LAKE ROAMING ROCK

Water Quality Monitoring 2021

Prepared for: **Rome Rock Association**
1875 U.S. Route 6
Roaming Shores, OH 44085

Project No.: 14299
Date: January 05, 2022

Prepared by:

EnviroScience
Excellence In Any Environment
5070 Stow Rd.
Stow, OH 44224
800-940-4025
www.EnviroScienceInc.com

Lake Management Services
Final Report, Rev 01/05/2022
Document Date: 01/05/2022

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Authorization for Release

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The undersigned attest, to the best of their knowledge, that this document and the information contained herein is accurate and conforms to EnviroScience's internal Quality Assurance standards.

Brad Bartelme
Aquatic Biologist
Project Manager

Martin Hilovsky
EnviroScience Principal & Founder
Senior Technical Reviewer

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EXECUTIVE SUMMARY

Lake Roaming Rock (LRR) is a 464-acre lake created to support a private lake community located in Rome Township, Ashtabula County, Ohio. It is a recreational impoundment of Rock Creek, a major tributary to the Grand River watershed. The watershed area is comprised of predominately residential and agricultural land-use types. In early 2020 RomeRock Association (RRA) expressed interest in a diagnostic study of the lake after observing a general decline in water quality throughout the last decade. Common observations included: excessive algae, increased turbidity, and low dissolved oxygen. EnviroScience proposed several tasks to help gain a better understanding of the overall health of LRR, including implementation of a water quality monitoring program. Tasks in the program included:

1. Lake Sampling, including biological and chemical analyses
2. Tributary Sampling, including chemical analyses

By analyzing the water quality in the lake and feeder streams, LRR can begin to identify the cause(s) and degree of degradation by the following factors:

1. Tributary nutrient and sediment loading, e.g., phosphorus inputs and/or sediments from upstream in the watershed (analytical sampling of tributaries)
2. Biotic contributions from within the lake itself, e.g., nutrients derived from the digestive processes of fish and plankton suspended in the water column and/or re-suspended from the sediments.

This study aimed to determine which of these factors are having the greatest effect on the water quality and lake health to prioritize future management decisions. These decisions will be prioritized based on how to best improve the overall health of the lake at the lowest possible cost with actions such as dredging, watershed restoration, fishery management, aquatic plant management, etc.

EnviroScience, Inc. tested several parameters at LRR during 2021 in response to the RRA's increasing concerns with degraded water quality, including the persistent algae blooms. Targeted areas included both open water and tributaries.

The results showed that LRR continues to be in a eutrophic state, based on both chemical and biological water quality indicators. Ohio EPA inland lake water quality criteria for total phosphorus and total nitrogen (Erie Ontario Lake Plain ecoregion) are 0.034 ppm and 0.740 ppm respectively. Both primary nutrient groups (Phosphorus and Nitrogen series) were consistently higher than inland lake water quality criteria set forth by Ohio EPA standards (OEPA, 2010). Bottom samples exhibited higher nutrient values than surface samples. Pairing this knowledge with observed stratification, it is likely that internal loading is a major issue for LRR.

It should be noted that the degree of eutrophication and the elevated nutrient levels are common among many of Ohio's lakes and reservoirs, particularly those with predominantly agricultural watersheds.

Biological indicators monitored during 2021 include chlorophyll-a, phytoplankton, and zooplankton. Initially chlorophyll-a concentrations were greater than Ohio EPA criteria (14 ppb) pre-algaecide application, but subsequently decreased in concentration post-application, ultimately meeting OEPA criteria. Phytoplankton analyses validated the chlorophyll-a data. In general, blue-green algae (cyanobacteria) were dominant throughout sampling season, but only exhibited bloom densities (>100,000 cells/ml) pre-algaecide treatment on June 15, 2021.

Independent of this study, LRR contracted with Aqua Doc LLC to provide a whole-lake treatment of Vodaguard® C, a copper-based herbicide manufactured by AgroShield, LLC. The decision to apply Vodaguard® to open water and bays of LRR was made with the concurrence of EnviroScience to provide a more aggressive treatment to control the blue-green algae blooms seen in recent years.

Summer dominance of cyanobacteria in the 2021 samples suggests that a potential human (and domestic animal) health risk is present in the lake, but may be abated through consistent monitoring, controlled algaecide treatments, and implementation of long-term management strategies (to be decided). Along with all other indicators, the survey showed a typical eutrophic zooplankton community structure. Characteristic of a cyanobacteria-dominant phytoplankton community, rotifers were the dominant zooplankters throughout the entire sampling season. Rotifer abundance is often positively correlated with high levels of blue-green algae because they can feed on these more successfully than cladocerans or other more desirable zooplankton.

Four tributaries within RRA boundaries with the largest drainage areas influent to LRR other than Rock Creek were sampled monthly from May-August. The mainstem of Rock Creek was sampled only during July and August. Of the four smaller tributaries, each one contributed nutrients (total nitrogen and total phosphorus) throughout the sampling season but had relatively small contributions compared with the Rock Creek mainstem (exhibiting nearly 2x TN and TP concentrations). External loading of nitrogen and phosphorus will likely continue and should be addressed in the long term, but may be more difficult to mitigate versus internal loading.

Considering the suite of parameters measured in the lake and tributaries, the 2021 sample results remain consistent with past reports indicating that Lake Roaming Rock is a eutrophic system with both internal and external nutrient sources. Despite current management efforts, algal bloom issues remain an ongoing concern. We are optimistic that the situation can be managed as was shown by the summer 2021 Vodaguard treatment which temporarily improved the transparency and delayed what would likely have been a major mid-season bloom. Although detailed management recommendations are beyond the scope of this report, we recommend that the RRA Board consider a multi-tiered approach including a combination of biological, physical, and chemical controls, coupled with long-term watershed education and management to mitigate the current eutrophic state.

1.0 INTRODUCTION

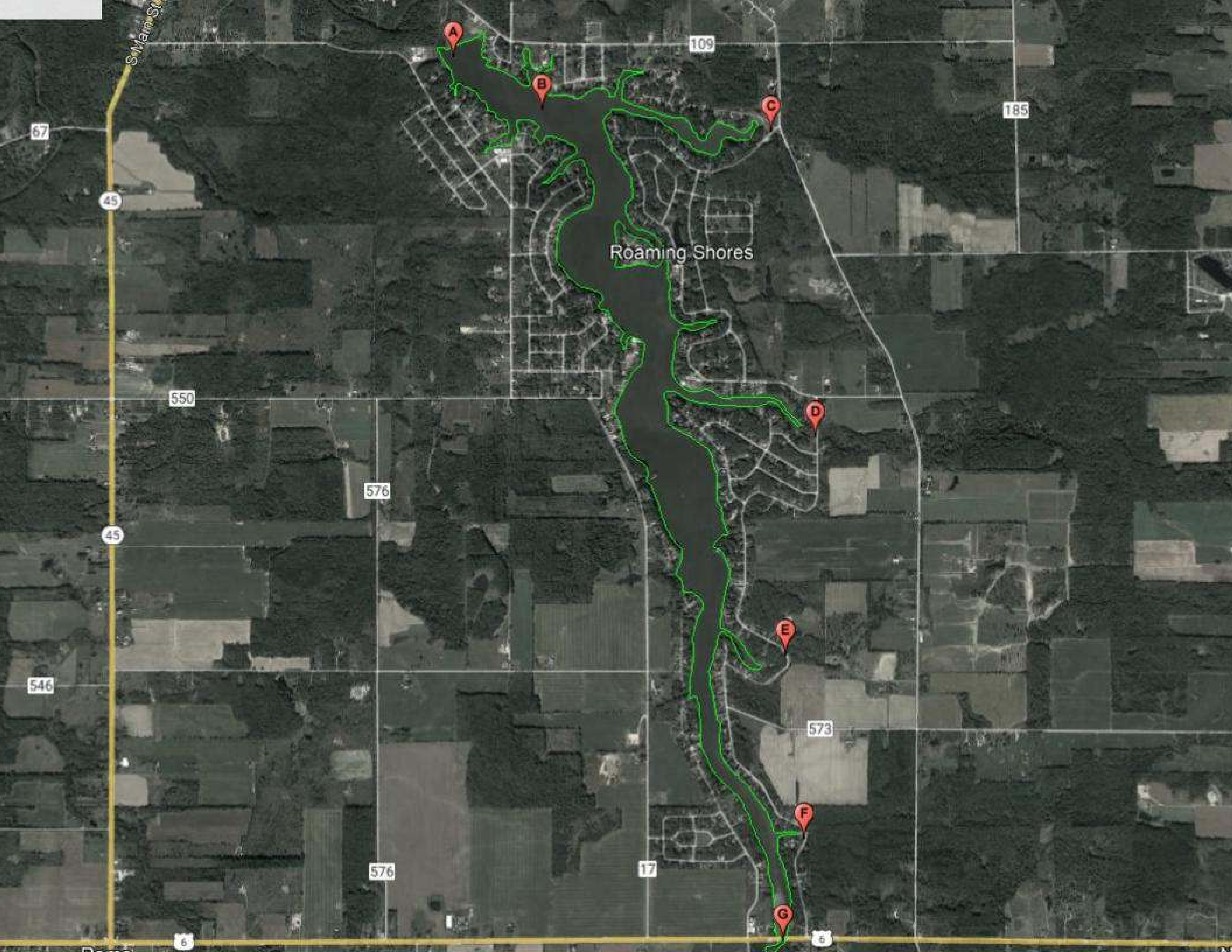
Many riparian property owners in the northern United States face similar problems with maintaining the quality of the beautiful natural resources of lakes and ponds. Lakeside property owners range from cities to private citizens, and nearly everyone can enjoy some type of recreational activity during both summer and winter months. However, sometimes, a problem arises in the chemical or biological balance of a lake. Human activities can be detrimental to water quality, aquatic plant community growth, or fish habitat. Without careful monitoring and management, beautiful lakes can become unsightly and unpleasant to visit.

In 2020 EnviroScience, Inc. was contracted by RRA for lake advisory services to evaluate current in-lake conditions and guide future management programs at LRR. In recent years, the frequency of algal blooms has increased and is currently the top concern of the community (Data provided by RRA). Up until 2021, treatment efforts to mitigate these blooms have been scattered. From the early 2000s to 2020 all treatment efforts mainly focused on invasive submerged aquatic vegetation and the control of Eurasian Water Milfoil to keep waterways open. The targeted treatment of these macrophytes is crucial for recreation and has had a very minor effect on the overall aquatic macrophyte community. Since the early 90's trends in aquatic macrophyte densities have been largely on the decline for unknown reasons, but may be potentially related water clarity. Without the presence of a well-balanced macrophyte community a niche opened for other primary producers, mainly algae and cyanobacteria. Algae blooms have been present throughout the history of the lake but have reached levels and frequencies that now approach human health standards.

The objectives of this study were to:

1. Determine the chemical, physical, and biological characteristics of the lake by using currently accepted monitoring and evaluation techniques during the summer of 2021. Utilize the data to assess current conditions, measure lake response to short-term management decisions (implementation of a whole-lake algaecide treatment), and compare current conditions to recent studies.
2. Gather quantitative information on nutrients in the major influent streams to the lake under both high and low flow conditions.

In addition, detailed plankton analysis of both zooplankton and phytoplankton, as well as analysis for algal toxins were completed throughout the study. Analysis of the phytoplankton communities is critical to generating meaningful management recommendations, and algal toxin monitoring is important to protect public health.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2.0 METHODS

EnviroScience visited LRR on four occasions (May 27, June 14, July 19, and August 24) during the summer of 2021 to gather representative data under both wet and dry weather conditions, capturing any influx of nutrients or changes in water chemistry in the watershed. For the purposes of this study, dry weather conditions were defined as being a period where no measurable precipitation had occurred within the past seven days and the influent streams were flowing at relatively low levels. Wet weather conditions were defined as periods where a minimum of 0.5 inches of precipitation had been recorded at a nearby National Weather Service monitoring station within the previous 24-hour period. Sampling locations are shown in Figure 1. Stream sampling locations were selected to provide information on potentially significant sources of nutrients/sediments based on USGS Stream Stats drainage areas.

2.1 LAKE WATER QUALITY MONITORING METHODS

In Situ Measurements

During each summer (June, July, August) lake sampling event, samples were collected at two locations: mid-lake and near the dam (Figure 1 – A & B). Sample sites were geo-located using a handheld GPS device to facilitate re-sampling. Water samples were collected using a 2.0-liter Van Dorn sampler one meter below the lake surface and one meter above the lake bottom. Each sample was analyzed for total suspended solids (TSS), total phosphorus (TP), low-level dissolved reactive phosphorus (LLDRP), total Kjeldahl nitrogen (TKN), ammonia-N (NH4), and nitrate-nitrite (NO_2NO_3).

In addition, the surface samples were analyzed for chlorophyll-a and transparency (Secchi depth). The water samples collected for chlorophyll-a analysis were collected at a depth of 0.5 meters. Chlorophyll samples were processed utilizing modified EPA 446 methods. Each sample was taken to the EnviroScience laboratory, drawn through GFF filters via vacuum filtration, and frozen until analysis. Chlorophyll-a was extracted using acetone, and the absorbance of the pigment was measured using a spectrophotometer. Concentrations of chlorophyll-a and pheophytin-a (the degraded form of chlorophyll-a) in the sample were determined using Lorenzen's Pheopigment-corrected Chlorophyll-a and Pheophytin-a equations. Transparency was measured with a 20-centimeter Secchi disk at each sampling station.

To capture measurements of thermal stratification, temperature, dissolved oxygen, specific conductance, and pH were profiled at both locations in the lake by immersing a portable YSI™ Pro DSS multiprobe water quality meter at half a meter, then subsequent one-meter intervals from the surface to the bottom.

At the request of RRA an additional water sample was taken at Flame Lake (as small, adjacent pond that discharges to LRR) during the September sediment sampling event.

Biological Analyses

During the first and third summer sampling events (June and August), zooplankton and phytoplankton samples were collected for identification and enumeration. Upon direction by RRA, water samples were periodically collected for cyanotoxin analysis.

Phytoplankton

Phytoplankton samples were taken using an integrated tube sampler to collect organisms from the water column at each lake sampling site. The integrated tube sampler collects a column of water from the lake surface down to twice the Secchi depth. This is known as the photic zone, or the portion of the lake where photosynthesis, and thus the phytoplankton, mostly occurs. The sample was homogenized in a triplerinsed stainless-steel bucket and transferred to a sample jar, then preserved with Lugol's solution and transported to the EnviroScience laboratory for analysis.

Samples were analyzed with an Olympus IX73 phase contrast microscope at 400x total magnification. Subsamples were concentrated for ease of identification, and each subsample was counted in an Utermöhl plankton counting chamber. Phytoplankton taxa were reported in natural units per milliliter and cells per milliliter and relative abundance are presented in Appendix A.

Zooplankton

Zooplankton samples were collected using a 0.3-meter diameter Wisconsin-style tow net with a 0.2-meter throat and 50 µm mesh. A vertical tow was performed, sampling the entire water column from the bottom. The net was rinsed, and the collection jar removed. The sample was preserved in ethanol and transported to the EnviroScience laboratory for analysis.

The collection jar was transferred to a 500 mL container to analyze the zooplankton community using subsamples. The zooplankton were then identified to the lowest practical taxonomic unit and enumerated. Zooplankton density was reported in numbers per meter cubed. Zooplankton abundance was estimated by calculating the volume of water sampled and the numbers of taxa within the zooplankton sample. All zooplankton data are presented in Appendix A.

