Investigation of Drivers of Harmful Algal Blooms on Lake Anna, Virginia

Virginia and West Virginia Water Science Center

Eukaryotic algae and cyanobacteria, commonly referred to collectively as algae, are vital components of aquatic ecosystems, providing the base of food chains in many streams and lakes. However, excessive growth of algae can have detrimental effects on aquatic ecosystems, reduce the quality of water resources, and can pose significant human health risks. The Virginia Department of Environmental Quality (DEQ) defines excessive growths of algae as Harmful Algal Blooms (HABs) "that produce toxins that may adversely affect human health through ingestion of contaminated water or shellfish" (Commonwealth of Virginia, 2021). While some primary drivers of HABS, nutrients and sunlight, are well documented, the interactions among these drivers and other environmental factors, such as stream flow, are complex and less well understood.

Lake Anna is a reservoir formed by the impoundment of the North Anna River in central Virginia to provide cooling water for the North Anna Power Station (NAPS) – a nuclear power plant operated by Dominion Power. The lake, and surrounding communities, are a popular vacation destination for recreation including boating, watersports, and fishing. Portions of Lake Anna, notably the riverine and portions of the transitional areas of the lake, have had consistent elevated cell counts of potential toxigenic species starting in the mid-summer each year since 2018, resulting in Virginia Department of Health (VDH) HAB advisories each year, advising the public to avoid primary contact recreation (e.g., swimming) for portions of the lake. The DEQ has identified a 303(d) recreation use impairment for the upper portion of Lake Anna in the 2022 Integrated Report due to the HAB advisories. Additionally, the Virginia legislature, through House Bill 30, has allocated funding to DEQ to conduct studies of harmful algal blooms occurring in the Shenandoah River and Lake Anna, in collaboration with the VDH.

Objectives

This proposal details an approach to address several key science needs identified by DEQ and VDH, including:

1. Identifying and understanding the factors and processes leading to HAB initiation, persistence, and decline;
2. Identifying primary sources of the factors contributing to the formation of HABs; and
3. Identifying technologies or approaches to help predict or provide early detection of a HAB event.

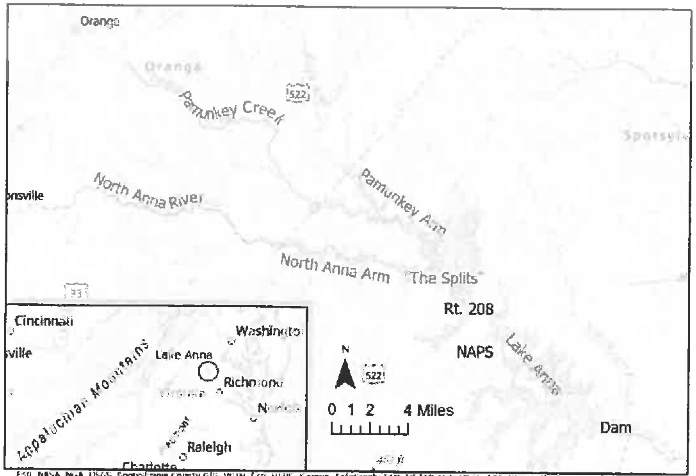

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Figure 1. Locational map of Lake Anna, Virginia.

Ultimately, the understanding gained through the science proposed herein will be used to inform management strategies to prevent and/or mitigate HABs; however, that phase of the overall effort is beyond the scope of this proposal.

Environmental Setting

The environmental setting of Lake Anna is complex and, consequentially, the potential factors, sources, and/or processes leading to HAB formation are diverse and complex. The environmental setting includes conditions and activities in the watershed, physical and hydrologic characteristics of the lake, and conditions and activities on and around the lake. These factors must be understood and accounted for in the design of the data collection approach to ensure all possible factors, sources, and/or processes are accurately reflected in the resultant data and interpretations.

Lake Anna is a 9,600 acre, approximately 17 mile long, reservoir formed by the 90 foot high North Anna Dam on the North Anna River in Spotsylvania County, Virginia (Fig. 1). The main body of the lake is formed by the flooded mainstem of the North Anna River, transitioning to the flooded two main tributaries (hereafter termed "arms) in the upper portion of the lake – Pamunkey Creek and North Anna River. This creates two hydrologically distinct environments on the lake that are further defined by a physical obstruction created by the Route 208 causeway. With this, the "uplake" portion is primarily riverine/lotic, particularly above "The Splits" where the two arms meet, and the "downlake" portion is primarily lacustrine/lentic.

