/2024**	**Apple Valley** **Deep Point Grab**				
TKN (Total Kjeldahl Nitrogen)						
Total Kjeldahl Nitrogen (TKN) as N		Hach 10242	1	mg/L	6/27/2024	JWK

Total Nitrogen = 1.04 mg/L

Test		Method	Result	Units	Date	Analyst
73603-04	**6/20/2024**	**Apple Valley** **Deep Point Bottom**				
TKN (Total Kjeldahl Nitrogen)						
Total Kjeldahl Nitrogen (TKN) as N		Hach 10242	2	mg/L	6/27/2024	JWK

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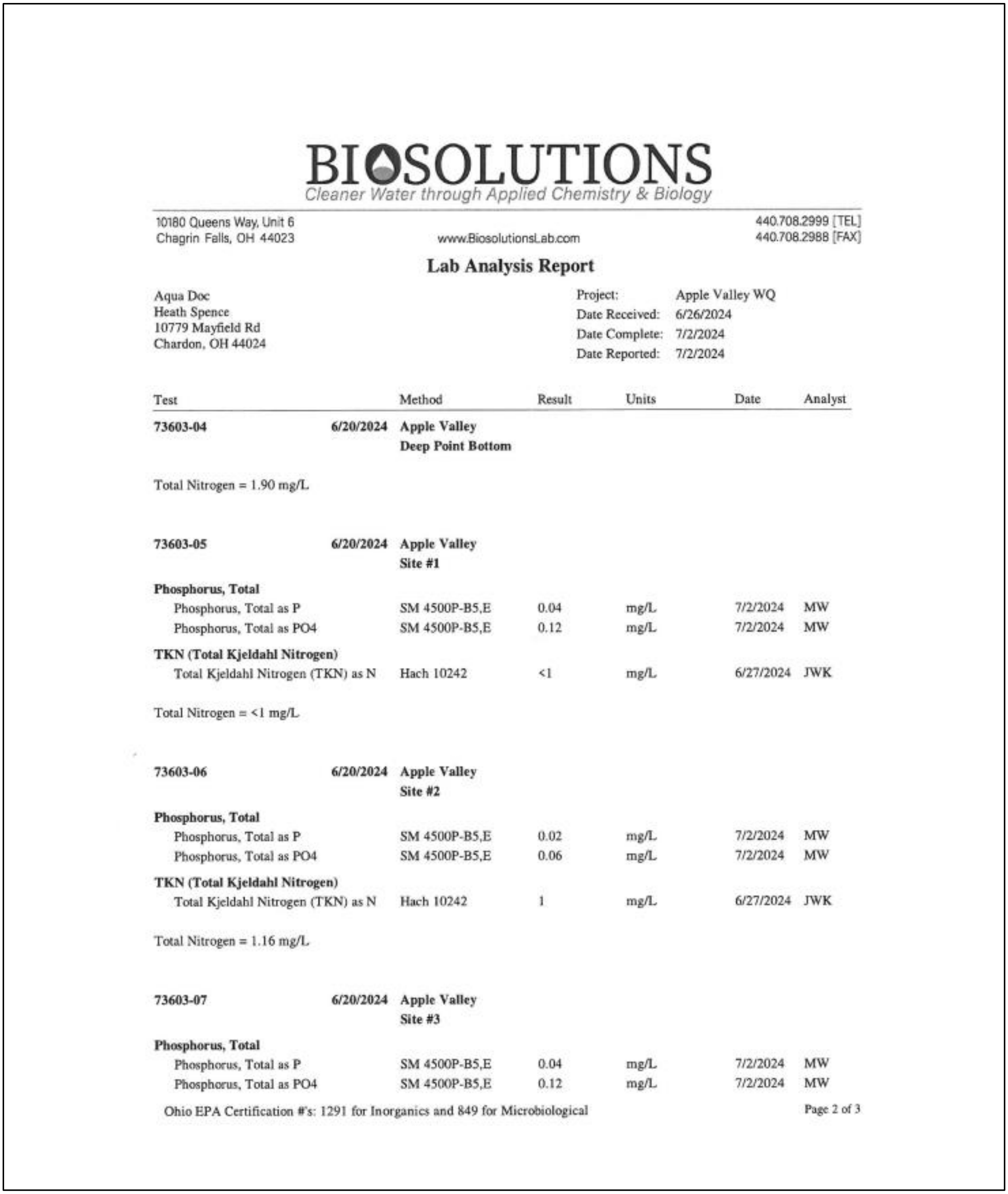

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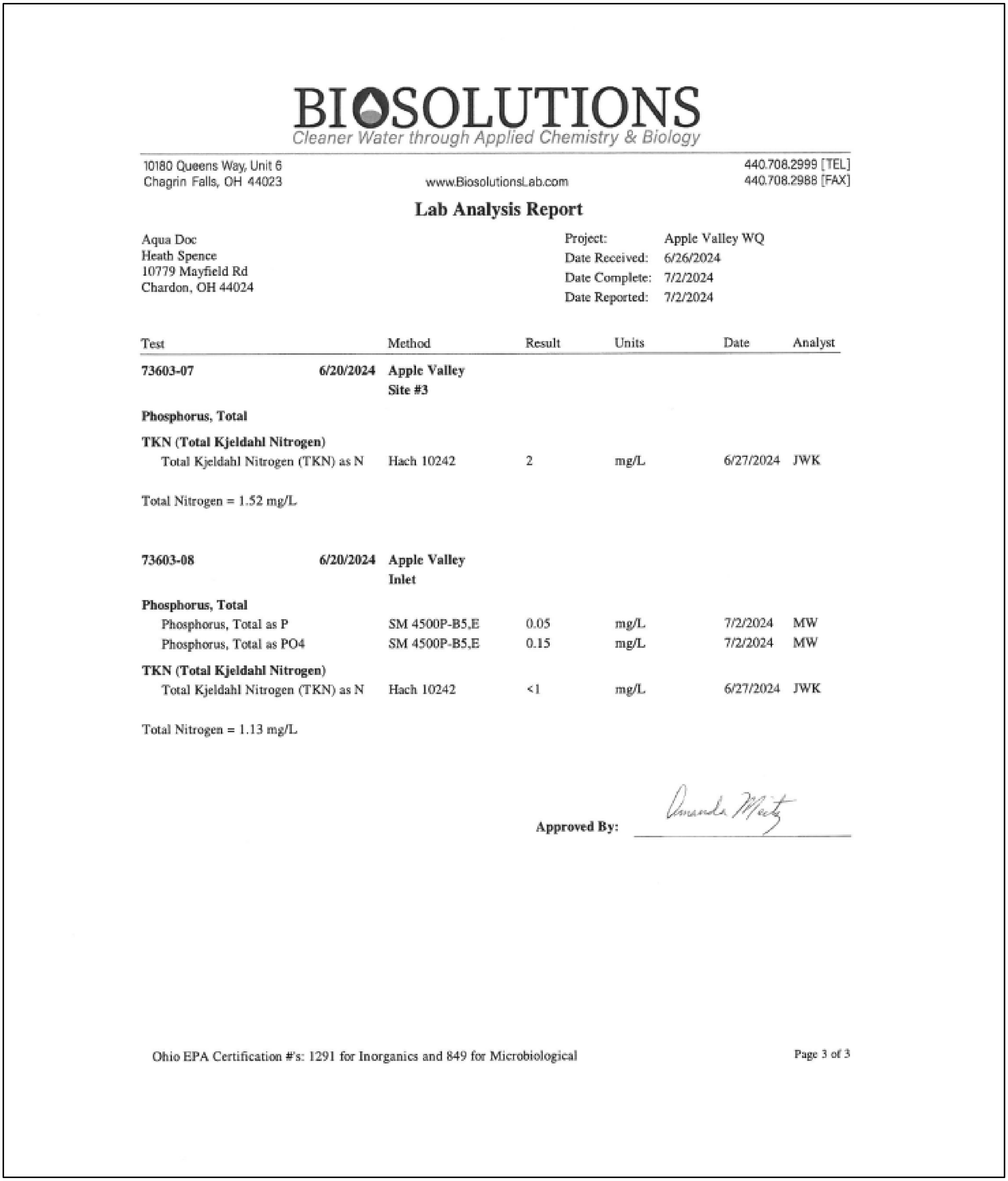
Heath Spence
10779 Mayfield Rd
Chardon, OH 44024