2.2 LAKE SEDIMENT SAMPLING

Lake water and sediment quality are closely interlinked with one another. Collecting information about the lake sediments is crucial in identifying and quantifying any sources of internal nutrient loading or chemical insults. Sediment cores were taken at eight (8) locations (five in the main lake; three in the coves) identified by EnviroScience and SePro (Figure 2). The top 10 cm of sediment was collected at each location and analyzed for Phosphorus and Copper.

Sub-samples were taken from each core and shipped to the SePro Research & Technology Campus, Whitakers, NC for phosphorus analysis. A total of two Level 2 analyses and six Level 1 analyses were completed. The comprehensive Level 2 analysis identified the percent solids and the concentrations of labile, reductant-soluble, metal-oxide, organic, apatite, and residual phosphorus. The Level 1 analysis only measured the concentrations of mobile (potentially bio-available), apatite, and residual phosphorus. In addition, sediment from each core was sent to Eurofins – Test America for copper analysis to monitor any long-term effects of copper-based algaecides moving forward.

2.3 STREAM WATER QUALITY MONITORING

EnviroScience utilized USGS StreamStats to remotely identify four tributaries having the greatest drainage areas influent to LRR other than the Rock Creek mainstem (Figure 1). In July 2021, Rock Creek was added to the monitoring stations and was regularly sampled throughout the rest of the season. During the first spring sampling event (5/27/21), a small reconnaissance survey was performed to ground truth stream sampling locations previously identified via desktop analysis. At each sampling location water samples and discharge measurements were taken during seasonal low-flow conditions. Concurrently, four-foot staff gauges were permanently installed at each location to act as a proxy for changes in flow over time. Changes in depth were noted every sampling visit including additional data points provided by volunteer monitors. Water quality sampling stations were identified, marked with differential GPS equipment, and samples were collected. Field parameters including temperature, conductivity, pH, and DO were measured using a YSI Pro DSS multi-parameter meter, and stream height was measured via the staff gauge. Analytical parameters analyzed by Northeast Ohio Regional Sewer District (NEORSD – Cleveland, OH) included total suspended solids (TSS), total phosphorus (TP), low-level dissolved reactive phosphorus

(LLDRP), total Kjeldahl nitrogen (TKN), ammonia-N (NH_4), and nitrate-nitrite (NO_2NO_3). Sampling was completed during a multitude of conditions (representing at least 1 wet- and dry-weather event) coinciding with summer lake monitoring efforts.

Water samples were preserved and analyzed within prescribed holding times according to methods outlined in Standard Methods for the Examination of Water and Wastewater (APHA, 1995).

3.0 RESULTS AND DISCUSSION

3.1 LAKE WATER QUALITY MONITORING

In Situ Measurements

The results for temperature, conductivity, and pH throughout the three sampled time periods were within expected ranges and are conducive to aquatic life use. Surface dissolved oxygen (DO) at all locations was adequate but drops dramatically below 3-5 meters in depth. In eutrophic systems, DO generally declines with depth and approaches zero near the bottom of the lake as the summer progresses (thermal stratification). Lake Roaming Rock exhibits textbook, normal eutrophic lake characteristics. Dissolved oxygen was consistently below 5 mg/L from 4 meters to the bottom at both sampling locations. Throughout the summer bottom DO measurements were consistently low ranging from 0.22-0.62mg/l. Low DO readings below 4 meters are not conducive to aquatic life and generally restricts fish activity in these areas except for short periods. The low DO conditions at the sediment/water interface also results in the release of phosphorus and metals such as iron and manganese from the sediments to the water column, which as is seen in the analytical results in the following section.

Table 1. Lake Roaming Rock Depth Profile and In Situ Measurements

Mid-Lake 06/14/21 (DRY)						Dam 06/14/21 (DRY)					
Depth (m)	Temp ˚C	DO %	DO mg/L	SPC µs/cm	pH	Depth (m)	Temp ˚C	DO %	DO mg/L	SPC µs/cm	pH
0.5	24.2	124.6	10.41	192.6	8.99	0.5	23.9	124.7	10.52	190.4	8.97
1	24.2	124.1	10.41	192.6	8.98	1	23.9	124.7	10.52	190.5	8.98
2	24.2	123.3	10.36	192.7	8.94	2	23.8	118.2	9.97	190.8	8.97
3	16.3	16.0	1.61	189.3	8.24	3	16.5	21.3	2.10	189.6	8.56
4	12.1	14.3	1.55	182.9	8.05	4	12.0	17.2	1.88	185.6	8.17
5	10.3	13.2	1.51	177	7.93	5	9.7	21.9	2.47	182.1	8.00
6	9.30	16.2	1.86	174.7	7.79	6	8.9	21.2	2.46	180.3	7.89
7	9.00	7.7	0.91	176	7.70	7	8.6	10.7	1.24	178.6	7.80
8	8.60	5.4	0.63	181.2	7.52	8	8.3	5.7	0.68	180.8	7.56
						9	8.1	5.2	0.62	191.6	7.41
Average Secchi depth (m): 1.25						Average Secchi depth (m): 0.95					
Mid-Lake 07/19/21 (WET)						Dam 07/19/21 (WET)					
Depth (m)	Temp ˚C	DO %	DO mg/L	SPC µs/cm	pH	Depth (m)	Temp ˚C	DO %	DO mg/L	SPC µs/cm	pH
0.5	22.4	71.8	6.08	136.1	7.01	0.5	22.5	72.4	6.15	142.2	7.24
1	22.4	71.5	6.06	136.1	7.02	1	22.2	68.0	5.78	142	7.14
2	22.2	64.2	5.56	124	7.03	2	22.1	66.8	5.69	141.3	7.12
3	21.4	54.1	4.67	127.3	6.90	3	21.2	56.3	4.89	116	7.10
4	20.6	49.4	4.34	115.7	6.88	4	20.8	45.0	3.94	127.6	6.97
5	20.2	34.5	3.06	139.3	6.70	5	20.0	34.4	3.06	140.3	6.94
6	13.20	2.6	0.27	198.8	6.66	6	14.0	4.6	0.50	199.9	6.84
7	10.60	2.1	0.23	190.2	6.72	7	10.2	2.6	0.29	191	6.85
8	9.50	2.0	0.22	197.1	6.69	8	9.4	2.1	0.23	189.5	6.81
9	9.00	1.8	0.20	199.5	6.74	9	9.2	1.9	0.22	192.5	6.77

Average Secchi depth (m): 0.45						Average Secchi depth (m): 0.55					
Mid-Lake 08/24/21 (DRY)						Dam 08/24/21 (DRY)					
Depth (m)	Temp ˚C	DO %	DO mg/L	SPC µs/cm	pH	Depth (m)	Temp ˚C	DO %	DO mg/L	SPC µs/cm	pH
0.5	26.3	129.5	10.15	146.5	8.26	0.5	27.1	142.2	11.00	145.2	8.89
1	26.1	1180.0	9.39	145	8.06	1	27.0	140.6	10.90	144.5	8.85
2	25.6	99.2	7.89	144	7.52	2	25.8	105.0	8.30	143.2	8.00
3	25.1	51.5	4.14	143.4	7.13	3	25.6	102.5	8.15	143	7.84
4	22.5	3.4	0.38	153.8	6.77	4	22.5	6.5	0.45	147.7	7.30
5	18.0	2.7	0.26	170.1	6.60	5	18.0	3.9	0.36	168.4	7.04
6	15.20	2.4	0.23	197.9	6.56	6	14.0	3.3	0.33	192	6.99
7	12.00	2.1	0.22	217.1	6.44	7	12.9	3.1	0.31	201	6.98
8	10.60	2.0	0.23	232.2	6.46	8	11.1	2.8	0.30	207.2	6.95
9	9.60	1.9	0.20	247	6.62	9	9.7	2.6	0.28	227.5	6.83
Average Secchi depth (m): 0.95						Average Secchi depth (m): 0.95					

Analytical Results

Overall, all nutrient concentrations were found to be consistently above state-wide nutrient criteria (Criteria for Erie Ontario Lake Plain: total phosphorus = 0.034 ppm; total nitrogen = 0.740 ppm) for both surface and bottom samples (OEPA 2010). Total Phosphorus and LLDRP samples, were significantly different when comparing surface and bottom concentrations in LRR. Internal phosphorus mechanisms in LRR most likely include the classic sediment release through iron-redox reactions, cyanobacteria uptake and migration, bacteria mineralization of sediment phosphorus, and bioturbation of aquatic organisms. Given the very low DO concentrations in the hypolimnion, significant internal loading of phosphorus is occurring and may be the dominant source of phosphorus loading to the overall water column. All other phosphorus measurements taken from the surface waters (both lake and feeder streams) were relatively low in comparison to the bottom samples. However, Rock Creek is undoubtedly a major contributor to external phosphorus loading with TP and LLDRP samples producing consistently high levels during both high and low flow conditions Despite elevated phosphorus levels in Rock Creek surface waters, much of it appears to be assimilated throughout the reservoir considering the relatively low TP and LLDRP measurements in the Mid-Lake and Dam surface water samples (outside of rain events). Without additional lake phosphorus samples as well as a phosphorus mass balance model, the magnitude and timing of the internal loading, however, cannot be determined.

While phosphorus is certainly the main concern, nitrogen is the other crucial element that contributes to primary production. As with phosphorus, total nitrogen values observed at LRR are consistently greater than state-wide nutrient criteria. Nitrogen was speciated by measuring levels of ammonia-nitrogen (NH3-T), biologically available nitrogen in the form of nitrate-nitrite (NO3NO2), organically bound nitrogen and ammonia (TKN), and total nitrogen by calculation (TKN + NO3NO2). Overall, ammonia levels were relatively low in surface samples, but were slightly elevated near the bottom. In relation to the other nitrogen species, these are relatively negligible. The dominant nitrogen species (which contribute to total nitrogen) are organically bound nitrogen (measured through TKN) and biologically available nitrogen (measured as Nitrate-Nitrite). Higher nitrogen values observed in the bottom waters suggests leaching from sediments.Throughout the entire sampling season among both sites, total nitrogen values from the surface and bottom ranged from 1.816 – 3.380 ppm and 2.240 – 3.676 ppm respectively. Observed values were 2.5 - 5 times greater than statewide nutrient criteria.

Total suspended solids (TSS) values were relatively constant throughout the sampling period. The only notable changes in TSS were observed during the 7/19 sampling period after a large rain event.

Flame Lake did not present any concern in terms of nutrient discharge into LRR. All analytical levels were far below state-wide nutrient criteria (Table 4).

Table 2. Lake Roaming Rock Water Chemistry – MID-LAKE

SURFACE	6/14/2021 (DRY)	7/19/2021 (WET)	8/24/2021 (DRY)
LLDRP (ppb)	3.49	58.7	5.27
NH3-T (ppm)	<0.0220	0.065	<0.0220
NO3NO2 (ppm)	0.329	1.62	0.242
TP (ppm)	0.0411	0.139	0.0703
TKN (ppm)	1.55	1.49	1.58
TSS (ppm)	9.2	14	8
Total Nitrogen (ppm)	1.879	3.11	1.822
BOTTOM	**6/14/2021 (DRY)**	**7/19/2021 (WET)**	**8/24/2021 (DRY)**
LLDRP (ppb)	52.6	64.7	215
NH3-T (ppm)	0.44	0.663	1.38
NO3NO2 (ppm)	0.654	0.695	0.0929
TP (ppm)	0.134	0.25	0.575
TKN (ppm)	1.64	1.83	2.7
TSS (ppm)	2.8	9.4	5.2
Total Nitrogen (ppm)	2.294	2.525	2.7929

Table 3. Lake Roaming Rock Water Chemistry – DAM

SURFACE	6/14/2021 (DRY)	7/19/2021 (WET)	8/24/2021 (DRY)
LLDRP (ppb)	3.44	52.4	4.81
NH3-T (ppm)	<0.0220	0.0477	<0.0220
NO3NO2 (ppm)	0.284	1.86	0.226
TP (ppm)	0.0419	0.134	0.0724
TKN (ppm)	1.6	1.52	1.59
TSS (ppm)	9.3	12.2	8.8
Total Nitrogen (ppm)	1.884	3.38	1.816

BOTTOM	6/14/2021 (DRY)	7/19/2021 (WET)	8/24/2021 (DRY)
LLDRP (ppb)	58.1	58.5	356
NH3-T (ppm)	0.485	0.511	2.36
NO3NO2 (ppm)	0.69	0.861	0.0459
TP (ppm)	0.144	0.18	0.991
TKN (ppm)	1.55	1.55	3.63
TSS (ppm)	3.1	9.9	7.5
Total Nitrogen (ppm)	2.24	2.411	3.6759

Table 4. Flame Lake Water Chemistry

	09/28/21 (DRY)
LLDRP (ppb)	6.21
E. coli (MPN/100mL)	6.00
NH3-T (ppm)	0.0510
NO3NO2 (ppm)	0.0371
TP (ppm)	0.0383
TKN (ppm)	0.944
TSS (ppm)	2.90
Total Nitrogen (ppm)	0.9811

Trophic Status and TSI Calculation

In any given lake system, the trophic state of the lake can be defined as the total amount of living material (biomass) present in the water column at a given time. Trophic state is generally accepted as a biological response to factors such as nutrient addition, with phosphorus being the primary growth-limiting nutrient for algae and macrophytes in lakes (Horne and Goldman, 1994). Eutrophication, although a natural process over time, is often accelerated by human activities, namely those that increase plant nutrients (i.e., phosphorus) in the lake. Nutrients enter the lake through run-off or direct input from fertilizer-rich agricultural soils, sewage, or other wastewater. Enrichment of the nutrients in the water results in increased algal densities (algal “blooms”), which in turn may produce a host of undesirable effects including discoloration, taste and odor problems, low DO conditions, changes in fish species abundance, and toxicity problems. Toxicity is of concern with increasing awareness that some strains of algae produce toxins at doses that are lethal to animals and humans.

Due to its importance in lake dynamics, monitoring of total phosphorus was an important part of the current study. Samples of chlorophyll-a provided an estimate of the amount of primary production in the system.

The more chlorophyll-a that is present, the larger the algal biomass, and the more eutrophic the lake is. Additionally, the clarity of the lake, as measured by Secchi disc transparency, is a function of the density of varying algal concentrations and other suspended material.

Table 5. Lake Roaming Rock Chlorophyll-a Data

Site	Sample Date	Chl-a (ppb)
DAM	6/14/2021	48.1
MID-LAKE	6/14/2021	64.0
DAM	7/19/2021	13.4
MID-LAKE	7/19/2021	10.7
DAM	8/24/2021	10.7
MID-LAKE	8/24/2021	9.3

Carlson's Trophic State Index (TSI) (Carlson, 1977) is a relatively simple way of comparing these three measurements. Chlorophyll a (CHL), Secchi depth (SD), and total phosphorus (TP) are used in the TSI calculations to independently estimate algal biomass. Each measurement is converted to an index value ranging from 0 to 100 using the following equations:

$$\mathrm{TSI(SD)} = 60 - 14.41\ln(\mathrm{SD})$$

$$\mathrm{TSI(CHL)} = 9.81\ln(\mathrm{CHL}) + 30.6$$

$$\mathrm{TSI(TP)} = 14.42\ln(\mathrm{TP}) + 4.15$$

Based on its TSI values, a lake can be placed into one of four categories of trophic status (Table 6): oligotrophic, mesotrophic, eutrophic, and hypereutrophic. Oligotrophic lakes (TSI <40) are typically clear, well-oxygenated throughout, with little phytoplankton and low nutrient levels. Mesotrophic lakes (TSI between 40-50) are intermediate between oligotrophic and eutrophic lakes and are characterized by moderate clarity and nutrient levels and increasing probability of anoxic conditions at depth during the summer. Eutrophic lakes (TSI between 50 and 70) are often characterized by a disappearance of oxygen (anoxia) in the deeper parts of the lake and nuisance levels of macrophytes and blue-green algal scums during the summer. Hypereutrophic lakes (TSI >70) have algal densities so high that light rather than nutrients becomes limiting to plant growth. Macrophytes often disappear because there is insufficient light to support their growth. Fish species shift towards roughfish that can tolerate low oxygen levels. In extreme hypereutrophic situations, winter and summer fish kills may occur.