The North Anna Power Station (NAPS) is located downlake, creating additional hydrologic complexity. The NAPS uses water drawn from the lake to cool two nuclear reactors – the cooling water is drawn from near the upstream extent of the lentic portion of the lake and then, after use, routed through a series of three cooling lagoons comprising the Waste Heat Treatment Facility (WHTF), separated from the lake by a series of three dikes, before being returned to the lake through an outlet structure on the downstream-most dike (Dike 3). The withdrawal and return of water from and to the lake creates an upstream/uplake flow in this portion of the lake. Colloquially, the main lake is referred to as the "Public" or "Cold" side, and the WHTF is referred to as the "Private" or "Hot" side, because of the access to and relative temperatures of each. Herein, "Lake Anna" refers to the main lake ("Public" or "Cold" side) not including the WHTF ("Private" or "Hot" side).

Lake Anna has approximately 200 miles of shoreline and a maximum depth of about 80 feet. The uplake portion is generally much shallower than downlake, with maximum depths of about 50 feet and depths less than 20 feet common in coves and tributaries. The uplake portion is also much narrower than downlake, resulting in a higher shoreline:water surface ratio.

Land use in the Lake Anna watershed is diverse and has changed over time. Currently, the land use is predominantly forested (59%), with grass (23%) and agriculture (7%) being the second and third largest uses (Austin and others, 2011; as quantified for USGS Streamgage 01670400 North Anna River at Route 601 near Partlow, VA). Urban land use occurs on about 2.5% of the watershed area, primarily in the towns of Louisa and Mineral. The shoreline of Lake Anna contains a mix of these land uses, with notable recent growth of residential properties along and near the shoreline. Historic land uses in the watershed, notably mining, continue to affect the lake. In particular, Contrary Creek, which enters the lake at approximately the mid-point, was home to base- and precious-metal mines in the 19th and 20th centuries and continues to have degraded water quality resulting from acid mine discharge – this acidic input is apparent in relevant measures of water quality within the upper portion of the inundated waters of the Contrary Creek branch of Lake Anna.

Potential HAB Factors

The potential factors, and interaction among factors, leading to the development, persistence, and decline

- **Nutrients:** Nutrients, especially nitrogen and phosphorus, are among the primary drivers of algal growth. In short supply nitrogen and phosphorus can limit growth, an abundance of these nutrients can trigger rapid proliferation. Measuring nutrient concentrations in Lake Anna and the major tributary inputs can help understand their role in promoting blooms.
- **Temperature:** Temperature has strong influences on biological communities. All species have ideal temperature ranges, within which they exhibit optimal growth and reproduction.
- **Climate:** Climate patterns influence algal growth by controlling growing season length, available light, and storm-caused inputs of sediment and nutrients. Additionally, wind can drive algae into downwind areas, leading to concentrated algal patches.
- **Wave action:** Wave action, whether from wind or boating activity, can cause shoreline erosion or resuspension of lake-bed sediments. These eroded or resuspended sediment particles can be a source of required nutrients, particularly phosphorus.
- **Geochemistry:** The geochemistry of Lake Anna is the sum of the interactions of the entire watershed and its underlying geology, living components of the watershed, and the waters of the lake itself and its tributaries. These interactions control the availability of many of the resources required for algal growth. An understanding of the geochemistry and its influence on available resources, including micronutrients essential for algal growth.
- **Light:** Algae and cyanobacteria require light as the energy source driving photosynthesis. This can be assessed by monitoring photosynthetically active radiation and the factors that may limit its availability, such as cloud cover and turbidity.

Approach

The approach to satisfy the stated objectives of the effort requires an extensive monitoring program with elements representing the meteorology of the area, the tributaries of Lake Anna, and the Lake itself. The specific activities proposed to represent those elements are presented in that order, essentially working from top down in the lake system with a focus on the "uplake" region (above Route 208) where HABs have predominantly occurred.

Meteorological Monitoring

Measurement of meteorological conditions, to include air temperature, precipitation, photosynthetically active radiation (PAR), and wind speed/direction is necessary to inform if and how these parameters affect HABs. A single station will be established and operated at a technically appropriate location, likely near the "splits" (fig. 2), to be determined through consultation with collaborators and stakeholders. The station will be operated year-round during the data collection period (fig. 3) and all data collected will be uploaded and publicly served on NWISWeb (waterdata.usgs.gov) within 1-hour of collection. All data collection will be performed in accordance with USGS Quality Assurance policies or other appropriate guidance. This standalone station will be equipped with a datalogger and telemetry unit, solar-charged DC power system, and the following sensors:

- **Air temperature** will be measured with a thermistor housed inside a louvered radiation shield.
- **Precipitation** monitoring will be conducted using a weighing-type gage (such as the Ott Pluvio^{2}L) following published USGS procedures (U.S. Geological Survey, 2009). A weighing-type gage is preferable over other gages such as a tipping bucket because it overcomes inaccuracies in very intense precipitation events. A precise measurement of the precipitation inputs to the watershed is vital for understanding numerous hydrological metrics. This precipitation gage will provide cumulative precipitation accumulation and intensity data.