Project: Apple Valley WQ
Date Received: 6/26/2024
Date Complete: 7/2/2024
Date Reported: 7/2/2024

Test		Method	Result	Units	Date	Analyst
73603-04	**6/20/2024**	**Apple Valley** **Deep Point Bottom**				
Total Nitrogen = 1.90 mg/L						
73603-05	**6/20/2024**	**Apple Valley** **Site #1**				
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	0.04	mg/L	7/2/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	0.12	mg/L	7/2/2024	MW
TKN (Total Kjeldahl Nitrogen)						
Total Kjeldahl Nitrogen (TKN) as N		Hach 10242	<1	mg/L	6/27/2024	JWK
Total Nitrogen = <1 mg/L						
73603-06	**6/20/2024**	**Apple Valley** **Site #2**				
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	0.02	mg/L	7/2/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	0.06	mg/L	7/2/2024	MW
TKN (Total Kjeldahl Nitrogen)						
Total Kjeldahl Nitrogen (TKN) as N		Hach 10242	1	mg/L	6/27/2024	JWK
Total Nitrogen = 1.16 mg/L						
73603-07	**6/20/2024**	**Apple Valley** **Site #3**				
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	0.04	mg/L	7/2/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	0.12	mg/L	7/2/2024	MW



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Chardon, OH 44024

Project: Apple Valley WQ
Date Received: 6/26/2024
Date Complete: 7/2/2024
Date Reported: 7/2/2024

Test	Method	Result	Units	Date	Analyst
73603-07 **6/20/2024**	**Apple Valley Site #3**				
Phosphorus, Total					
TKN (Total Kjeldahl Nitrogen)					
Total Kjeldahl Nitrogen (TKN) as N	Hach 10242	2	mg/L	6/27/2024	JWK
Total Nitrogen = 1.52 mg/L					
73603-08 **6/20/2024**	**Apple Valley Inlet**				
Phosphorus, Total					
Phosphorus, Total as P	SM 4500P-B5,E	0.05	mg/L	7/2/2024	MW
Phosphorus, Total as PO4	SM 4500P-B5,E	0.15	mg/L	7/2/2024	MW
TKN (Total Kjeldahl Nitrogen)					
Total Kjeldahl Nitrogen (TKN) as N	Hach 10242	<1	mg/L	6/27/2024	JWK
Total Nitrogen = 1.13 mg/L					

Approved By: Amanda Metz

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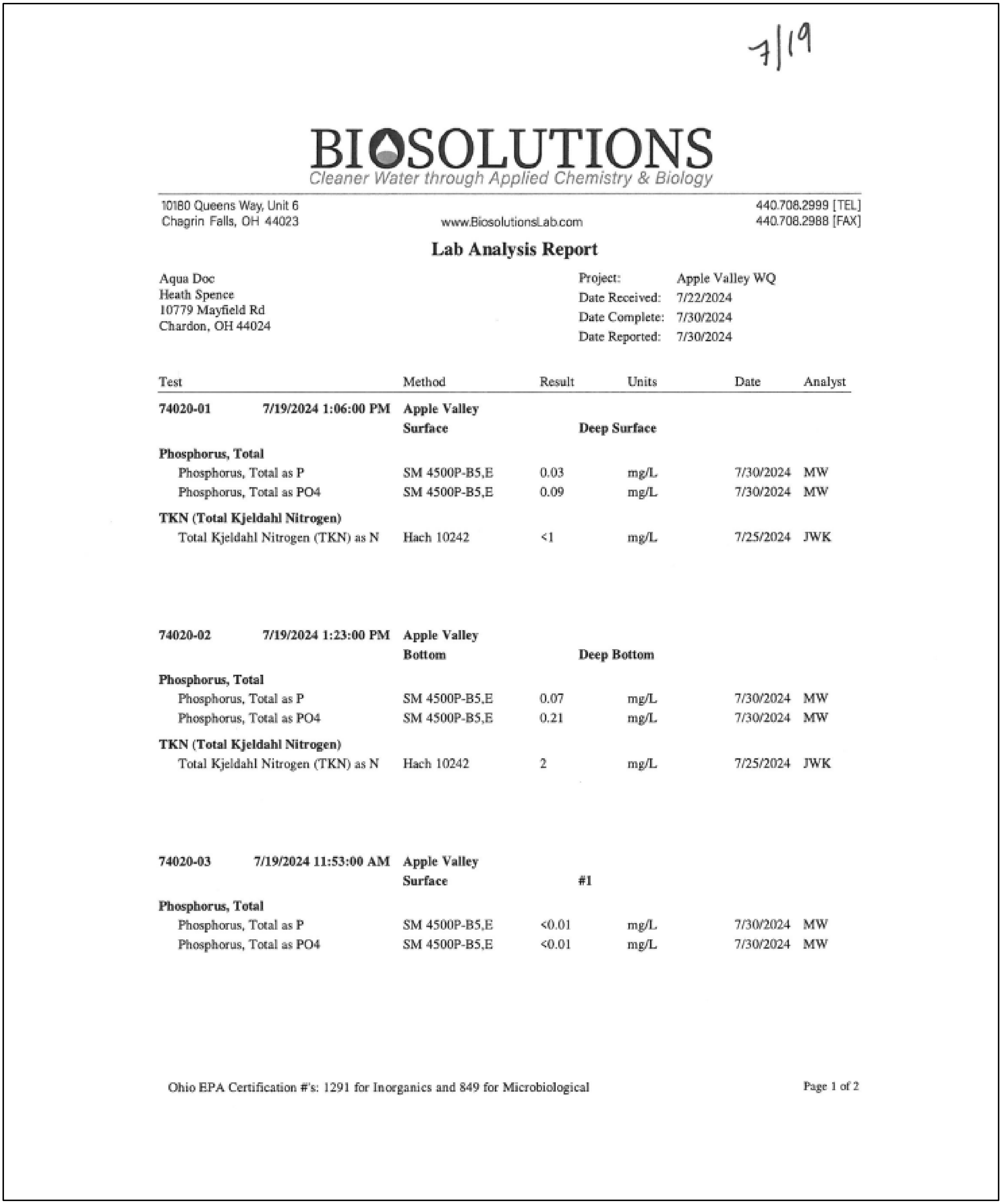