Table 6. TSI Scoring Rubric (NALMS – Carlson, 1996)

TSI	Chl(µg/L)	SD(m)	TP (µg/L)	Attributes	Water Supply	Fisheries & Recreation
< 30	< 0.95	> 8	< 6	**Oligotrophy:** Clear water, oxygen throughout the year in the hypolimnion.	Water may be suitable for an unfiltered water supply.	Salmonid fisheries dominate.
30 – 40	0.95 – 2.6	8 – 4	6 – 12	Hypolimnia of shallower lakes may become anoxic.		Salmonid fisheries in deep lakes only.
40 – 50	2.6 – 7.3	4 – 2	12 – 24	**Mesotrophy:** Water moderately clear; increasing probability of hypolimnetic anoxia during summer.	Iron, manganese, taste, and odor problems worsen. Raw water turbidity requires filtration.	Hypolimnetic anoxia results in loss of salmonids. Walleye may predominate.
50 – 60	7.3 – 20	2 – 1	24 – 48	**Eutrophy:** Anoxic hypolimnia, macrophyte problems possible.		Warm-water fisheries only. Bass may dominate.
60 – 70	20 – 56	0.5 – 1	48 – 96	Blue-green algae dominate, algal scums and macrophyte problems.	Episodes of severe taste and odor possible.	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
70 – 80	56 – 155	0.25 – 0.5	96 – 192	**Hypereutrophy:** (light limited productivity). Dense algae and macrophytes.		
> 80	> 155	< 0.25	192 – 384	Algal scums, few macrophytes		Rough fish dominate; summer fish kills possible.

TSI values calculated for Lake Roaming Rock are as follows:

Table 7. Calculated TSI Values

MID-LAKE			
Date	**TSI(SD)**	**TSI(CHL-a)**	**TSI(TP)**
6/14/2021	56.78	71.40	57.73
7/19/2021	71.51	53.85	75.31
8/24/2021	60.74	52.48	65.47
Average	**63.01**	**59.24**	**66.17**
DAM			
6/14/2021	60.74	68.60	58.01
7/19/2021	68.61	56.06	74.78
8/24/2021	60.74	53.85	65.90
Average	**63.36**	**59.50**	**66.23**
Combined Average	**63.19**	**59.37**	**66.20**

The calculated values place Lake Roaming Rock near the middle of the eutrophic range when considering all of the indicators, especially Chlorophyll-a (the strongest indicator). A four-fold decrease in Chlorophyll-a concentration was observed post algaecide treatment, placing it below OEPA criteria for inland lakes (14 ppb). The fact that the three indices tend to trend similarly on the same dates is indicative that there is little non-algal turbidity in the water and that the transparency is being largely affected by algae concentrations. Situations where there are similarities between the average phosphorus and chlorophyll index values suggest that phosphorus is the limiting nutrient, as is typical for most lakes in the Midwest.

Biological Analyses

Phytoplankton

The results of the phytoplankton (algae) analysis are provided in Appendix A. The first sampling event in June was taken before the whole-lake algaecide treatment. At that time the lake was already exhibiting bloom conditions (cell counts >100,000 cells/ml). Overall diversity was very low among both sites (<10 species) and the community was comprised of 97% blue-green algae. In July there was a significant decrease in algae post-treatment. The phytoplankton sample exhibited a well-balanced algal community with a decrease in algal density (<10,000 cells/ml) and an increase in diversity (Appendix A). Despite this overwhelmingly positive result, August samples showed a slight increase in algal densities (>10,000 cell/ml, but <100,000 cells/ml) and a decrease in diversity. During the short-term management planning phase it was posited that two treatments throughout the season may be necessary to mitigate bloom conditions. This proved true and this may be the case for future summer seasons.

The algae community is largely dominated by blue-green algae, with *Aphanizomenon flos-aquae*, *Microcystis aeruginosa*, *Woronichinia naegeliana*, and *Aphanocapsa delicatissima* being the most dominant species. These species are common in nutrient-rich surface water and generally do well in warm temperatures and in high light levels. Some species, such as *Aphanizomenon flos-aquae,* can increase their population size every year, due to their physiology. Certain blue-green algae produce specialized resting cells called akinetes. When conditions become unfavorable the cyanobacteria die-off and settle to the bottom, but the akinete can persist in the sediment allowing for easy recolonization for the next season. If conditions are right, significant blooms may be observed in fall, winter, and spring.

All the dominant species observed in LRR are considered potentially toxic, meaning they can produce cyanotoxins under varying conditions. For water quality managers, blue-green algae blooms can prove to be a conundrum. Bloom severity is not always a good indication of toxin concentration. While most minor cyanobacteria blooms will only have very low levels of toxins present, in other cases minor blooms may have higher concentrations of toxins. Multiple possible explanations exist for why some blooms of the same species produce toxins and some do not, and these include environmental conditions and the presence or absence of toxin-producing genes. Therefore, what may look like a minor bloom, may have high toxins and what may look like a major bloom may not be producing toxin at all. In addition, some cyanobacteria are more likely to produce toxins than others, so it is impossible to assess toxin concentrations by visual evidence alone.

Cyanotoxin concentrations (microcystin) were measured throughout the season in areas with the greatest recreational exposure (i.e. beaches). Only the 8/31/2021 sampling event had a concentration above the OEPA recreational advisory limit (8 ppb). This event was followed up immediately a couple days later and microcystin concentrations significantly decreased. The cause for the sudden spike in toxin is unknown, but may be explained by sampling technique. In many cases, results were below the reporting limit (>0.3 ppb).

Table 8. Cyanotoxin Analysis (Microcystin ppb)

Date	Roaming Rock Blvd (Beach #1)	Morningstar Drive (Beach #2)	Dam	Lot 1459
05/25/2021	<0.3	<0.3	-	-
06/08/2021	0.642	<0.3	-	-
06/22/2021	<0.3	-	-	-
06/30/2021	<0.3	<0.3	-	-
07/13/2021	<0.3	<0.3	-	-
07/27/2021	<0.3	<0.3	-	-
08/03/2021	1.344	<0.3	-	-
08/13/2021	1.935	<0.3	4.562	<0.3
08/17/2021	4.449	0.792	-	-
08/23/2021	1.719	1.407	-	-
08/31/2021	**>25.0**	0.938	**>25.0**	-
09/03/2021	0.271	2.207	-	-

Zooplankton

Zooplankton are microscopic invertebrates that are the second form of biological production in a waterbody after the primary producers (phytoplankton). They play a vital role in a lake's ecosystem by providing forage for larval and juvenile fish. Analysis of the lake's zooplankton can provide insight into the availability and quality of larval fish forage and reveal facets of the LRR food web from the lower trophic perspective.

Zooplankton communities are dynamic, changing throughout the year, with populations responding to available phytoplankton communities as well as predation by larval fish. Their role in the food web is crucial to converting energy from the phytoplankton to a form that can be utilized by the larvae and juvenile fish populations of the lake, including top predators like bass and pike.

Overall, the 2021 zooplankton survey reveals a typical assemblage and density of zooplankton commonly established in eutrophic lakes, most notably the cladocerans *Daphnia mendotae*, *Eubosmina sp.*, *Diaphanosoma sp,* and the rotifers *Keratella*, and *Kellicotia.* No exotic or invasive zooplankton species, such as zebra mussel veligers (larvae), were observed in the sample. The zooplankton community consisted of species at densities typical of other eutrophic lakes and would adequately sustain larvae and juveniles of the fish community, such as largemouth bass, crappie, sunfish, and catfish.

Changes in zooplankton community structure were noticeable as the season progressed, however, the system was rotifer dominant throughout. Rotifers are very small multi-cellular animals that filter planktonic algae for food. The relative shift in dominance of rotifers in the lake is likely related to the abundance of blue-green algae. Rotifer abundance is often positively correlated with high levels of blue-green algae because rotifers seem to be able to feed on toxin-producing blue-green algae more successfully than cladocerans or other zooplankton. Continuing zooplankton analysis can reveal long-term trends in recruitment, food web dynamics, and reflect potential environmental stressors in the lake. The results of the zooplankton analysis are presented in Appendix A.

3.2 SEDIMENT ANALYSIS

Overall, sediment samples exhibited high concentrations of bio-available phosphorus. Shallow sampling locations (<15ft), including coves, exhibited mobile phosphorus values of 275-360 mg/kg. Sediments with phosphorus values >300 mg/kg are generally considered eutrophic (personal communication SePro). The deeper (>15ft) main lake locations (901-Dam, 902-Mid Lake, and 904) had double the total phosphorus and three to four times greater amount of mobile (bio-available) phosphorus than samples collected in shallower locations. The Dam, the deepest location, had the highest TP concentration (~2000 mg/kg) of the eight locations. The high TP concentrations in the sediment at the Dam were mostly due to high concentrations (~1515 mg/kg – 75%) of mobile phosphorus (reductant-soluble, metal-oxide, and organic phosphorus). Under the right conditions (including anoxic conditions), the mobile phosphorus constituents can mobilize out of the lake sediments into the overlying water column where they can become available for algal and plant uptake. TP concentrations in the sediment cores at the Dam in LRR were very similar to TP concentrations in Buckeye Lake, OH, and Lake Ketchum, WA. Legacy sediment phosphorus from historic agricultural impacts in Lake Ketchum continues to fuel internal phosphorus loading leading to excessive algal blooms, similar to LRR (TetraTech, 2014). Sediment results for each separate location are located in Appendix B.

Lake Roaming Rock sediments across all sites generally had a normal level of elemental copper present (Range: 20-39 mg/kg). The highest levels of copper (values of 39 mg/kg) were observed in the deeper portions of the lake (901-Dam, 902-Mid Lake, and 904). Ohio EPA sediment quality guidelines for freshwater ecosystems list copper to have a threshold effect concentration (TEC) of 31.6 mg/kg (Ohio EPA, 2008). The TEC is a concentration below which adverse effects on benthic organisms are unlikely to occur. LRR does exhibit values greater than the TEC, but only in the deepest portions of the lake. Considering the parent material (general soil profiles in the surrounding watershed) the values are well within the range of normal, and not a human health concern if removed or disturbed.

Table 9. Concentration of Copper in LRR Sediments (mg/kg)

Location	Cu (mg/kg)
901 - Dam	39
902 – Mid Lake	39
904	39
906	20
908	23
Plum Creek Cove	25
Sugar Creek Cove	30
Fisherman's Cove	27

3.3 INFLUENT STREAM SAMPLING

The stream sampling results summarized below show moderate levels of nutrients entering LRR from the surrounding watershed. In situ measurements taken via a multiparameter probe were relatively similar among sites and are considered normal for the area. However, Fisherman's cove exhibited elevated specific conductance, and lower dissolved oxygen relative to all other sites sampled (Table 11). The elk-farm upstream along with lack of canopy cover and riparian buffers likely accounts for the differences observed.

In general, both nutrients and suspended solids were generally constant throughout wet and dry weather conditions. Slight increases in both nutrients and total suspended solids were observed during wet weather conditions, but only for certain sites and parameters. Although the lack of calibrated flow information prevents calculation of mass loadings, the observed concentrations and the size of the watershed make it clear that Rock Creek is the major source of phosphorus and nitrogen entering LRR. Sampling results from the major influent sources including Rock Creek are presented for each site.

Discharge measurements were taken during the initial sampling event (Table 11). In future monitoring events, more discharges will be measured to create a regression relating staff gauge measurements. Ultimately, once enough discharge measurements are collected during various conditions, staff gauges may be used as a predictor of discharge. Differences in staff gauge height were observable with rain events, but rarely varied >1ft (Table 10).

Table 10. Influent Streams - Observed Changes in Staff Gauge Height (feet)

Site ID	5/26	6/14	6/22	7/09	7/11	7/18	7/19	8/14	8/24
Plum Creek	0.30	0.52	1.62	0.85	2.40	1.60	0.84	0.30	0.26
Sugar Creek	0.38	0.55	1.40	1.00	-	1.60	0.90	0.76	0.44
Fisherman's Cove	1.12	1.25	1.67	1.56	3.0	2.12	1.57	1.40	1.12
Spanish Cove	0.09	0.15	0.83	0.60	3.35	0.81	0.48	0.16	0.12

Table 11. Lake Roaming Rock Influent Stream In Situ Measurements

Dry Weather Event 05/26/21						
Stream ID	**Temp ˚C**	**DO %**	**DO mg/L**	**SPC µs/cm**	**pH**	**Discharge m^3/s**
Plum Creek	21.3	100.2	8.86	301.8	7.51	0.0008
Sugar Creek	20.1	68.0	6.17	285.5	6.86	0.0001
Fishermans Cove	22.4	69.3	6.00	468.9	7.36	<0.0001
Spanish Cove	20.5	88.7	8.01	408.8	7.76	0.0001

Dry Weather Event 06/14/21						
Stream ID	**Temp ˚C**	**DO %**	**DO mg/L**	**SPC µs/cm**	**pH**	**Discharge m^3/s**
Plum Creek	18.3	89.4	7.95	308.2	8.14	-
Sugar Creek	18.5	93.2	8.75	268.7	8.15	-
Fishermans Cove	18.5	63.9	6.00	490	7.8	-
Spanish Cove	17.2	83.3	8.02	371.1	7.97	-

Wet Weather Event 07/19/21						
Stream ID	**Temp ˚C**	**DO %**	**DO mg/L**	**SPC µs/cm**	**pH**	**Discharge m^3/s**
Plum Creek	20.6	95.3	8.37	146.1	7.55	-
Sugar Creek	20.5	98.7	8.66	153.1	7.62	-
Fishermans Cove	21.4	84.8	7.31	271.8	7.70	-
Spanish Cove	21.0	93.2	8.10	174.6	7.68	-
Rock Creek @ Rt. 6	21.60	58.3	5.01	119.6	7.00	-

Dry Weather Event 08/24/21						
Stream ID	**Temp ˚C**	**DO %**	**DO mg/L**	**SPC µs/cm**	**pH**	**Discharge m^3/s**
Plum Creek	21.1	51.2	4.43	352.6	7.31	-
Sugar Creek	24.3	82.2	6.70	326.9	7.34	-
Fishermans Cove	24.9	74.3	5.98	498.1	7.43	-
Spanish Cove	21.60	95.0	8.14	403.6	8.03	-
Rock Creek @ Rt. 6	22.8	32.0	2.68	209.8	7.38	-

Plum Creek

This tributary drains approximately 3.16 sq miles of the northeastern side of Lake Roaming Rock. The watershed isn't very developed (5.23% urban) and maintains ~44.7% tree/forested cover. The impervious surface percentage is very low at only 0.72%. A majority of the watershed is impacted by agricultural land use, a source of impairment through nutrient runoff. Nitrogen and phosphorus values were slightly elevated throughout the sampling period but are within a normal range for OEPA warmwater criteria (Ohio EPA, 2011). Of the four feeder streams sampled (outside of mainstem Rock Creek), Total nitrogen concentrations were highest on average at this site.