- **Wind speed and direction** will be measured with a propeller style wind speed sensor (such as the R.M. Young Wind Monitor).
- **Photosynthetically Active Radiation** will be measured with a solar pyranometer (such as an Apogee ePAR sensor). PAR sensors measure light from solar radiation and other sources in the wavelength range of 400-750 nm. PAR is reported as μmol/m^2/s.

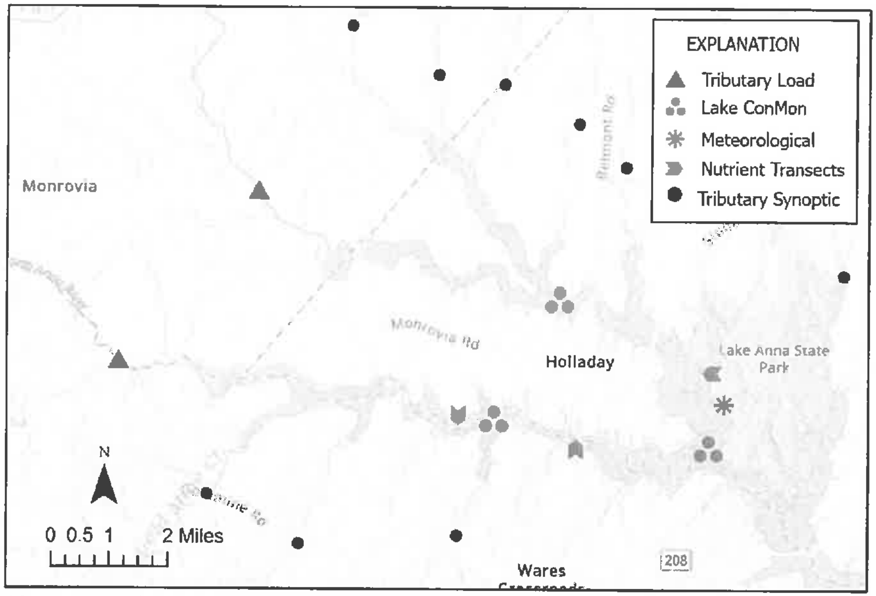

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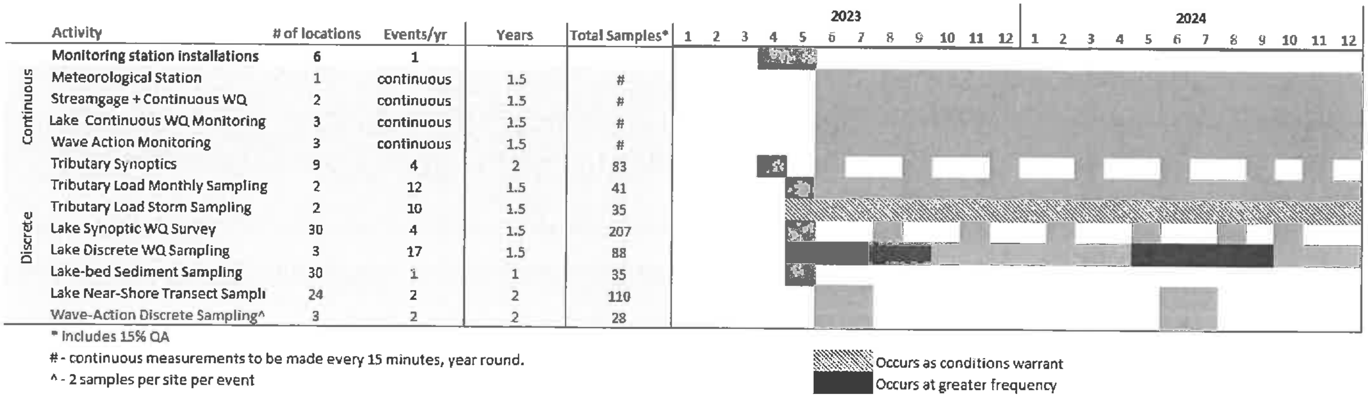
Figure 2. Tentative approximate locations of individual monitoring activities. Lake discrete water quality sampling and bed sediment sampling (not shown) will be evenly distributed throughout the lake, upstream of Rt. 208. All locations subject to change.



	Activity	# of locations	Events/yr	Years	Total Samples*
	Monitoring station installations	6	1		
Continuous	Meteorological Station	1	continuous	1.5	#
	Streamgage + Continuous WQ	2	continuous	1.5	#
	Lake Continuous WQ Monitoring	3	continuous	1.5	#
	Wave Action Monitoring	3	continuous	1.5	#
Discrete	Tributary Synoptics	9	4	2	83
	Tributary Load Monthly Sampling	2	12	1.5	41
	Tributary Load Storm Sampling	2	10	1.5	35
	Lake Synoptic WQ Survey	30	4	1.5	207
	Lake Discrete WQ Sampling	3	17	1.5	88
	Lake-bed Sediment Sampling	30	1	1	35
	Lake Near-Shore Transect Sampli	24	2	2	110
	Wave-Action Discrete Sampling^	3	2	2	28

* Includes 15% QA

\# - continuous measurements to be made every 15 minutes, year round.