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Lab Analysis Report

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Project: Apple Valley WQ
Date Received: 7/22/2024
Date Complete: 7/30/2024
Date Reported: 7/30/2024

Test	Method	Result	Units	Date	Analyst
74020-01 **7/19/2024 1:06:00 PM**	**Apple Valley Surface**		**Deep Surface**		
Phosphorus, Total					
Phosphorus, Total as P	SM 4500P-B5,E	0.03	mg/L	7/30/2024	MW
Phosphorus, Total as PO4	SM 4500P-B5,E	0.09	mg/L	7/30/2024	MW
TKN (Total Kjeldahl Nitrogen)					
Total Kjeldahl Nitrogen (TKN) as N	Hach 10242	<1	mg/L	7/25/2024	JWK
74020-02 **7/19/2024 1:23:00 PM**	**Apple Valley Bottom**		**Deep Bottom**		
Phosphorus, Total					
Phosphorus, Total as P	SM 4500P-B5,E	0.07	mg/L	7/30/2024	MW
Phosphorus, Total as PO4	SM 4500P-B5,E	0.21	mg/L	7/30/2024	MW
TKN (Total Kjeldahl Nitrogen)					
Total Kjeldahl Nitrogen (TKN) as N	Hach 10242	2	mg/L	7/25/2024	JWK
74020-03 **7/19/2024 11:53:00 AM**	**Apple Valley Surface**		**#1**		
Phosphorus, Total					
Phosphorus, Total as P	SM 4500P-B5,E	<0.01	mg/L	7/30/2024	MW
Phosphorus, Total as PO4	SM 4500P-B5,E	<0.01	mg/L	7/30/2024	MW

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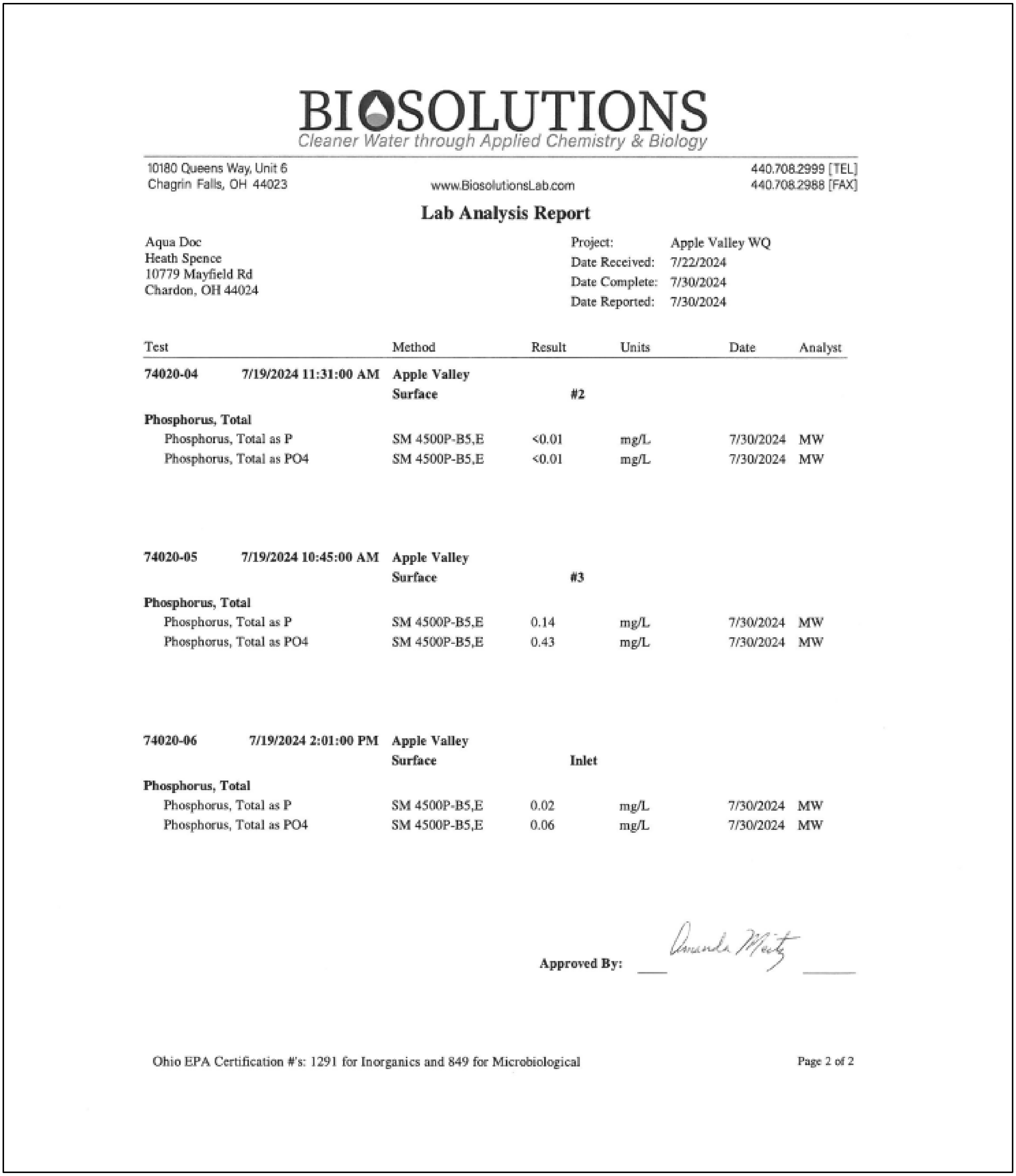

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Lab Analysis Report

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Chardon, OH 44024

Project: Apple Valley WQ
Date Received: 7/22/2024
Date Complete: 7/30/2024
Date Reported: 7/30/2024

Test		Method	Result	Units	Date	Analyst
74020-04	**7/19/2024 11:31:00 AM**	**Apple Valley Surface**	**#2**			
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	<0.01	mg/L	7/30/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	<0.01	mg/L	7/30/2024	MW
74020-05	**7/19/2024 10:45:00 AM**	**Apple Valley Surface**	**#3**			
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	0.14	mg/L	7/30/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	0.43	mg/L	7/30/2024	MW
74020-06	**7/19/2024 2:01:00 PM**	**Apple Valley Surface**	**Inlet**			
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	0.02	mg/L	7/30/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	0.06	mg/L	7/30/2024	MW