Figure 3. Plum Creek Sub-watershed

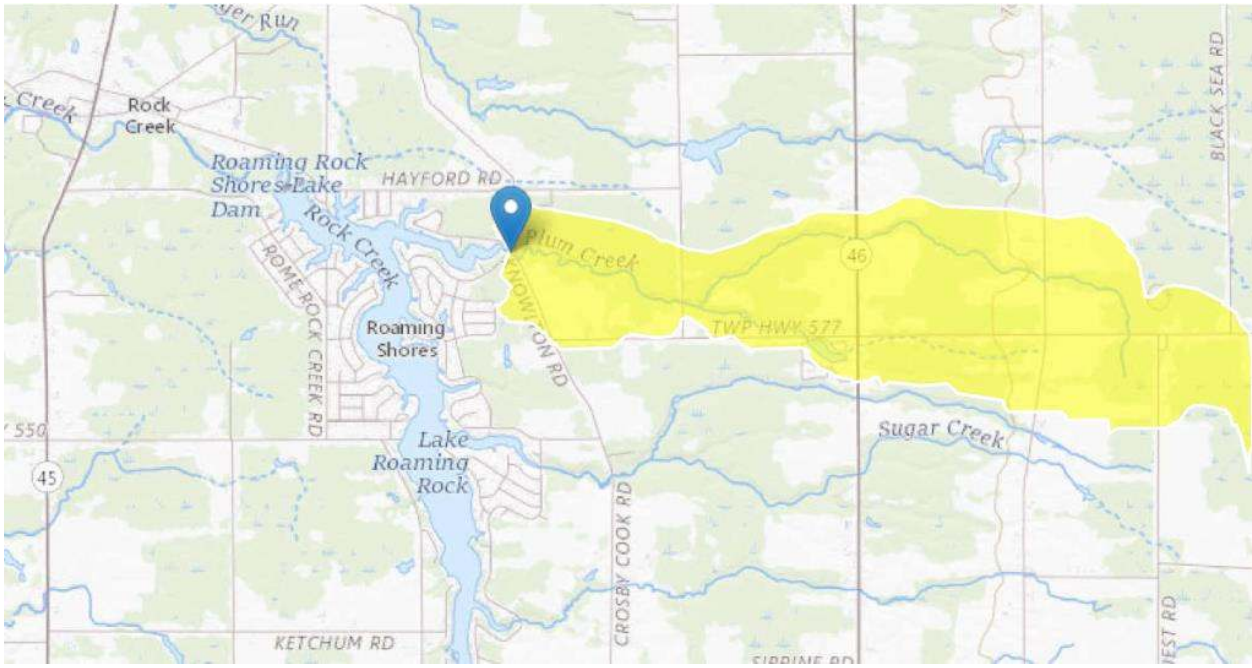

Table 12. Plum Creek Water Chemistry

Date	5/27/2021 (DRY)	6/14/2021 (DRY)	7/19/2021 (WET)	8/24/2021 (DRY)
LLDRP (ppb)	5.15	11.2	28	8.02
E. coli (MPN/100mL)	-	-	461	-
NH3-T (ppm)	0.112	0.0805	0.0244	0.0828
NO3NO2 (ppm)	0.103	2.28	1.46	0.109
TP (ppm)	0.0361	0.0757	0.0846	0.0377
TKN (ppm)	0.93	1.62	1.15	0.91
TSS (ppm)	7.2	88	6.3	4.2
Total Nitrogen (ppm)	1.033	3.9	2.61	1.019

Sugar Creek

This tributary drains approximately 3.23 sq miles of the eastern side of Lake Roaming Rock. The watershed isn't developed (3.9% urban) and maintains a similar area covered by forest at ~43.5% when compared to Plum Creek. The impervious surface percentage is very low at only 0.62%. As with Plum Creek, a majority of the watershed is impacted by agricultural land use, a source of impairment through nutrient runoff. Nitrogen and phosphorus values were slightly elevated throughout the sampling period but are within a normal range for OEPA warmwater criteria.

Figure 4. Sugar Creek Sub-Watershed

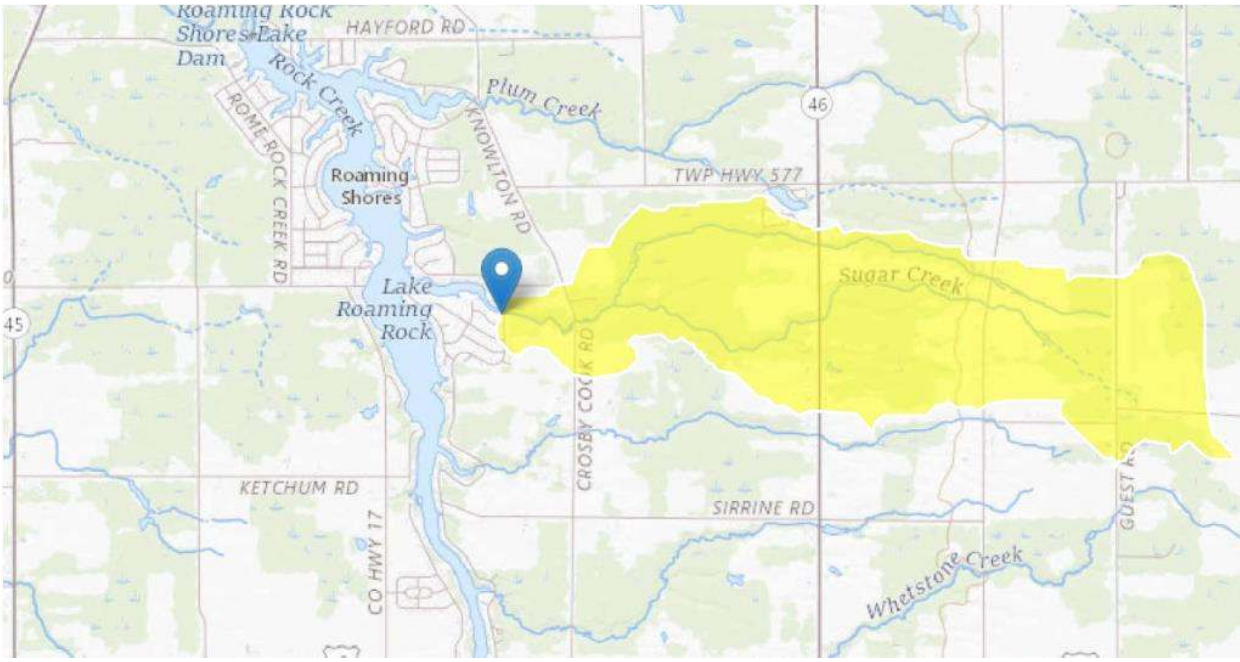

Table 13. Sugar Creek Water Chemistry

Date	5/27/2021 (DRY)	6/14/2021 (DRY)	7/19/2021 (WET)	8/24/2021 (DRY)
LLDRP (ppb)	5.89	16.1	52	16.4
E. coli (MPN/100mL)	-	-	461	-
NH3-T (ppm)	0.0461	0.0353	0.0248	0.0472
NO3NO2 (ppm)	0.0697	1.49	0.301	0.0786
TP (ppm)	0.0398	0.0538	0.114	0.0521
TKN (ppm)	0.806	1.15	0.933	0.874
TSS (ppm)	3.7	6.7	6	1.4
Total Nitrogen (ppm)	0.8757	2.64	1.234	0.9526

Site X – Fisherman's Cove

This tributary drains approximately 1.83 sq miles of the eastern side of Lake Roaming Rock. The watershed is undeveloped (4.1% urban) and only maintains 34.1% forest cover. The impervious surface percentage is very low at only 0.72%. A majority of the watershed is impacted by agricultural land use, a source of impairment through nutrient runoff. Nitrogen and phosphorus) values were elevated throughout the sampling period. Interestingly, nutrient values were nearly double and the single E. coli measurement taken was nearly 5 times greater in comparison to other feeder streams sampled on average (Table 14). It's very likely the lower forest cover, lack of riparian buffers along the stream (observed via satellite imagery), and presence of an elk-farm may account for this marked difference.

Figure 5. Site X – Fisherman's Cove Sub-Watershed

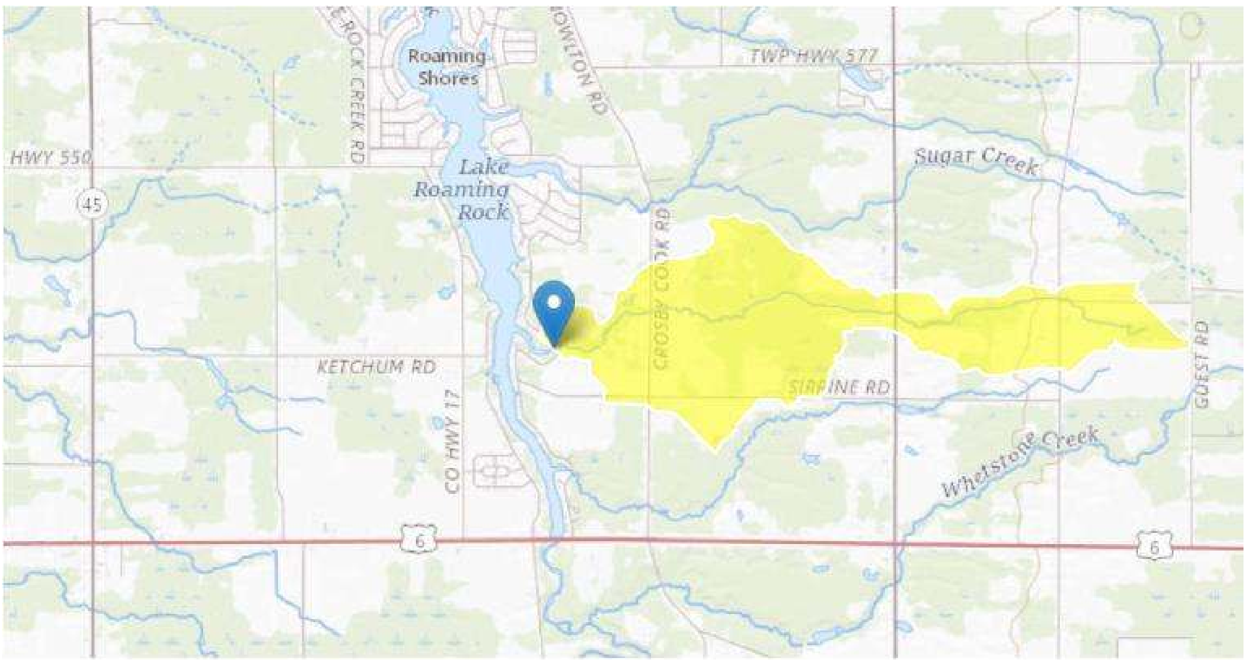

Table 14. Site X – Fisherman's Cove Water Chemistry

Date	5/27/2021 (DRY)	6/14/2021 (DRY)	7/19/2021 (WET)	8/24/2021 (DRY)
LLDRP (ppb)	9.6	53.6	41	44.6
E. coli (MPN/100mL)	-	-	2160	-
NH3-T (ppm)	0.146	0.263	0.0345	0.17
NO3NO2 (ppm)	0.0891	0.421	0.118	0.782
TP (ppm)	0.0586	0.169	0.126	0.0934
TKN (ppm)	1.04	2.24	1.37	1.27
TSS (ppm)	8.4	10.5	5.8	4.3
Total Nitrogen (ppm)	1.1291	2.661	1.488	2.052

Site Y – Spanish Cove

This tributary drains approximately 1.91 sq miles of the southeastern side of Lake Roaming Rock. The watershed is the most developed of the four small feeder streams tested (8.35% urban) and maintains a similar area covered by forest at ~44.6% when compared to Plum Creek and Sugar Creek. Despite the slightly higher urban metric, impervious surfaces are very low at only 1.22%. A majority of the watershed is impacted by agricultural land use, a source of impairment through nutrient runoff. Nitrogen and phosphorus values were slightly elevated throughout the sampling period but are within the normal range for OEPA warmwater criteria.

Figure 6. Site Y – Spanish Cove Sub-Watershed

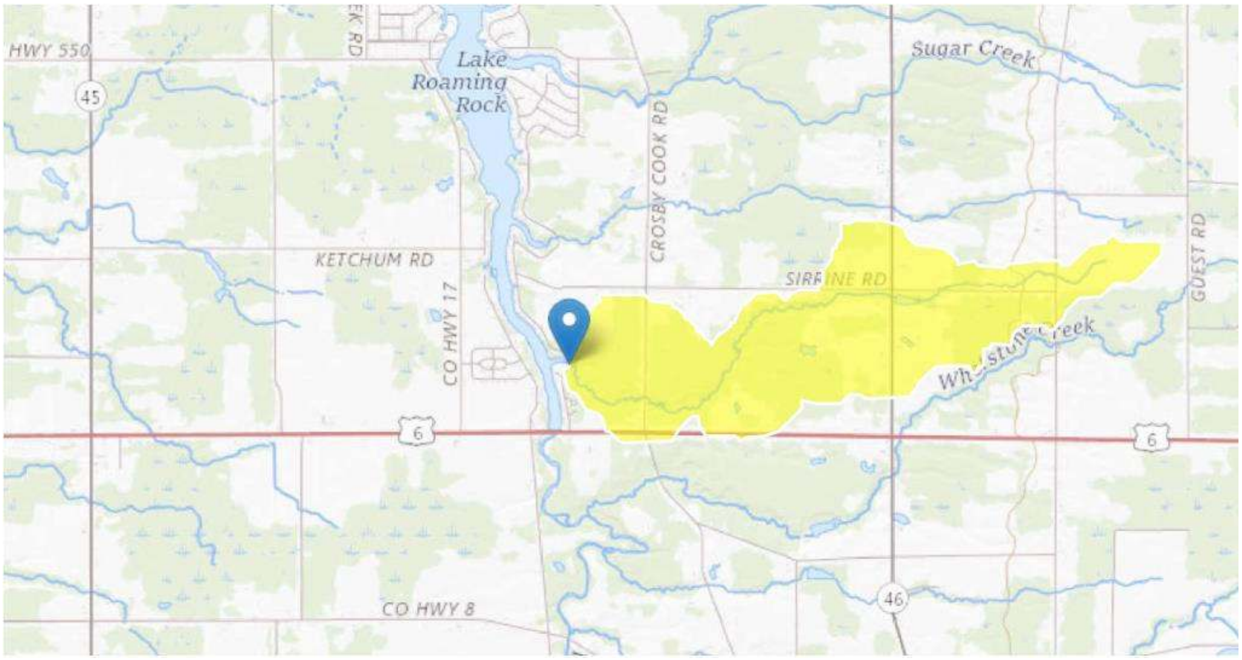

Table 15. Site Y – Spanish Cove Water Chemistry

Date	5/27/2021 (DRY)	6/14/2021 (DRY)	7/19/2021 (WET)	8/24/2021 (DRY)
LLDRP (ppb)	16.4	27.8	33.8	23.4
E. coli (MPN/100mL)	-	-	112	-
NH3-T (ppm)	<0.0220	0.0262	<0.0220	<0.0220
NO3NO2 (ppm)	0.256	0.347	0.169	0.229
TP (ppm)	0.0347	0.0766	0.082	0.043
TKN (ppm)	0.684	0.998	0.856	0.685
TSS (ppm)	1.8	24.4	4.2	4.1
Total Nitrogen (ppm)	0.94	1.345	1.025	0.914

Rock Creek (Route 6)

Rock Creek is the main stream that feeds Lake Roaming Rock. It has a drainage area of approximately 51.9 sq miles. The watershed within the drainage area is 32.9% forested and 5.26% urban. Like all other streams assessed, the majority of the watershed is impacted by agricultural land use, a source of impairment through nutrient runoff. Nitrogen and phosphorus) values were elevated for the two sampling events and were the highest numbers observed across all stream sample sites for the entire monitoring season (Table 16).