Approved By: Amanda

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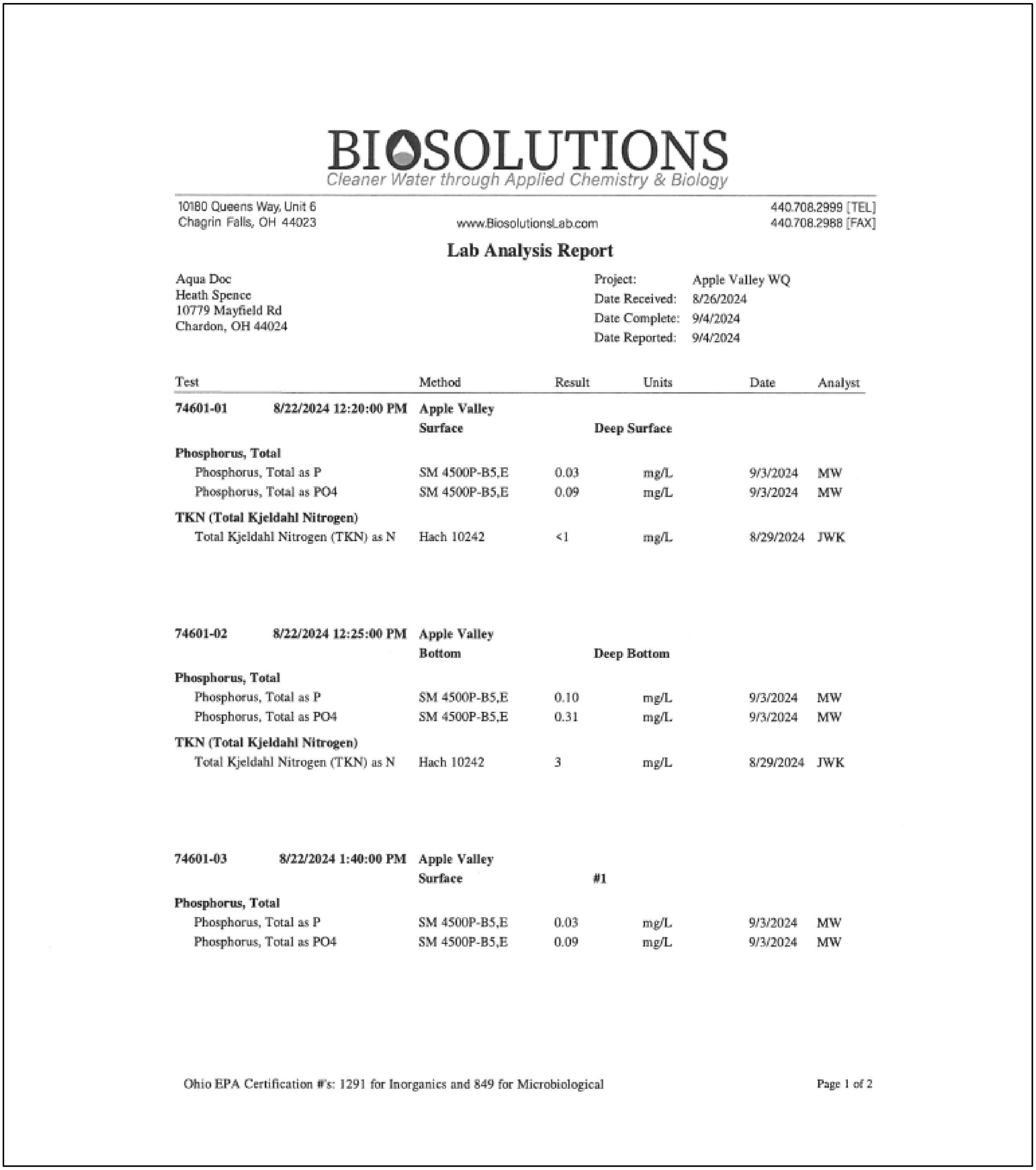

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Lab Analysis Report

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Chardon, OH 44024

Project: Apple Valley WQ
Date Received: 8/26/2024
Date Complete: 9/4/2024
Date Reported: 9/4/2024

Test		Method	Result	Units	Date	Analyst
74601-01	**8/22/2024 12:20:00 PM**	**Apple Valley Surface**		**Deep Surface**		
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	0.03	mg/L	9/3/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	0.09	mg/L	9/3/2024	MW
TKN (Total Kjeldahl Nitrogen)						
Total Kjeldahl Nitrogen (TKN) as N		Hach 10242	<1	mg/L	8/29/2024	JWK
74601-02	**8/22/2024 12:25:00 PM**	**Apple Valley Bottom**		**Deep Bottom**		
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	0.10	mg/L	9/3/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	0.31	mg/L	9/3/2024	MW
TKN (Total Kjeldahl Nitrogen)						
Total Kjeldahl Nitrogen (TKN) as N		Hach 10242	3	mg/L	8/29/2024	JWK
74601-03	**8/22/2024 1:40:00 PM**	**Apple Valley Surface**		**#1**		
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	0.03	mg/L	9/3/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	0.09	mg/L	9/3/2024	MW

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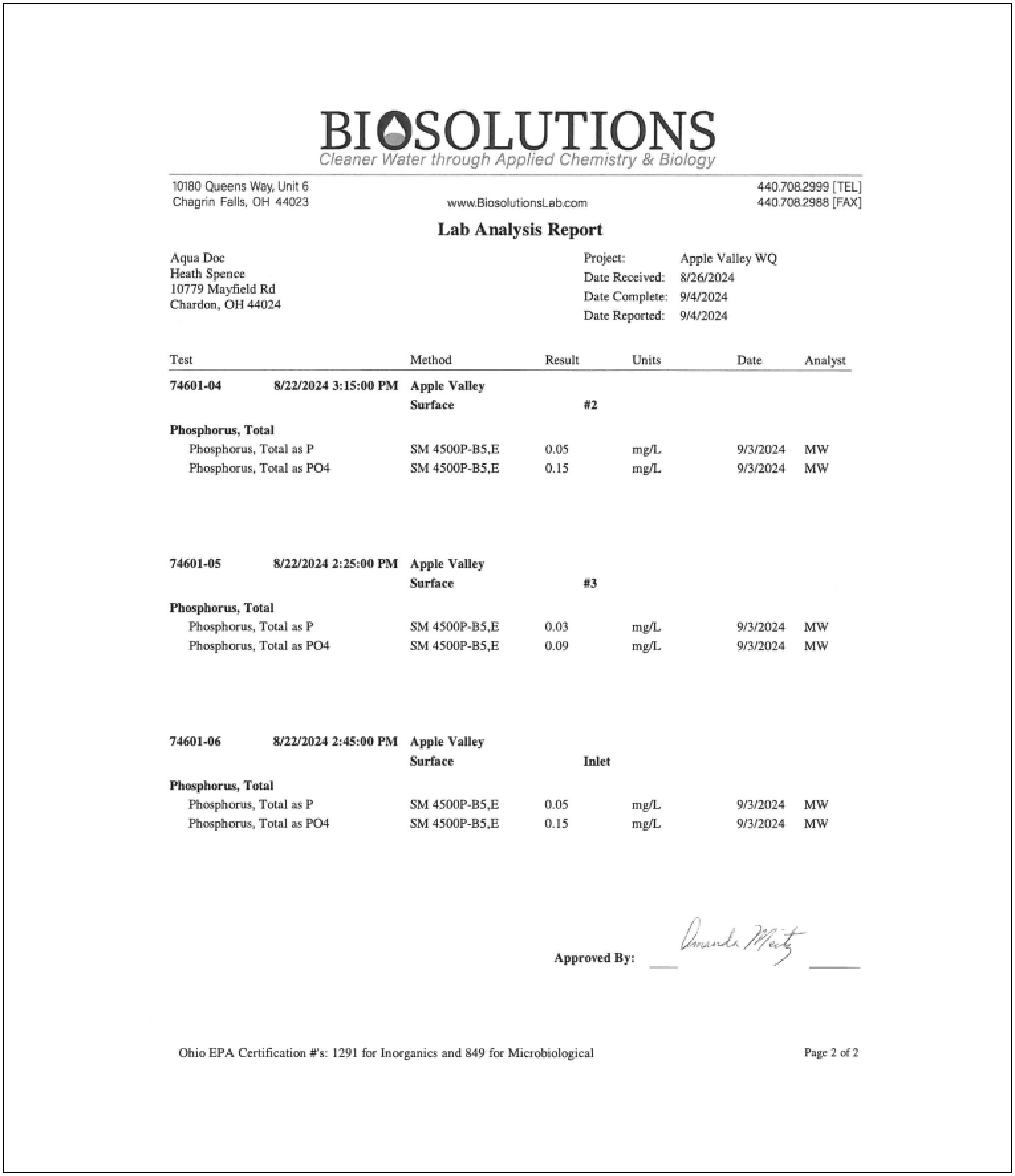

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Lab Analysis Report

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Heath Spence
10779 Mayfield Rd
Chardon, OH 44024

Project: Apple Valley WQ
Date Received: 8/26/2024
Date Complete: 9/4/2024
Date Reported: 9/4/2024

Test	Method	Result	Units	Date	Analyst
74601-04 **8/22/2024 3:15:00 PM**	**Apple Valley** **Surface**	**#2**			
Phosphorus, Total					
Phosphorus, Total as P	SM 4500P-B5,E	0.05	mg/L	9/3/2024	MW
Phosphorus, Total as PO4	SM 4500P-B5,E	0.15	mg/L	9/3/2024	MW
74601-05 **8/22/2024 2:25:00 PM**	**Apple Valley** **Surface**	**#3**			
Phosphorus, Total					
Phosphorus, Total as P	SM 4500P-B5,E	0.03	mg/L	9/3/2024	MW
Phosphorus, Total as PO4	SM 4500P-B5,E	0.09	mg/L	9/3/2024	MW
74601-06 **8/22/2024 2:45:00 PM**	**Apple Valley** **Surface**	**Inlet**			
Phosphorus, Total					
Phosphorus, Total as P	SM 4500P-B5,E	0.05	mg/L	9/3/2024	MW
Phosphorus, Total as PO4	SM 4500P-B5,E	0.15	mg/L	9/3/2024	MW

Approved By: Amanda Mertz

Ohio EPA Certification #'s: 1291 for Inorganics and 849 for Microbiological

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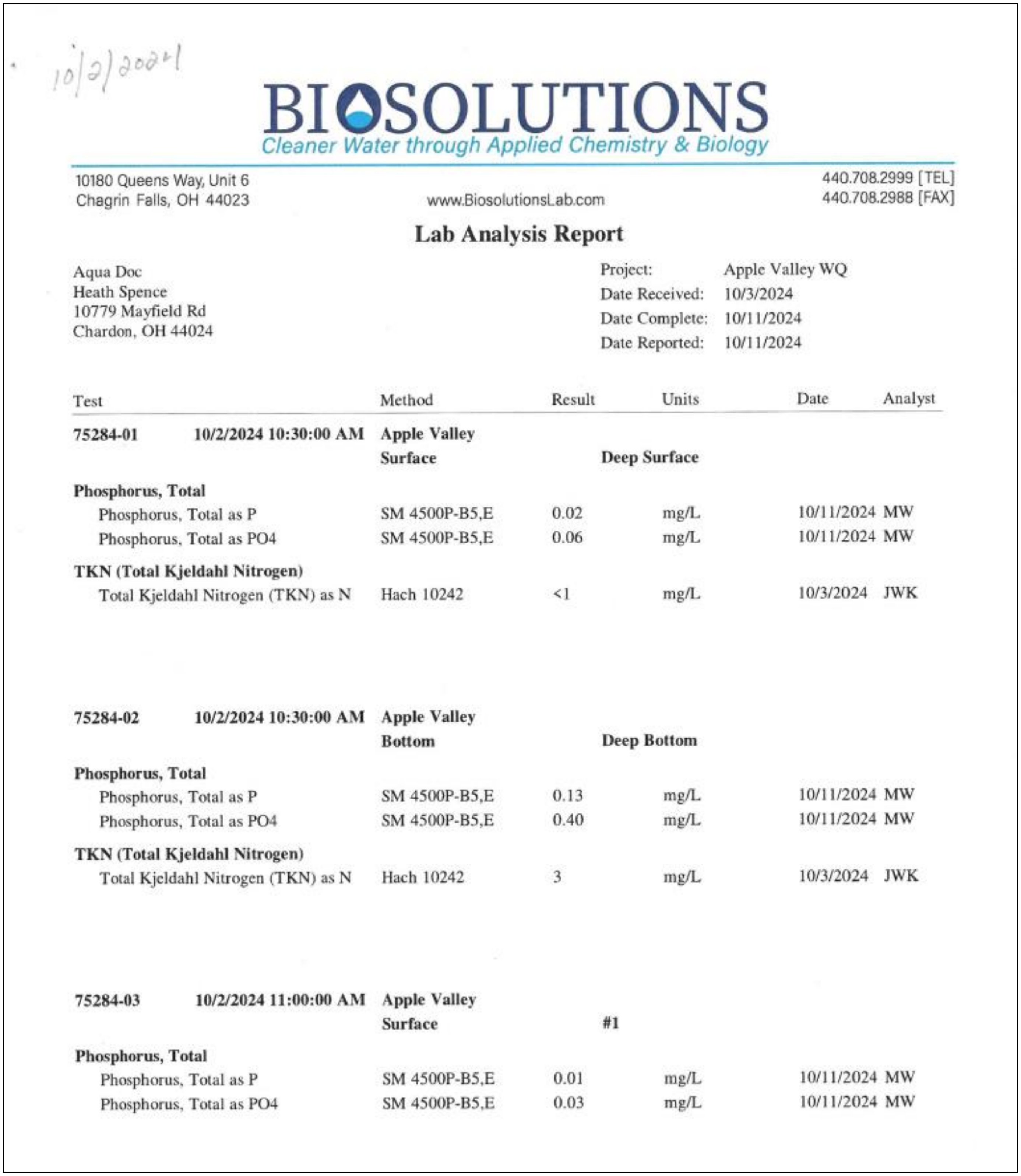

10/2/2024

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Lab Analysis Report

Aqua Doc
Heath Spence
10779 Mayfield Rd
Chardon, OH 44024

Project: Apple Valley WQ
Date Received: 10/3/2024
Date Complete: 10/11/2024
Date Reported: 10/11/2024