Figure 7. Rock Creek Sub-Watershed

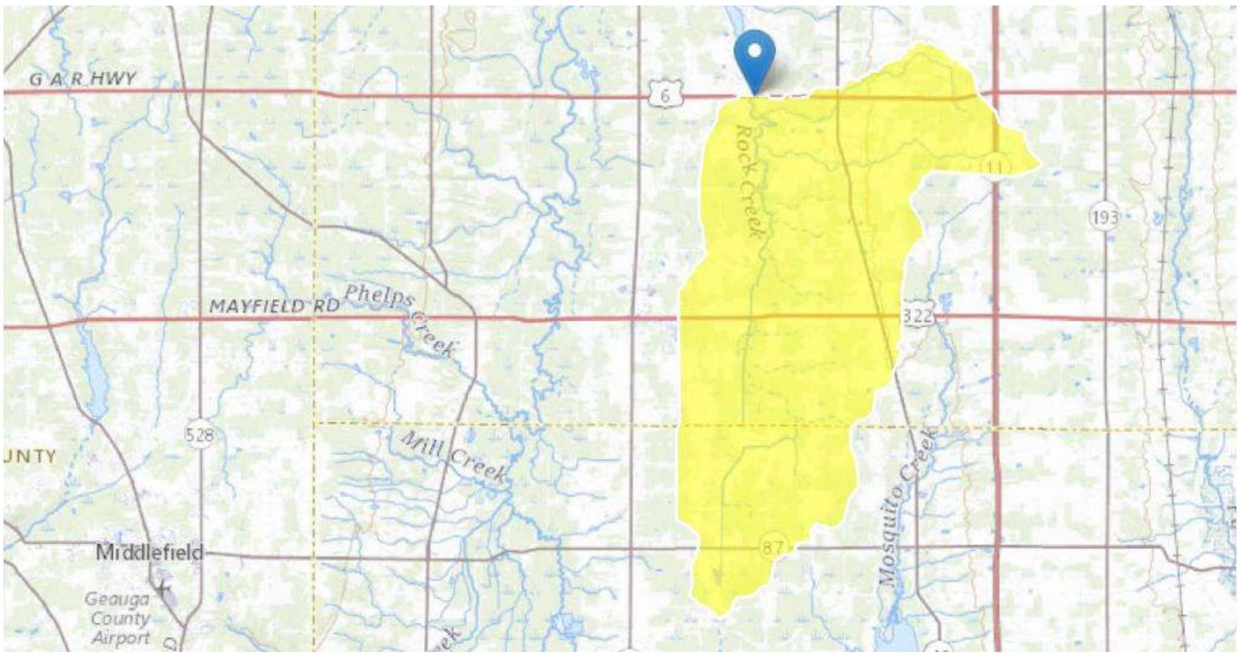

Table 16. Rock Creek Water Chemistry

Date	5/27/2021 (DRY)	6/14/2021 (DRY)	7/19/2021 (WET)	8/24/2021 (DRY)
LLDRP (ppb)	-	-	110	47
E. coli (MPN/100mL)	-	-	102	26
NH3-T (ppm)	-	-	0.0586	<0.0220
NO3NO2 (ppm)	-	-	0.843	0.0257
TP (ppm)	-	-	0.184	0.364
TKN (ppm)	-	-	1.52	5.18
TSS (ppm)	-	-	6.6	28
Total Nitrogen (ppm)			2.363	5.2057

4.0 MANAGEMENT RECOMMENDATIONS

The results gathered to date indicate that Lake Roaming Rock is in a eutrophic state and this trend has continued over the past two decades. Steady inputs of nitrogen and phosphorus from what are likely agricultural sources in the watershed, coupled with internal loading of phosphorus from the sediment under anoxic conditions, steadily contribute to the increasing eutrophication of the lake. This has resulted in more frequent blooms of nuisance and noxious blue-green algae. These blooms are not only aesthetically unpleasing but may also pose several problems if not addressed. These include:

- A direct threat to human health from algal toxins produced by blue-green algae.
- A reduction of sunlight in the water column makes it more difficult for aquatic macrophytes to become established and grow.
- A general depression in dissolved oxygen levels caused by decomposition ultimately leads to unfavorable conditions for aquatic life.

If not addressed, the severity and frequency of blue-green algal blooms in LRR are likely to worsen in the coming years.

The following sections summarize some information contained in previous reports and LRR's short-term management plan and will outline restoration and management techniques that may be used to address these related problems.

4.1 ALGAE CONTROL

In discussions with the board, the most frequent complaint regarding the lake was the frequent blooms of algae. Many management options exist for the control of algae in lakes. These can be broadly categorized as 1) nutrient control techniques, 2) physical controls, 3) chemical controls, and 4) biological controls. Several control techniques may overlap with one or more of these categories. Similarly, some of the techniques may be useful in addressing other problems in addition to nuisance algae, and in fact, this was a primary criterion when selecting potential management options and technologies for further consideration below.

Nutrient Control

Watershed Source Reduction

Because algal growth is fueled by high nutrient levels, consideration should be given to identifying and controlling the external sources of these nutrients wherever possible. Although a formal nutrient budget was beyond the scope of the current project, sampling data collected to date reveals that significant amounts of nutrients are entering the lake from the surrounding watershed. The nutrients responsible for excess algae growth appear to be both nitrogen and phosphorus. Watershed sources of nitrogen and phosphorus vary and may come from distant points of the watershed as well as agricultural point sources.

Most nutrients usually enter waterways or the lake via overland runoff (as opposed to sewers and other man-made conveyances), they are referred to as non-point source pollution. Non-point sources of biologically important nutrients can be difficult to control, particularly when they originate in distant parts of the watershed and different political subdivisions. For this reason, the Association should consider becoming an active participant in regional watershed organizations and contacting the local soil and water conservation district. Working cooperatively with state agencies, local conservation districts, and regional organizations can help develop and encourage the use of best management practices by landowners in the watershed.

In addition to long-term controls in the watershed, several techniques can be readily implemented by Association members and lake residents to reduce the influx of nutrients from property bordering the lake. These include:

- Reducing the use of fertilizer on lawns
- Requiring the use of phosphorus-free fertilizers.
- Raking up and removing fallen leaves from the shore.
- Naturalizing the lakeshore and providing buffers along the shoreline to slow runoff into the lake and increase infiltration into the soil.

Although some public education efforts have been directed toward these control techniques, we believe additional effort could provide benefits, and education regarding them should be part of an ongoing campaign by the Board.

Despite being a worthwhile long-term objective, source reduction of the external nutrients in the watershed is unlikely to affect desirable short-term changes in the lake, and more active control measures are warranted.

Physical Control Techniques

A wide variety of physical algae control techniques exist, ranging from aeration to dredging. Table 17, adapted from the North American Lake Management Society (2001), provides a brief overview of these technologies.

Table 17. Physical Control Options for Algae Issues

Option	Mode of Action	Advantages	Disadvantages
1. Aeration or oxygenation	• Addition of air or oxygen at varying depths create oxic conditions throughout the water column • May break stratification	• Oxic conditions promote binding/ sedimentation of phosphorus; less phosphorus in the water column = less algae • Oxic conditions improve habitat for fish and invertebrates	• Capital intensive • Relatively high ongoing operating and maintenance (O&M) costs • May promote supersaturation with gases harmful to fish.
2. Circulation and destratification	• Similar to aeration but may involve use of water or air to keep water in motion • Generally driven by mechanical force	• Reduces surface buildup of algal scums • May disrupt growth of some algae • Similar benefits to aeration when toxic conditions are created	• May spread locally troubling impacts • Capital intensive • Relatively high O&M costs
3. Dilution/Flushing	• Addition of higher quality water can dilute nutrients • Addition of water helps flush the system to minimize algae buildup	• Dilution reduces nutrient concentrations without altering load.	• Diverts water from other uses • Flushing may wash desirable zooplankton from the lake • Possible downstream impacts

Option	Mode of Action	Advantages	Disadvantages
4. Drawdown	• Lowering of water allows desiccation, oxidation, compaction, and freezing of sediments • Nutrients may become unavailable resulting in reduction of algae	• May reduce available nutrients affecting algal biomass • Opportunity for shoreline and structure maintenance • May provide limited rooted plant control	• Possible impacts on contiguous wetlands • Possible impacts on overwintering reptiles and amphibians • Alteration of downstream flows
5. Dredging	• Sediment is physically removed by wet or dry excavation with deposits placed in a containment area for dewatering • Nutrient stores are removed and algal growth can be limited by nutrient availability	• Can result in good algae control if internal cycling is the main nutrient source • Increases water depth • Can reduce sediment oxygen demand • Can improve spawning habitat for many fish species • Allows complete renovation of the system	• Very expensive undertaking • Temporarily removes benthic invertebrates • May eliminate current fish community • Large nearby area needed for containment area • May interfere with recreation during dredging
6. Dyes	• Water-soluble dye is mixed with lake water limiting light penetration and inhibiting algal growth • Dye remains in system until flushed out	• Inert dye is non-toxic	• May be impractical in larger lakes or those with rapid flushing • May not control surface bloom-forming species or shallow water algal mats
7. Mechanical Removal	• Collection of floating sums or mats with harvesters, booms, nets, or other devices	• Algae and associated nutrients can be removed from system • Surface collection may be done on an "as needed" basis • Collected algae dry to minimal volume	• Very labor intensive unless a mechanized system is used, in which case it becomes capital intensive • Many algal forms are not amenable to collection by net or boom

Aeration/Circulation

Of the physical control techniques listed in Table 17, lake aeration/circulation is probably the most widely used technique to control algae in smaller lakes and reservoirs. This technique functions by reducing the amount of phosphorus released from the lake sediments. The basic concept of an aeration system is to maintain oxygen at the bottom of the lake so that iron, which binds up phosphorus, will remain in a solid form and out of the water column. Under anoxic conditions iron dissolves and releases phosphorus. Secondarily, aeration helps control algae by creating an increased space for zooplankton to avoid predation. By oxygenating the bottom water, zooplankton (which prey on algae) can swim deeper into the dark bottom water during the day. They come up to feed on algae at night.

The most common type of aeration—termed artificial circulation—introduces air bubbles at the bottom of the lake or pond. Rising air bubbles push oxygen-poor bottom water to the surface where it is re-aerated through contact with the atmosphere at the surface. This type of aeration system works best in lakes that are 15 feet deep or greater.

Conventional subsurface aeration systems typically utilize one or more shore-based compressors with air lines running out to devices called diffusers on the bottom of the lake. In general, an airflow rate of approximately 1.3 cubic feet per minute per acre is required to control algae and maintain a recommended minimum DO concentration of 5 ppm.

To be effective, aeration systems must be appropriately sized and powered. Systems with inadequate power may bring up nutrient-rich water without re-oxygenating the lake, resulting in algae becoming an even greater nuisance. Once begun, the system must be continuously operated. If turned off, algae may rapidly reappear because phosphorus will be rapidly released from the sediment under anoxic conditions. These systems can also be operated during the entire year to improve water quality. This type of system is considered safer than floating aerators and fountains due to the fact no electrical cords are used in the water.

Other types of aeration systems include fountain surface units and horizontal spray units. Surface units are best used in less than 12ft/4m depth and in irregularly shaped lakes. Surface units also are generally more expensive, often primarily decorative, use more horsepower, and contain electrical cords that could create safety hazards. Horizontal spray units are best used for long, narrow bodies of water due to the directional spray pattern it ejects.

More than 100 different aeration/circulation systems are on the market in various sizes and configurations. Among these are both solar and wind-powered aerators. Although they may be well-suited to small lakes where electricity is not available, solar and wind-powered in-lake units are generally deemed unfeasible for Lake Roaming Rock due to 1) the large number that would be required, 2) the large surface profiles these units typically have which would pose a hazard to boat traffic on the lake.

Although aeration/circulation can be an effective method to control internal sources of phosphorus, we are unaware of examples where any of the above techniques have been used effectively in a waterbody as large as LRR. Additionally, these methods are not amenable to small-scale trials in a large reservoir having many coves. In short- it would be very difficult to evaluate the effectiveness of aeration in LRR unless the entire water body is aerated.

Finally, our experience with aeration in a 100-acre kettle lake in Northeast Ohio revealed that despite very favorable initial results, blue-green algae rebounded after four years requiring chemical controls. Although the reasons for this resurgence are unknown, we suspect that aerating the top layer of sediments may have resulted in changes to the available iron concentrations lowering the ability of the sediments to bind phosphorus.

Other Physical Control Techniques

A brief review of the remaining physical control options listed in Table 17 indicates they are largely unsuitable in Lake Roaming Rock due to environmental constraints (dilution/flushing), very high cost (whole lake dredging), or impracticality due to the large size of the lake (dyes and mechanical removal).

Chemical Control Techniques

Two major types of chemical controls are used to control nuisance algae, and they vary greatly in both their mode of action and in their effectiveness over time. They are algaecides and phosphorus inactivation.

Algaecides

As the name implies, chemical algaecides target algae in the lake. The most common and widely used algaecide is copper, a cellular toxicant that comes in a variety of forms. Copper sulfate ($CuSO_4$) is the most common and basic form and can be used in potable water, though restrictions apply in most states. In alkaline water, hard water, or water having high organic content, copper can be quickly lost from solution. In these cases, liquid chelated form is used to allow the copper to remain in solution long enough to kill the algae.

Although relatively inexpensive, a major limitation for use of copper-based algaecides in Lake Roaming Rock is its relatively short period of efficacy. Throughout 2021 a single whole-lake treatment (broken up into 2 treatment events) of the copper-based product VodaGuard C, served the lake community for a month before efficacy began to wane. To provide good control of algae (including blue-green species), the application may need to be repeated as often as 2-3 times throughout the summer season to maintain favorable recreational water quality.

Although the accumulation of copper in the sediments does not appear to be a significant concern after the initial treatments in LLR, sediment monitoring should be completed periodically to prevent levels of toxicity from increasing and ultimately negatively affecting aquatic life.

Phosphorus inactivation

Phosphorus inactivation controls algae by limiting phosphorus availability. This is accomplished by using chemicals to precipitate phosphorus from the water column and by adding a binder to the lake to prevent the release of phosphorus from the sediments. The most commonly used chemical for this purpose is aluminum sulfate (or alum). Often applied in a buffered form at the water surface at a rate between 100 and 500 pounds per acre, alum forms a nontoxic precipitate that scavenges phosphorus as it settles through the water column. When used in an appropriate dose, a thin layer of aluminum hydroxide will cover the sediments and continue to tie up phosphorus as it is released from lake sediments.