Test	Method	Result	Units	Date	Analyst
75284-01 10/2/2024 10:30:00 AM	**Apple Valley Surface**		**Deep Surface**		
Phosphorus, Total					
Phosphorus, Total as P	SM 4500P-B5,E	0.02	mg/L	10/11/2024	MW
Phosphorus, Total as PO4	SM 4500P-B5,E	0.06	mg/L	10/11/2024	MW
TKN (Total Kjeldahl Nitrogen)					
Total Kjeldahl Nitrogen (TKN) as N	Hach 10242	<1	mg/L	10/3/2024	JWK
75284-02 10/2/2024 10:30:00 AM	**Apple Valley Bottom**		**Deep Bottom**		
Phosphorus, Total					
Phosphorus, Total as P	SM 4500P-B5,E	0.13	mg/L	10/11/2024	MW
Phosphorus, Total as PO4	SM 4500P-B5,E	0.40	mg/L	10/11/2024	MW
TKN (Total Kjeldahl Nitrogen)					
Total Kjeldahl Nitrogen (TKN) as N	Hach 10242	3	mg/L	10/3/2024	JWK
75284-03 10/2/2024 11:00:00 AM	**Apple Valley Surface**		**#1**		
Phosphorus, Total					
Phosphorus, Total as P	SM 4500P-B5,E	0.01	mg/L	10/11/2024	MW
Phosphorus, Total as PO4	SM 4500P-B5,E	0.03	mg/L	10/11/2024	MW

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Aqua Doc
Heath Spence
10779 Mayfield Rd
Chardon, OH 44024

Project:	Apple Valley WQ
Date Received:	10/3/2024
Date Complete:	10/11/2024
Date Reported:	10/11/2024

Test		Method	Result	Units	Date	Analyst
75284-04	**10/2/2024 11:30:00 AM**	**Apple Valley Surface**	**#2**			
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	<0.01	mg/L	10/11/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	<0.03	mg/L	10/11/2024	MW
75284-05	**10/2/2024 12:00:00 PM**	**Apple Valley Surface**	**#3**			
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	0.01	mg/L	10/11/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	0.03	mg/L	10/11/2024	MW
75284-06	**10/2/2024 12:20:00 PM**	**Apple Valley Surface**	**Inlet**			
Phosphorus, Total						
Phosphorus, Total as P		SM 4500P-B5,E	0.02	mg/L	10/11/2024	MW
Phosphorus, Total as PO4		SM 4500P-B5,E	0.06	mg/L	10/11/2024	MW

Approved By: Amanda Mertz

Appendix J: Glossary of Useful Terms Related to Lake Management

Anoxic – a condition of having no oxygen present.

Benthos/Benthic – A term used to describe or imply the bottom of a water body.

Dimictic – A pond or lake that turns over twice in a given year.

Epilimnion – When a body of water is stratified (has distinct density layers), this is the depth of water closer to the surface (upper layer). In the summer, it is between the thermocline and water/air interface.

HAB – Harmful algal bloom, describes excessive growth of cyanobacteria which are a type of algae known to be able to produce harmful toxins. These toxins can be harmful to human and animal health at high enough quantities.

Hypolimnion – When a lake is stratified (has distinct density layers), this is the depth of water near the bottom of the water body. In the summer, it is defined as the area under the thermocline.

Hypoxic – a condition of having very little oxygen present.

Internal Loading – a term used to describe the phenomenon of increased phosphorus levels in the hypolimnion of a stratified lake when oxygen is depleted in this region. Changes in the chemistry of iron in the sediment layer cause phosphorus to be released from these sediments.

Littoral Zone – The area of a lake where macrophytes can grow due to the availability of light for growth.

Macrophytes – A term that describes aquatic plants as well as some species of “plant-like” algae.

Primary Productivity – Reference to photosynthetic plant and algae growth in aquatic systems.

Production – A way to describe plant and algae growth potential in a water body. Typically, it is described by quantity of chlorophyll *a* (primary photosynthetic pigment of many algal species), Secchi transparency (how clear the lake is), and the amount of available phosphorus for biological uptake (primary growth nutrient in limited quantities in water).

Polymictic **–** A pond or lake that turns over multiple times in a given year.

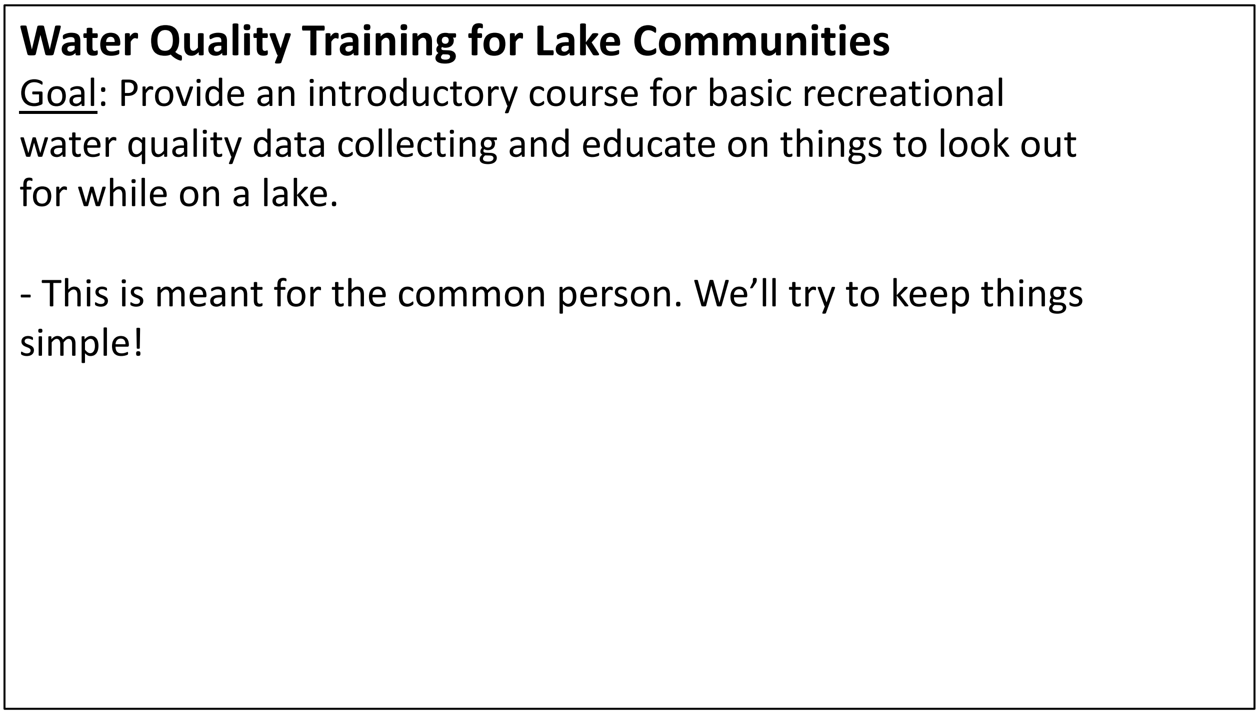
Stratification – The process by which different layers of water are created in a lake due to density differences driven by temperature.