Nutrient inactivation has received increasing attention over the last decade as long-lasting results have been demonstrated in many projects (North American Lake Management Society, 2001). The longevity of alum treatments has been generally excellent where external inputs of phosphorus have been controlled. Suitable candidate lakes for alum treatment are those with low external nutrient loads and high internal phosphorus release from the sediment. Where significant nutrient inputs from the watershed exist, algal blooms may still result. If the external nutrient inputs from the Lake Roaming Rock watershed can be controlled, or if further studies demonstrate that the external nutrient loading is relatively small compared to internal loading, alum treatment may prove to be a viable treatment option.

Biological Control Techniques

A variety of biological management techniques are available and these include bacterial addition, roughfish removal, and biomanipulation. Although the potential of these techniques to effect significant change by themselves in LRR is limited, brief descriptions of these techniques are included below.

Microbial Addition

Many products on the market claim to add microbial components to reduce algae in lakes. The concept is that with some assistance, natural populations of bacteria can gain a competitive advantage and out-compete algae for nutrients. With less available nutrients, algae should decline according to theory. In practice, however, current scientific literature has been unable to verify that these products do decrease algal growth.

Roughfish Removal

Roughfish is a category that includes bottom feeding fish such as carp and bullheads. Browsing activities of roughfish such as carp and bullhead catfish result in significant releases of nutrients into the water column. In addition to this direct effect, other negative consequences of these fish include uprooting aquatic plants (and consuming them in the case of white amurs), their excretion, which contributes to phosphorus loads, and an increase in turbidity in the water column. Removal of as many of these fish as possible from Lake Roaming Rock is a desirable goal. By reducing sediment disturbance and excretion-related phosphorus sources, a reduction in roughfish may also result in a decrease of nuisance algal production. Fishing techniques that may be considered include electrofishing, spring archery tournaments, carp fishing derbies, baited traps, and commercial fishing

Biomanipulation

Biomanipulation is another type of fish management involving a set of procedures that manipulate the natural biological components of a lake to produce desired conditions. In most cases, the objective is to increase zooplankton numbers because, at times, grazing zooplankton and not the quantity of nutrients control the amount of algae in the water column (McQueen et al., 1986).

Although some algae are immune to grazing, continued strong grazing can reduce algae abundance and increase clarity. An adequate population of large-bodied zooplankton depends on their being protected from zooplanktivorous fish such as small panfish and minnow-sized fish. The management goal is to either reduce the number of zooplanktivorous fish or to create a refuge for the zooplankton.

If fish habitat is adequate and anglers cooperate through catch and release programs, a healthy and balanced game fish population will help control the planktivores. The reduced number of zooplanktivorous fish then allows more zooplankton to survive. A semi-quantitative fish survey conducted in the spring would be useful in determining the relative balance of the fish community.

A lack of macrophytes severely limits the ability of zooplankton to find shelter and produces poor conditions for zooplankton survival. Although not widely used in the U.S., McComas (2003) reports the use in Europe of dense brush piles having openings too small for fish entry, thereby providing refuge for the zooplankton.

While discussing the importance of zooplankton, it should be noted that populations of large-bodied zooplankton may also be negatively impacted by low oxygen conditions near the lake bottom and copper sulfate application for algae control. Cooke *et. al.* (2005) suggests that impacts to the zooplankton community may be a primary mechanism responsible for the commonly observed rebound of algae following a copper treatment.

Reestablishment of Aquatic Macrophytes

As has been noted in previous reports, a balanced and healthy native plant community is critical to the ongoing health of Lake Roaming Rock. Additionally, because aquatic plants compete for and tie up substantial amounts of nutrients in the lake, a healthy plant community can help control nuisance algae problems. For this reason, we continue to emphasize the importance of controlling aquatic plants to the minimum extent necessary to allow for recreational uses.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Lake Roaming Rock is an outstanding recreational resource and serves as the centerpiece for the community. It currently provides excellent opportunities for swimming, boating, and fishing.

Despite these positive features, several related water quality problems exist. Owing to the agricultural setting of the community, the lake has historically received a steady influx of nutrients, such as nitrogen and phosphorus, from the watershed. Large amounts of these nutrients—in particular, phosphorus—accumulate in the sediments of Lake Roaming Rock where they are seasonally re-entrained into the water column due to anoxic conditions resulting from stratification of the lake and potentially re-suspended by dredging activities.

Data generated as part of the current study indicate that the lake has steadily maintained a eutrophic condition over the years. Under such conditions, recreational activities important to the community such as swimming, skiing, and fishing will likely continue to be negatively affected.

We note that Lake Roaming Rock's condition and problems are common to most Ohio lakes and reservoirs, and in fact, many of these lakes experience more severe issues including bans on nearly all forms of recreation due to HABs

Regardless of the progress that may be made with long-term nutrient source reduction in the watershed, the internal phosphorus cycling that occurs in Lake Roaming Rock as a result of anoxic conditions is likely to result in ongoing and worsening nuisance algae blooms for the foreseeable future unless in-lake treatment options are implemented.

Although several management options for dealing with these problems are discussed above, it is difficult and likely inadvisable to make definitive recommendations here for long-term management without considerable input from and discussion among the community. Having stated this, the Lake Roaming Rock community will need to start employing comprehensive strategies to address the summer algal bloom issues.

A short-term palliative approach using herbicides may be able to keep nuisance algal blooms in check, and reasonable success was achieved in controlling blooms was achieved in LRR with two applications of VodaGuard C during the summer of 2021. Although largely successful, this approach does nothing to remedy the problem of elevated nutrient concentrations from internal and external loading.

More comprehensive approaches that address the nutrients by either aerating the water column or inactivating phosphorus in the sediment and water column will likely be more costly but have the potential to provide long-term improvements to LRR's water. We expect to more fully address the potential and costs associated with these approaches in the Long-term Management Plan.

Next Steps Include:

1. Completion of the Long-term Management Plan, including recommendations for monitoring and algal control activities for 2022.
2. Schedule a community meeting to disseminate information gathered from this study and solicit input from RRA leadership and members regarding their priorities for future action.
3. Continue limited summer in-lake and stream monitoring efforts to further assess the level of nutrients and algae present and how these relate to the amount and concentration of nutrients entering the lake.

Early and late-season monitoring will help confirm the internal phosphorus dynamics of the lake and provide information useful in:

a. The design of a large-scale aeration system

b. Feasibility analysis of phosphorus inactivation products and techniques

4. Conduct aerial and ground surveillance in the LRR watershed to identify locations where it appears that high concentrations of nutrients are found and collect repeated samples. It is important to locate any obvious nutrient sources within the watershed since it may be possible to use existing regulations and cooperative efforts of the local Soil and Water Conservation District Offices and Ohio EPA to lessen the loading to the lake.

6.0 LITERATURE CITED

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Appendix A

Biological Data

2021 Lake Roaming Rock - Phytoplankton Results

ProjectID	Lab_ID	Lab2_ID	Type_Code	Date_sampled	BioDataTaxonName	ALGALGROUP	%_community_composition	Natural_Units_per_mL	Cells_per_mL
85	ROSH0002	Dam	AT2	6/15/2021	*Aphanizomenon flos-aquae*	Blue-Green Algae	95.09	9,082	165,158
85	ROSH0002	Dam	AT2	6/15/2021	*Chlamydomonas spp.*	Green Algae	2.35	4,089	4,089
85	ROSH0002	Dam	AT2	6/15/2021	*Dolichospermum spp.*	Blue-Green Algae	1.24	43	2,152
85	ROSH0002	Dam	AT2	6/15/2021	*Dolichospermum sigmoideum*	Blue-green Algae	1.24	43	2,152
85	ROSH0002	Dam	AT2	6/15/2021	*Fragilaria spp.*	Diatom	0.05	86	86
85	ROSH0002	Dam	AT2	6/15/2021	*Cryptomonas erosa*	Cryptophytes	0.02	43	43
85	ROSH0003	Mid Lake	AT2	6/15/2021	*Aphanizomenon flos-aquae*	Blue-Green Algae	97.49	13,981	259,295
85	ROSH0003	Mid Lake	AT2	6/15/2021	*Chlamydomonas spp.*	Green Algae	2.20	5,854	5,854
85	ROSH0003	Mid Lake	AT2	6/15/2021	*Rhodomonas spp.*	Cryptophytes	0.16	413	413
85	ROSH0003	Mid Lake	AT2	6/15/2021	*Cryptomonas erosa*	Cryptophytes	0.08	207	207
85	ROSH0003	Mid Lake	AT2	6/15/2021	*Ceratium hirundinella*	Dinoflagellates	0.03	69	69
85	ROSH0003	Mid Lake	AT2	6/15/2021	*Centric Diatom spp. Live*	Diatom	0.03	69	69
85	ROSH0003	Mid Lake	AT2	6/15/2021	*Asterionella formosa*	Diatom	0.03	69	69
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Aphanocapsa delicatissima*	Blue-Green Algae	39.83	10	2,095
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Snowella atomus*	Blue-Green Algae	16.78	20	882
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Centric Diatom spp. Live*	Diatom	7.97	419	419
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Planktolyngbya limnetica*	Blue-Green Algae	6.09	10	320
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Chlamydomonas spp.*	Green Algae	5.34	281	281
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Cryptomonas spp.*	Green Algae	5.06	266	266
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Phormidium sp.*	Blue-Green Algae	3.28	5	173
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Actinastrum hantzschii*	Green Algae	2.16	25	113
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Pseudanabaena limnetica*	Blue-Green Algae	2.16	10	113
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Aulacoseira spp.*	Diatom	2.06	108	108
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Rhodomonas spp.*	Cryptophytes	1.59	84	84
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Trachelomonas sp.*	Euglenoids	1.22	64	64
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Coelastrum astroideum*	Green Algae	0.84	5	44
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Scenedesmus ecornis*	Green Algae	0.56	15	30
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Chroococcus limneticus*	Blue-Green Algae	0.56	15	30
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Coelastrum microporum*	Green Algae	0.47	5	25
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Fragilaria spp.*	Diatom	0.47	25	25
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Chlorella spp.*	Green Algae	0.47	25	25
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Scenedesmus quadricauda*	Green Algae	0.37	5	20
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Crucigeniella crucifera*	Green Algae	0.37	5	20
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Schroederia setigera*	Green Algae	0.37	20	20
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Tetrastrum triangulare*	Green Algae	0.37	5	20
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Elakatothrix gelatinosa*	Green Algae	0.37	5	20
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Micractinium sp.*	Green Algae	0.37	10	20
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Closterium acutum*	Green Algae	0.28	15	15
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Kirchneriella obesa*	Green Algae	0.19	5	10
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Monoraphidium arcuatum*	Green Algae	0.19	10	10
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Closteriopsis acicularis*	Green Algae	0.09	5	5
85	ROSH0004	Mid Lake	AT2	7/19/2021	*Golenkinia spp.*	Green Algae	0.09	5	5
85	ROSH0005	Dam	AT2	7/19/2021	*Centric Diatom spp. Live*	Diatom	29.14	330	330
85	ROSH0005	Dam	AT2	7/19/2021	*Chlamydomonas spp.*	Green Algae	13.10	148	148
85	ROSH0005	Dam	AT2	7/19/2021	*Planktolyngbya limnetica*	Blue-Green Algae	10.70	3	121
85	ROSH0005	Dam	AT2	7/19/2021	*Aulacoseira spp.*	Diatom	8.02	91	91
85	ROSH0005	Dam	AT2	7/19/2021	*Cryptomonas spp.*	Green Algae	6.68	76	76
85	ROSH0005	Dam	AT2	7/19/2021	*Crucigeniella crucifera*	Green Algae	5.61	12	63
85	ROSH0005	Dam	AT2	7/19/2021	*Actinastrum hantzschii*	Green Algae	4.81	9	54
85	ROSH0005	Dam	AT2	7/19/2021	*Micractinium sp.*	Green Algae	4.01	15	45
85	ROSH0005	Dam	AT2	7/19/2021	*Sphaerocystis schroeteri*	Green Algae	3.48	3	39
85	ROSH0005	Dam	AT2	7/19/2021	*Rhodomonas spp.*	Cryptophytes	2.94	33	33
85	ROSH0005	Dam	AT2	7/19/2021	*Scenedesmus ecornis*	Green Algae	1.60	6	18
85	ROSH0005	Dam	AT2	7/19/2021	*Trachelomonas sp.*	Euglenoids	1.34	15	15
85	ROSH0005	Dam	AT2	7/19/2021	*Scenedesmus quadricauda*	Green Algae	1.07	3	12
85	ROSH0005	Dam	AT2	7/19/2021	*Chroococcus minimus*	Blue-Green Algae	1.07	6	12
85	ROSH0005	Dam	AT2	7/19/2021	*Chroococcus limneticus*	Blue-Green Algae	1.07	3	12
85	ROSH0005	Dam	AT2	7/19/2021	*Golenkinia spp.*	Green Algae	1.07	12	12
85	ROSH0005	Dam	AT2	7/19/2021	*Schroederia setigera*	Green Algae	0.80	9	9
85	ROSH0005	Dam	AT2	7/19/2021	*Didymogenes anomala*	Green Algae	0.80	9	9
85	ROSH0005	Dam	AT2	7/19/2021	*Pennate Diatom spp. Live*	Diatom	0.80	9	9
85	ROSH0005	Dam	AT2	7/19/2021	*Closterium acutum*	Green Algae	0.53	6	6
85	ROSH0005	Dam	AT2	7/19/2021	*Cryptomonas erosa*	Cryptophytes	0.53	6	6
85	ROSH0005	Dam	AT2	7/19/2021	*Tetraedron triangulare*	Green Algae	0.27	3	3
85	ROSH0005	Dam	AT2	7/19/2021	*Chrysosphaera gallica*	Yellow-Green Algae	0.27	3	3
85	ROSH0005	Dam	AT2	7/19/2021	*Oocystis spp.*	Green Algae	0.27	3	3
85	ROSH0007	Mid Lake	AT2	8/24/2021	*Microcystis aeruginosa*	Blue-Green Algae	38.83	620	7,231
85	ROSH0007	Mid Lake	AT2	8/24/2021	*Chlamydomonas spp.*	Green Algae	36.89	6,870	6,870
85	ROSH0007	Mid Lake	AT2	8/24/2021	*Woronichinia naegeliana*	Blue-Green Algae	21.08	52	3,926
85	ROSH0007	Mid Lake	AT2	8/24/2021	*Dolichospermum spp.*	Blue-Green Algae	1.11	26	207
85	ROSH0007	Mid Lake	AT2	8/24/2021	*Centric Diatom spp. Live*	Diatom	0.83	155	155
85	ROSH0007	Mid Lake	AT2	8/24/2021	*Pseudanabaena limnetica*	Blue-Green Algae	0.42	26	77
85	ROSH0007	Mid Lake	AT2	8/24/2021	*Schroederia setigera*	Green Algae	0.42	77	77
85	ROSH0007	Mid Lake	AT2	8/24/2021	*Pennate Diatom spp. Live*	Diatom	0.28	52	52
85	ROSH0007	Mid Lake	AT2	8/24/2021	*Monoraphidium contortum*	Green Algae	0.14	26	26
85	ROSH0008	Dam	AT2	8/24/2021	*Microcystis aeruginosa*	Blue-Green Algae	60.87	885	17,296
85	ROSH0008	Dam	AT2	8/24/2021	*Woronichinia naegeliana*	Blue-Green Algae	17.31	59	4,919
85	ROSH0008	Dam	AT2	8/24/2021	*Chlamydomonas spp.*	Green Algae	17.24	4,900	4,900
85	ROSH0008	Dam	AT2	8/24/2021	*Pediastrum simplex*	Green Algae	2.29	20	649
85	ROSH0008	Dam	AT2	8/24/2021	*Coelastrum microporum*	Green Algae	1.11	20	315
85	ROSH0008	Dam	AT2	8/24/2021	*Centric Diatom spp. Live*	Diatom	0.55	157	157
85	ROSH0008	Dam	AT2	8/24/2021	*Aulacoseira spp.*	Diatom	0.55	157	157
85	ROSH0008	Dam	AT2	8/24/2021	*Trachelomonas volvocina*	Euglenoids	0.07	20	20