Thermocline – The depth designated as to where the greatest change in temperature is.

Appendix K: Water Quality Training for Lake Communities Presentation

Water Quality Training for Lake Communities

Prepared for Indian Lake
By: Edward Kwietniewski



Water Quality Training for Lake Communities

<u>Goal</u>: Provide an introductory course for basic recreational water quality data collecting and educate on things to look out for while on a lake.

- This is meant for the common person. We'll try to keep things simple!

Water Quality Training for Lake Communities

What is water quality?

- Physical, chemical, and biological components of water.
- Defined based on perspective and use of water.
- What makes ”good” water quality vs. “bad”?

Water Quality Training for Lake Communities

Overview of topics:

-Why even collect the information?
- What is water quality?
- What do we want to collect?
- What does the information mean?
- What should we look out for?

Water Quality Training for Lake Communities

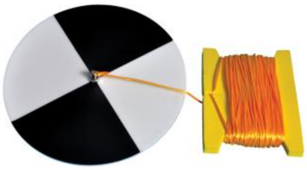
What is water quality?

- Physical, chemical, and biological components of water.
- Defined based on perspective and use of water.
- What makes ”good” water quality vs. “bad”?

Water Quality Training for Lake Communities

What do we want to collect?

- Information relevant to recreational waterbodies:
  1. Nutrient information (phosphorus and nitrogen)
  2. Secchi Transparency or depth
  3. Chlorophyll a
  4. Oxygen levels
  5. Temperature at depth
  6. “Lake specific” information



Water Quality Training for Lake Communities

What do we want to collect?

- Information relevant to recreational waterbodies:
  1. Nutrient information (phosphorus and nitrogen)

How to sample: Take a "grab sample" by collecting water in a proper sample bottle at arm depth. Be sure to open the cap under the water at the proper depth vs. out of the water.

Van Dorn Bottle Sampler

Collecting samples at different depths will require the use of a sampling device like a Van Dorn bottle.

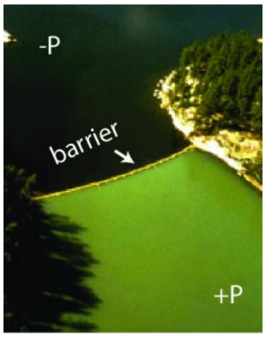
Be aware there may be preservatives in bottles being sent to labs.

Water Quality Training for Lake Communities

What do we want to collect?

- Information relevant to recreational waterbodies:
  1. Nutrient information (phosphorus and nitrogen)

Important notes: Make sure water samples (all samples) are put on ice after collection. When I ship them out to labs I put a ice pack (from a local pharmacy) in with the samples and put it all in a labelled gallon plastic bag. A chain of custody needs to be filled out for lab samples.
Make sure the bottles are also labelled with the following:
- Date
- Location
- Water Depth
- Water test to be performed



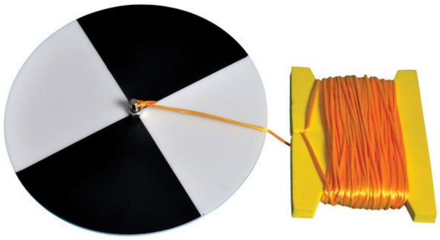
Water Quality Training for Lake Communities

What do we want to collect?

- Information relevant to recreational waterbodies:
  2. Secchi Transparency or depth

How to collect: We use a Secchi disk (pictured). Drop the disk on the *shady side* of a boat/dock until you cannot see it anymore. Then slowly raise it up until you can just barely see it. Take the average of these two numbers to get your Secchi depth.

Make sure you're not wearing sunglasses



Water Quality Training for Lake Communities

What do we want to collect?

- Information relevant to recreational waterbodies:
  2. Secchi Transparency or depth

Make your own! https://youtu.be/sbQ2nVt_5GY

Video from NALMS: https://www.nalms.org/secchidipin/monitoring-methods/quick-start-video/

* Environmental conditions (clouds, etc.) may impact readings*

Water Quality Training for Lake Communities

What do we want to collect?

- Information relevant to recreational waterbodies:
  3. Chlorophyll a

How to sample: See nutrient collection in previous slides. Procedures are the same! Just be sure to utilize a non-preserved bottle or a preserved bottle suggested by the laboratory (vary depending on technique they employ but most I've seen use vacuum filtration). LABEL!

Youtube link (simple!):
https://youtu.be/99VxjlslYBk

Water Quality Training for Lake Communities

What do we want to collect?

- Information relevant to recreational waterbodies:
  4. Oxygen levels

How to sample: A sampling probe will be needed here! Follow the procedures for use of the sampling device (may need to calibrate it, ensure you don't dry our probe membranes, etc.).

Most handheld probes have a readout unit, connection line, and probe assembly (picture). Surface units may be handheld but I would suggest one that can sample at various depths.
General guide: https://www.youtube.com/watch?v=YrA602_d-SI

Water Quality Training for Lake Communities

What do we want to collect?

- Information relevant to recreational waterbodies:
  5. Temperature at depth

  How to sample: Same as oxygen!

Water Quality Training for Lake Communities

What do we want to collect?

- Information relevant to recreational waterbodies:
  6. "Lake specific" information

  How to sample: Depends on what you're collecting!

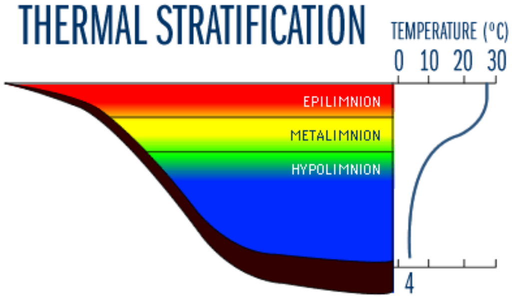
  Aquatic plant sampling with a "macrophyte rake"

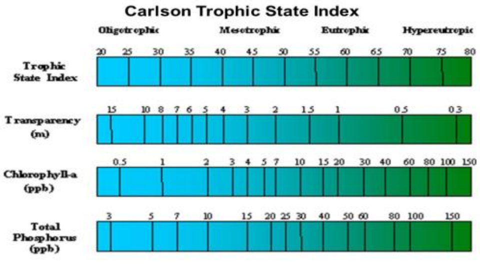
  Depth and sediment depth with a sediment probe

Water Quality Training for Lake Communities

What does the data mean?

- Nutrients, Secchi Transparency, Chlorophyll a
  - ➢ Relate to lake productivity. How much growth (algae and plants) should be expected? Can you expect this to change overtime?
- Temperature and oxygen
  - ➢ Relate to gilled organism survival and habitat availability. Also allows us look into lake *stratification.*





Carlson, R.E. 1977. A trophic state index for lakes. Limnol. Oceangr. 22:361-369.

Water Quality Training for Lake Communities

What does the data mean?

ALL DATA IS MORE POWERFUL AND IMPORTANT WHEN COLLECTED OVER A LONG PERIOD OF TIME!

Water Quality Training for Lake Communities

What should lake communities look out for?

- You don't need to always collect water quality info to be a part of helping the lake!
- Look out for these things:
  1. Identifying Harmful Algae Blooms (cyanobacteria)
  2. Identifying invasive species
  3. Knowing "water colors"

Water Quality Training for Lake Communities

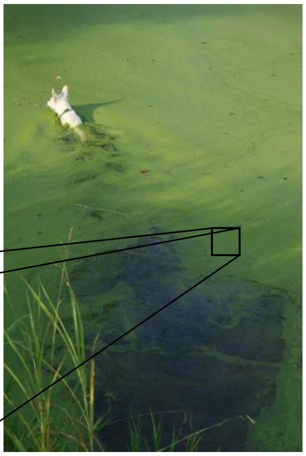
What should lake communities look out for?

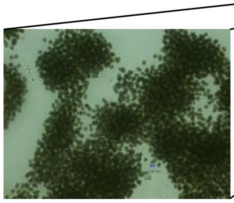
- Look out for these things:
  1. Identifying Harmful Algae Blooms (cyanobacteria)

HAB: Harmful Algae Bloom. Occur when a large bloom of cyanobacteria occurs and harmful ***cyanotoxins*** are potentially produced:

Toxin Type	What does it Harm?
Neurotoxin	Nervous System
Hepatoxin	Liver
Dermatoxin	Skin

Everyone should know how to Identify what a potential HAB looks like for their safety.





Zoomed in *Microcystis*

Water Quality Training for Lake Communities

What should lake communities look out for?

- Look out for these things:
  1. Identifying Harmful Algae Blooms (cyanobacteria)

Neon-green “paint-like” spatter

Odd smell from geosmin release

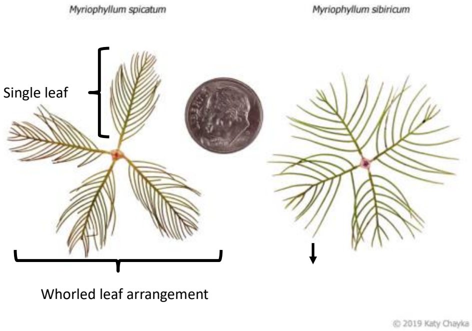
“Blue-green” color

Water Quality Training for Lake Communities

What should lake communities look out for?

- Look out for these things:
  2. Identifying Invasive Species

- Eurasian watermilfoil (*Myriophyllum spicatum*)
- Northern watermilfoil (*Myriophyllum sibiricum*)
- Parrotfeather (*Myriophyllum aquaticum*)



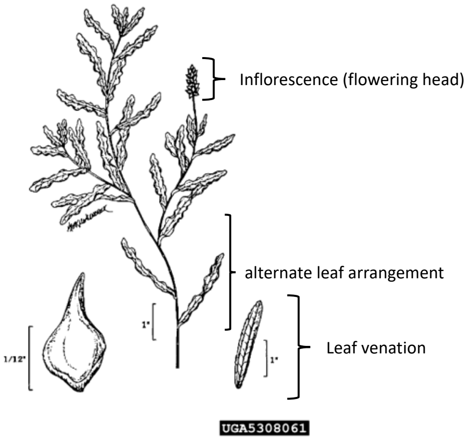
Northern watermilfoil and Eurasian watermilfoil are very similar in appearance to each other. Note the difference in leaflet structures per leaf. Also, there is the “hold upside down” trick.

Water Quality Training for Lake Communities

What should lake communities look out for?

- Look out for these things:
  2. Identifying Invasive Species

- Curly-leaf pondweed (*Potamogeton crispus*)
- Long-leaved/ American pondweed (*Potamogeton nodosus*)
- Illinois pondweed (*Potamogeton illinoensis*)
- ***Hundreds*** more species…



Inflorescence (flowering head)

alternate leaf arrangement

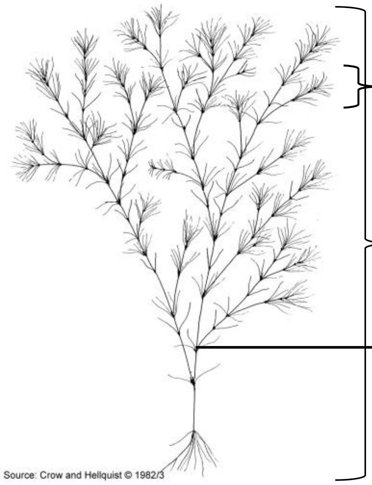
Leaf venation

Water Quality Training for Lake Communities

What should lake communities look out for?

- Look out for these things:
  2. Identifying Invasive Species

- Brittle naiad (*Najas minor*)
- Slender naiad (*Najas flexilis*)



Source: Crow and Hellquist © 1982/3

paired or whorled leaves.

"Bushy" appearance in the water

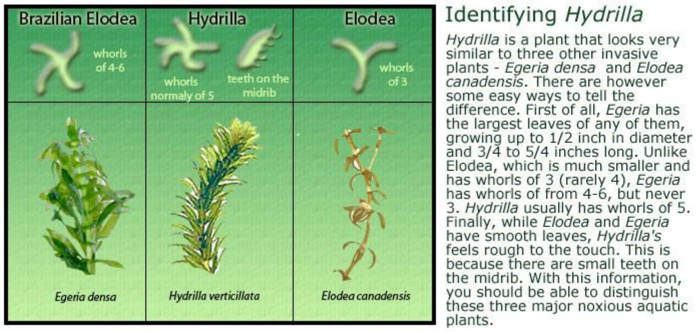
Seeds form at node base

Water Quality Training for Lake Communities

What should lake communities look out for?

- Look out for these things:
  2. Identifying Invasive Species

- Hydrilla
  (*Hydrilla verticillata*)
- Brazilian Elodea
  (*Egeria densa*)
- Common waterweed
  (*Elodea canadensis*)



Identifying *Hydrilla*

Hydrilla is a plant that looks very similar to three other invasive plants - *Egeria densa* and *Elodea canadensis*. There are however some easy ways to tell the difference. First of all, *Egeria* has the largest leaves of any of them, growing up to 1/2 inch in diameter and 3/4 to 5/4 inches long. Unlike Elodea, which is much smaller and has whorls of 3 (rarely 4), *Egeria* has whorls of from 4-6, but never 3. *Hydrilla* usually has whorls of 5. Finally, while *Elodea* and *Egeria* have smooth leaves, *Hydrilla's* feels rough to the touch. This is because there are small teeth on the midrib. With this information, you should be able to distinguish these three major noxious aquatic plants.

Water Quality Training for Lake Communities

What should lake communities look out for?

- Look out for these things:
  2. Identifying Invasive Species – Natives found in the lake

- Eels grass
  (*Vallisneria americana*)
- Bladderwort
  (*Utricularia*)

- Coontail
  (*Ceratophyllum demersum*)
- Sago pondweed
  (*Stuckenia pectinata*)

Water Quality Training for Lake Communities

<u>What should lake communities look out for?</u>

- Look out for these things:
  3. Knowing “water colors”

Clear-water

Nutrient-Rich

High Sedimentation

Blue-Green Algae

Iron-Source