2021 Lake Roaming Rock - Zooplankton Results

Sample Dam (6/14/2021)	Density	
	Subsample	#/m³
Cladocerans		
Daphnia mendotae	19	1862
TOTAL Cladocerans	**19**	**1862**
Copepods		
Mesocyclops edax w/o	2	196
TOTAL Copepods	**2**	**196**
Copepod Nauplii		
Cyclopoid Naupliii	66	6468
Calanoid Naupliii	22	2156
TOTAL Copepod Nauplii	**88**	**8624**
Copepoda		
Cyclopoid Copepodite	1	98
Calanoid Copepodite	2	196
TOTAL Copepodites	**3**	**294**
Rotifers		
Kellicotia bostoniensis	91	8918
Keratella earlinae	333	32634
Polyarthra remata	15	1470
Trichocerca lata	6	588
Filinia terminalus	11	1078
TOTAL Rotifers	**456**	**44688**

Sample Mid Lake (6/14/2021)	Density	
	Subsample	#/m³
Cladocerans		
Daphnia menotae	17	1666
Unidentified Daphnia sp.	1	98
TOTAL Cladocerans	**18**	**1764**
Copepods		
Mesocyclops edax w/o	1	98
TOTAL Copepods	**1**	**98**
Copepod nauplii		
Cyclopoid naupliii	72	7128
Calanoid naupliii	4	396
TOTAL Copepod nauplii	**76**	**7524**
Copepoda		
Cyclopoid copepodite	7	686
Calanoid copepodite	1	98
TOTAL Copepodites	**8**	**784**
Rotifers		
Kellicotia sp.	63	6174
Keratella sp.	203	19894
Polyarthra sp.	8	784
Filinia sp.	9	882
TOTAL Rotifers	**283**	**27734**

Sample Dam (8/24/2021)	Density	
	Subsample	#/m³
Cladocerans		
Bosmina sp. w/o	1	74
Eubosmina sp. w/o	2	148
Diaphanasoma sp. w/o	2	148
Ceriodaphnia sp. w/o	1	74
Unid. Daphnia sp.	6	444
Unidentified Cladaceran	3	222
TOTAL Cladocerans	**15**	**1110**
Copepods		
Acanthocyclops vernalis w/	1	74
Acanthocyclops vernalis w/o	1	74
Diacyclops thomasi w/o	1	74
Unidentified Cyclopoid	4	296
Unidentified Calanoid	3	222
TOTAL Copepods	**10**	**740**
Copepod Nauplii		
Cyclopoid Naupliii	2	148
Unidentified Nauplii	33	2442
TOTAL Copepod Nauplii	**35**	**2590**
Copepod eggs		
Acanthocyclops vernalis	1	74
TOTAL Copepod eggs	**1**	**74**
Copepoda		
Cyclopoid Copepodite	2	148
Calanoid Copepodite	2	148
TOTAL Copepodites	**4**	**296**
Rotifers		
Asplanchna sp.	52	3848
Kellicotia sp.	1	74
Keratella crassa	460	34040
Polyarthra sp.	12	888
Filinia sp.	9	666
Anuraeopsis sp.	1	74
Euchlanis sp.	2	148
Trichocera sp.	1	74
Unidentified Rotifers	1	74
TOTAL Rotifers	**539**	**39886**

Sample Mid Lake (8/24/2021)	Density	
	Subsample	#/m³
Cladocerans		
Bosmina sp. w/	1	29
Bosmina sp. w/o	18	522
Eubosmina sp. w/o	26	754
Daphnia galeata w/o	4	116
Diaphanasoma sp. w/o	12	348
Ceriodaphnia sp. w/o	1	29
Unidentified Daphnia sp.	2	58
Unidentified Cladaceran	19	551
TOTAL Cladocerans	**83**	**2407**
Copepods		
Acanthocyclops vernalis w/o	8	232
Diacyclops thomasi w/	1	29
Diacyclops thomasi w/o	3	87
Mesocyclops edax w/o	7	203
Tropocyclops prasinus mexicanus w/o	1	29
Unidentified Cyclopoid	1	29
Unidentified Calanoid	7	203
TOTAL Copepods	**28**	**812**
Copepod Nauplii		
Cyclopoid Naupliii	1	29
Calanoid Naupliii	5	145
Unidentified Nauplii	19	551
TOTAL Copepod Nauplii	**24**	**696**
Copepoda		
Cyclopoid Copepodite	1	29
Calanoid Copepodite	2	58
TOTAL Copepodites	**3**	**87**
Rotifers		
Asplanchna sp.	52	1508
Kellicotia sp.	1	29
Keratella sp.	460	13340
Polyarthra sp.	2	58
Lindia sp.	4	116
Habrotrocha sp.	1	29
Dicranophorus sp.	5	145
Unidentified Rotifers	1	29
TOTAL Rotifers	**526**	**15254**

Appendix B

Sediment Data

am.pdf

id Lake.pdf

lum Creek Cove.pdf

04.pdf

ugar Creek Cove.pdf

06.pdf

ite X Cove.pdf

08.pdf

SePRO Research & Technology Campus

Company Name: **EnviroScience Inc.**
Billing Address: 5070 Stow Rd.
City, State, Zip: Stow, OH 44224
Project Name: N/A

Waterbody Name: Lake Roaming Rock
Size (ac.): 464
Average Water Depth (ft): 15
Sample Collection Date: **9/28/2021**
Contact Person: Bradley Bartelme
Email Address: bbartelme@enviroscienceinc.com
Telephone: 330-688-0111 Ext. 327

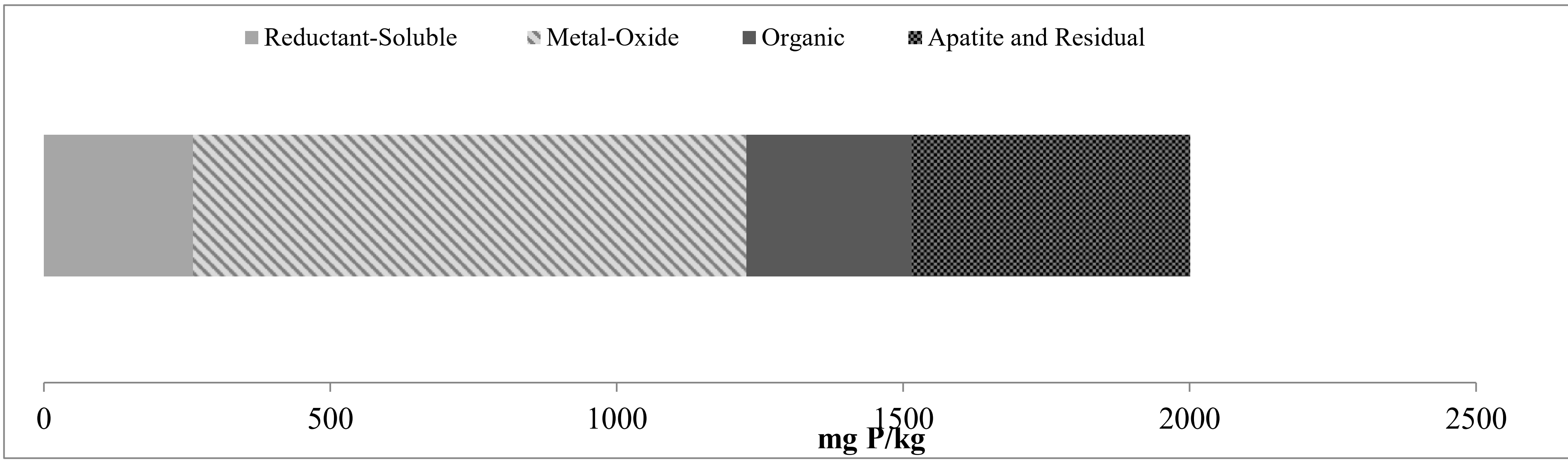
Chain of Custody: COC11238

Report Date: 10/7/2021

SeSCRIPT Analysis Performed: SRTC Comprehensive Level 2

Sample ID	% Solids (% Dry Wt.)	Labile (mg P/kg)	Reductant-Soluble (mg P/kg)	Metal-Oxide (mg P/kg)	Organic (mg P/kg)	Apatite and Residual (mg P/kg)
CTM31990-1	29	*	261	966	288	485

*** Concentration was less than reportable limits with 99% confidence**
All concentrations are reported based on dry weight



SRTC

SePRO Research & Technology Campus

SePRO

Company Name: EnviroScience Inc.
Billing Address: 5070 Stow Rd.
City, State, Zip: Stow, OH 44224
Project Name: N/A

Chain of Custody: COC11238

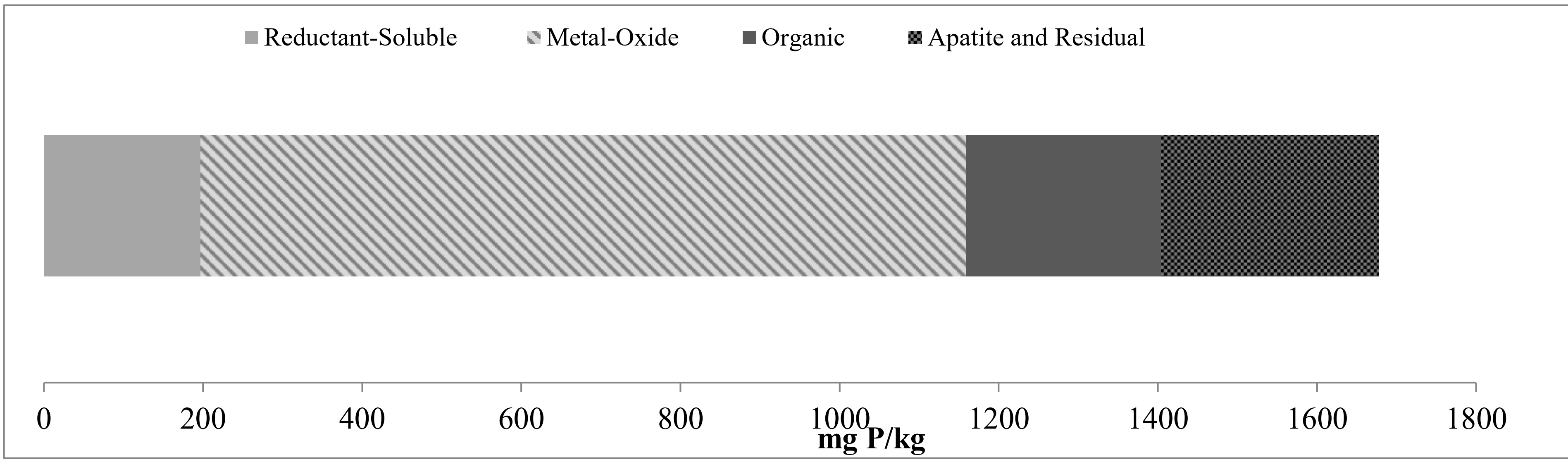
Report Date: 10/7/2021

Waterbody Name: Lake Roaming Rock
Size (ac.): 464
Average Water Depth (ft): 15
Sample Collection Date: 9/28/2021
Contact Person: Bradley Bartelme
Email Address: bbartelme@enviroscienceinc.com
Telephone: 330-688-0111 Ext. 327

SeSCRIPT Analysis Performed: SRTC Comprehensive Level 2

Sample ID	% Solids (% Dry Wt.)	Labile (mg P/kg)	Reductant-Soluble (mg P/kg)	Metal-Oxide (mg P/kg)	Organic (mg P/kg)	Apatite and Residual (mg P/kg)
CTM31986-1	32	*	197	962	245	273

*** Concentration was less than reportable limits with 99% confidence**
All concentrations are reported based on dry weight

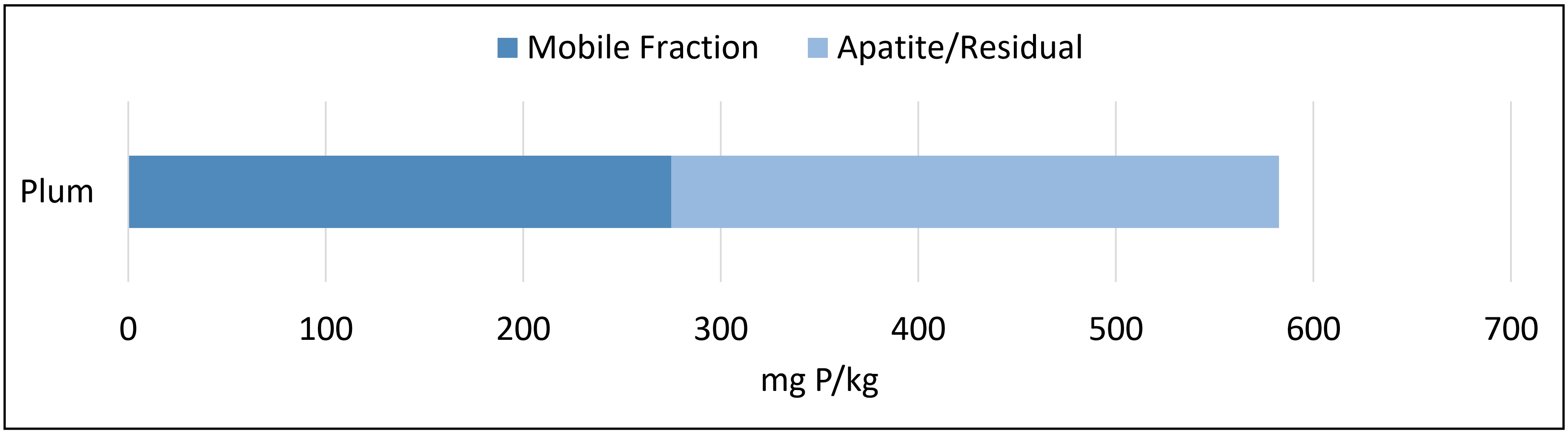


SePRO Research & Technology Campus

Laboratory Report: Level 1 Sediment Phosphorus Fractioning Analysis

Company Name:	**EnviroScience Inc.**	**Project Name:**	N/A
Billing Address:	5070 Stow Rd.	**Water Body:**	Lake Roaming Rock
City, State, Zip:	Stow, OH 44224	**Size (ac.):**	464
Contact Person:	Bradley Bartelme	**Average Depth (ft):**	**15**
Email Address:	bbartelme@enviroscienceinc.com	**Collection Date:**	9/28/2021
Telephone:	330-688-0111 Ext. 327	**Chain of Custody:**	COC11238 **Reported: 10/7/2021**

Sample ID	Sample Name	Apatite and Residual (mg P/kg)	Mobile Phosphorus[t] Fraction (mg P/kg)	Sum of Phosphorus Fractions (mg P/kg)	% Solids (% Dry Wt.)
CTM31984-1	Plum	308	275	583	46



[t] Mobile phosphorus represents fractions of sediment phosphorus that are potentially bio-available in typical aquatic environments. All concentrations are reported based on dry weight

SeSCRIPT* Analysis

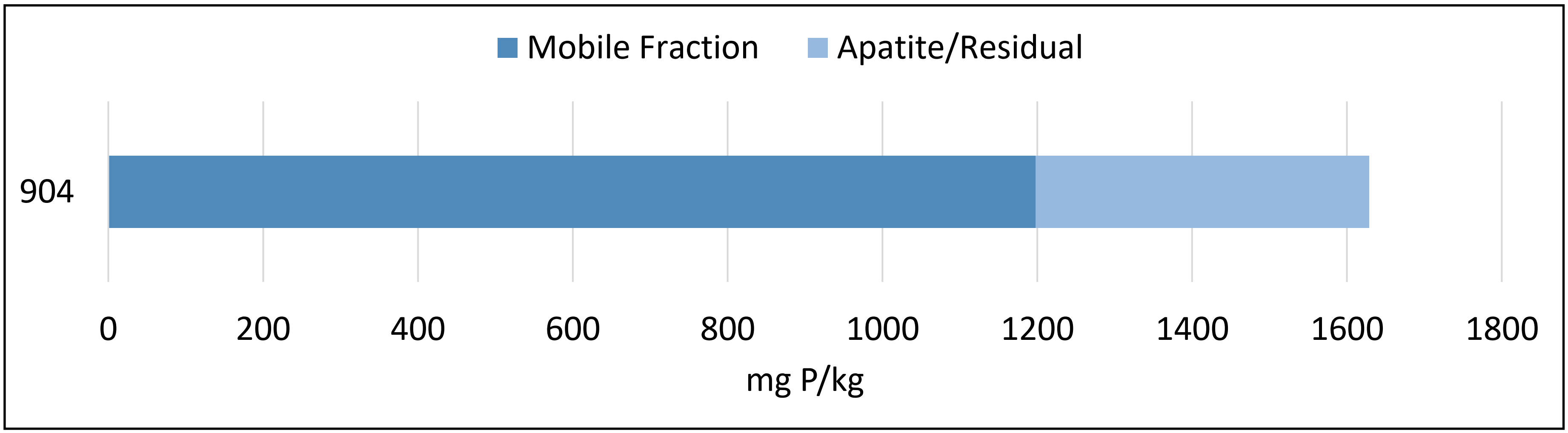
SePRO Research & Technology Campus
16013 Watson Seed Farm Road, Whitakers, NC 27891
Laboratory Email: srtclab@sepro.com Laboratory Phone: (252) 391-8375

SePRO Research & Technology Campus

Laboratory Report: Level 1 Sediment Phosphorus Fractioning Analysis

Company Name:	**EnviroScience Inc.**	**Project Name:**	N/A
Billing Address:	5070 Stow Rd.	**Water Body:**	Lake Roaming Rock
City, State, Zip:	Stow, OH 44224	**Size (ac.):**	464
Contact Person:	Bradley Bartelme	**Average Depth (ft):**	**15**
Email Address:	bbartelme@enviroscienceinc.com	**Collection Date:**	9/28/2021
Telephone:	330-688-0111 Ext. 327	**Chain of Custody:**	COC11238 **Reported: 10/7/2021**

Sample ID	Sample Name	Apatite and Residual (mg P/kg)	Mobile Phosphorus† Fraction (mg P/kg)	Sum of Phosphorus Fractions (mg P/kg)	% Solids (% Dry Wt.)
CTM31987-1	904	431	1198	1629	33



† Mobile phosphorus represents fractions of sediment phosphorus that are potentially bio-available in typical aquatic environments. All concentrations are reported based on dry weight

* Concentration was less than reportable limits with 99% confidence

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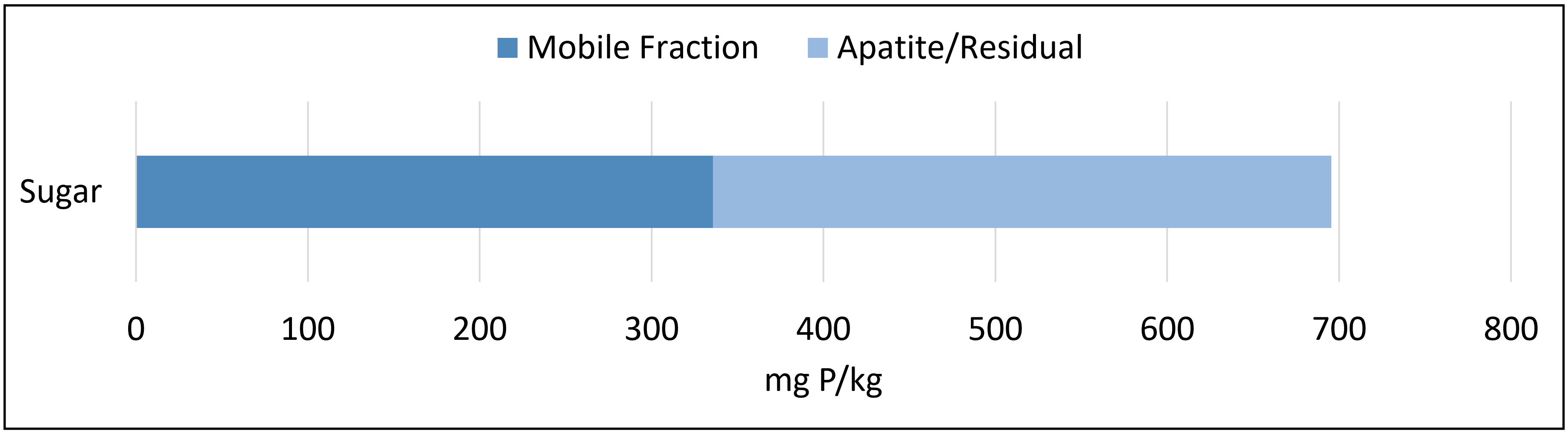
Billing Address:	5070 Stow Rd.	**Water Body:**	Lake Roaming Rock
City, State, Zip:	Stow, OH 44224	**Size (ac.):**	464
Contact Person:	Bradley Bartelme	**Average Depth (ft):**	**15**
Email Address:	bbartelme@enviroscienceinc.com	**Collection Date:**	9/28/2021
Telephone:	330-688-0111 Ext. 327	**Chain of Custody:**	COC11238 **Reported: 10/7/2021**

Sample ID	Sample Name	Apatite and Residual (mg P/kg)	Mobile Phosphorus[t] Fraction (mg P/kg)	Sum of Phosphorus Fractions (mg P/kg)	% Solids (% Dry Wt.)
CTM31985-1	Sugar	360	336	695	36



[t] Mobile phosphorus represents fractions of sediment phosphorus that are potentially bio-available in typical aquatic environments. All concentrations are reported based on dry weight

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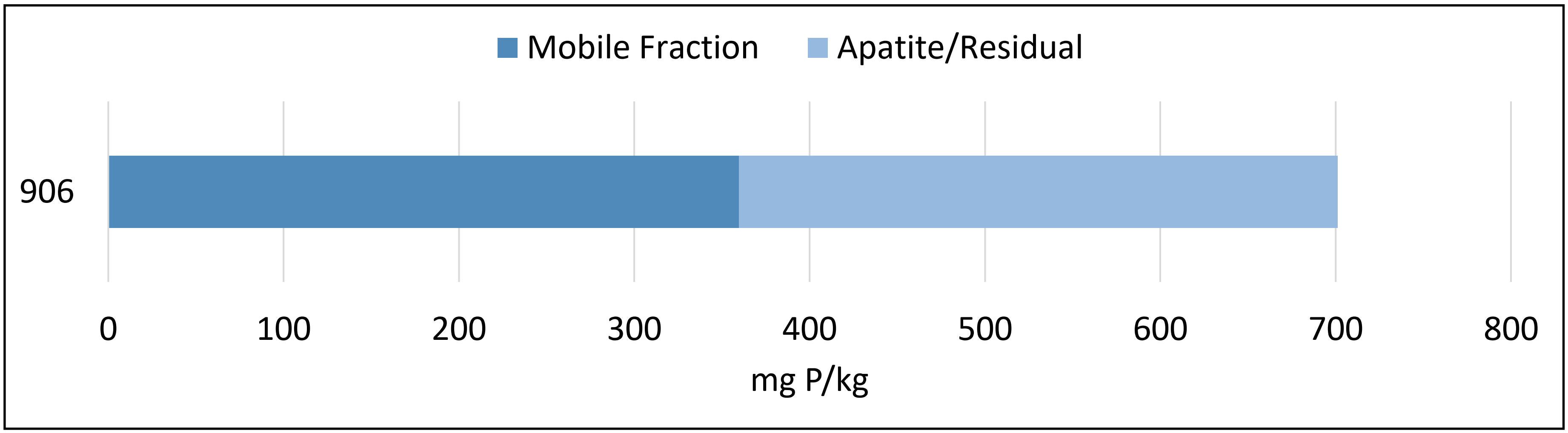
Email Address:	bbartelme@enviroscienceinc.com	**Collection Date:**	9/28/2021
Telephone:	330-688-0111 Ext. 327	**Chain of Custody:**	COC11238 **Reported: 10/7/2021**

Sample ID	Sample Name	Apatite and Residual (mg P/kg)	Mobile Phosphorus† Fraction (mg P/kg)	Sum of Phosphorus Fractions (mg P/kg)	% Solids (% Dry Wt.)
CTM31989-1	906	341	360	701	40



† Mobile phosphorus represents fractions of sediment phosphorus that are potentially bio-available in typical aquatic environments. All concentrations are reported based on dry weight

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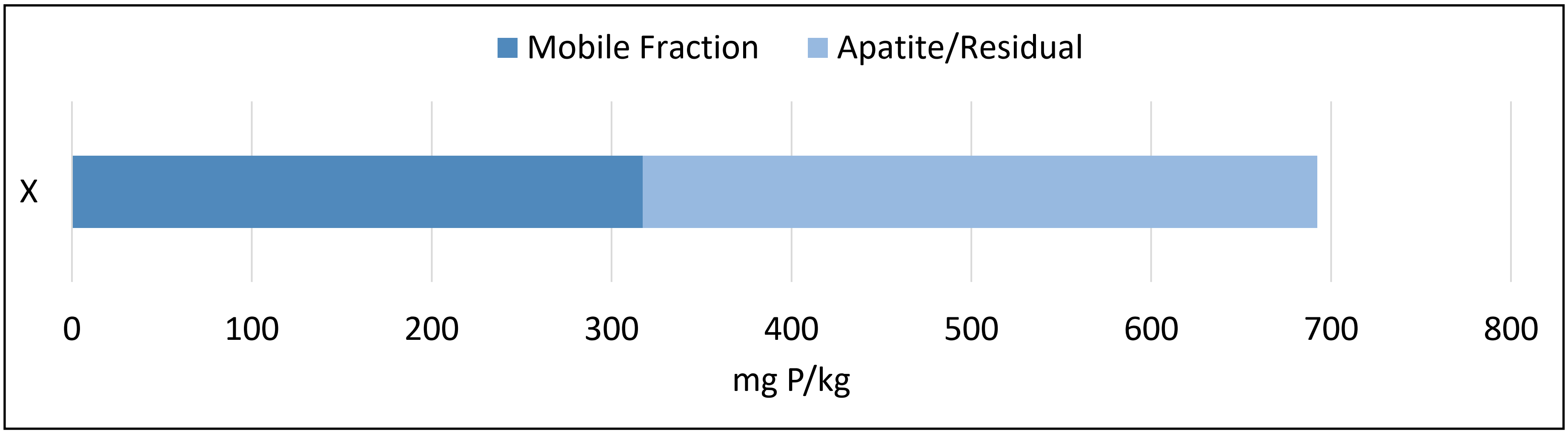
SRTC SePRO Research & Technology Campus SePRO

Laboratory Report: Level 1 Sediment Phosphorus Fractioning Analysis

Company Name:	**EnviroScience Inc.**	**Project Name:**	N/A
Billing Address:	5070 Stow Rd.	**Water Body:**	Lake Roaming Rock
City, State, Zip:	Stow, OH 44224	**Size (ac.):**	464
Contact Person:	Bradley Bartelme	**Average Depth (ft):**	**15**
Email Address:	bbartelme@enviroscienceinc.com	**Collection Date:**	9/28/2021
Telephone:	330-688-0111 Ext. 327	**Chain of Custody:**	COC11238 **Reported: 10/7/2021**

Sample ID	Sample Name	Apatite and Residual (mg P/kg)	Mobile Phosphorus† Fraction (mg P/kg)	Sum of Phosphorus Fractions (mg P/kg)	% Solids (% Dry Wt.)
CTM31988-1	X	375	317	692	45



† Mobile phosphorus represents fractions of sediment phosphorus that are potentially bio-available in typical aquatic environments. All concentrations are reported based on dry weight

* Concentration was less than reportable limits with 99% confidence

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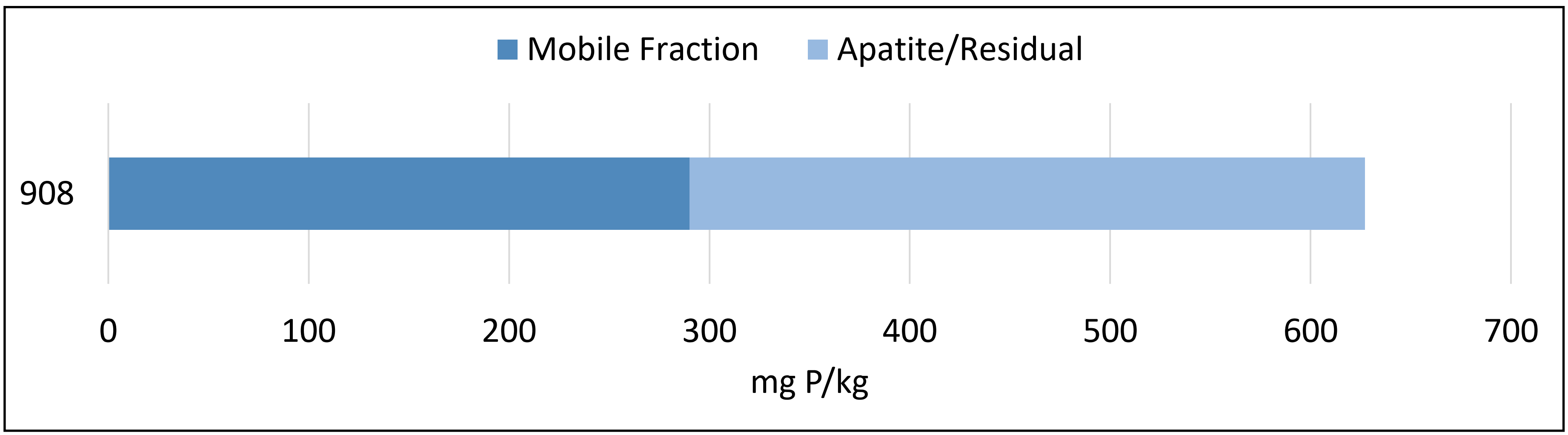
Email Address:	bbartelme@enviroscienceinc.com	**Collection Date:**	9/28/2021
Telephone:	330-688-0111 Ext. 327	**Chain of Custody:**	COC11238 **Reported: 10/7/2021**

Sample ID	Sample Name	Apatite and Residual (mg P/kg)	Mobile Phosphorus[ŧ] Fraction (mg P/kg)	Sum of Phosphorus Fractions (mg P/kg)	% Solids (% Dry Wt.)
CTM31983-1	908	337	290	627	44



[ŧ] Mobile phosphorus represents fractions of sediment phosphorus that are potentially bio-available in typical aquatic environments. All concentrations are reported based on dry weight

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