^ - 2 samples per site per event

Figure 3.Activity matrix indicating number of locations. events, years, total samples, and timeline for each monitoring activity.

Tributary Monitoring

The physical and chemical quality of water entering Lake Anna from its watershed will be quantified to determine how those factors affect the development, persistence, and decline of HAB events. Tributary loading of nutrients, major ions, and suspended sediment will be determined for the two major tributaries of Lake Anna and several additional tributaries will be sampled at a lesser frequency to evaluate the transferability of yields from the two major tributaries to smaller tributaries around the lake.

Tributary Load Monitoring

Intensive monitoring-based approaches are needed to accurately quantify the nutrient and sediment loads from the two major tributaries of Lake Anna – the North Anna River and Pamunkey Creek (fig. 2). Traditional approaches to quantify loads require only periodic sampling of water-quality constituents of interest and continuous measurement of streamflow; however, these approaches require at least five years of data before load computation can be performed. Modern "surrogate" approaches additionally rely on the use of continuous measurements of basic water-quality parameters to develop more accurate and precise quantifications of loads. Further, surrogate approaches can be employed in a faster timeframe than the traditional approaches, which is a specific need of the proposed monitoring program; therefore, continuous water-quality monitoring on tributaries is a necessity to accomplish study objectives. The tributary load monitoring approach for Lake Anna will consist of the following:

Streamflow Monitoring

Standard USGS streamgages will be operated continuously during the data collection period (fig. 3) at the two tributary load monitoring stations – one each on the North Anna River and Pamunkey Creek. These stations will be established at suitable locations as close to the transition to impounded water as practical. Preference will be given to readily accessible locations along roads and will need to be upstream enough of the impoundment to eliminate or minimize the impact of backwater during high flow conditions.

Streamflow will be measured according to published USGS methods for the operation of streamgages (Sauer, 2002; Turnipseed and others, 2010); this will include 15-minute interval measurements of stage (water level) coupled with periodic manual measurements of streamflow to generate a streamflow rating curve to support computation of a continuous streamflow time series. Periodic and targeted-condition manual measurements of streamflow will be made over the project duration to capture variability and change in hydrologic and geomorphic conditions, and indirect (surveying + modeling) approaches will be used to ensure the upper end of the rating is developed.

Streamgages will consist of a water-level sensor, datalogger and satellite telemetry unit, solar-charged DC power supply, and water-quality monitoring instrumentation described in subsequent sections. The water-level sensor, likely a non-submersible pressure transducer, will meet USGS requirements for sensor accuracy (0.01 ft; U.S. Geological Survey, 1996). Data telemetry will be accomplished using GOES satellite telemetry – this is the standard telemetry system used by USGS streamgages, providing reliable data relay with redundant ground stations across the nation to reliably serve data. Data will be uploaded and publicly served on the USGS National Water Information System web interface (NWISWeb; waterdata.usgs.gov) within 1-hour of collection. The solar-charged DC power system will provide necessary power to operate all continuous sensors (stage and water-quality) and to support the data logger and telemetry system. All accordance with local specifications. In-stream components will be secured using appropriate hardware and approaches for site conditions, such as anchoring by u-channel hammered into the stream bottom, direct anchoring to existing rock, or use of rail systems. The cables to communicate between in-stream and streamside components will be secured in conduit.

Continuous Water-Quality Monitoring

Continuous water-quality monitoring will be implemented at the two tributary load monitoring stations to provide the necessary data to support timely development of constituent loads. These stations will include sensors for the measurement of water temperature, specific conductance, dissolved oxygen, pH, turbidity, and nitrate at 15-minute intervals year-round during the data collection period (fig. 3). Basic field parameters will be measured with a multi-parameter water-quality sonde such as the YSI-EXO and nitrate will be measured with a state-of-the-art spectrophotometric nitrate analyzer such as the Satlantic SUNA. Spectrophotometric nitrate analyzers provide lab-grade measurements within the range of concentrations observed in Eastern streams which cannot be achieved with ion selective electrode probes. These continuous monitors will be operated in accordance with published USGS methods (Wagner and others, 2006; Pellerin and others, 2013), which include procedures for routine servicing of sensors to ensure sensors are clean and within calibration, procedures for correcting data affected by minor fouling and calibration drift, and procedures for thorough review of data. Further, these sensors will be visited as-needed between scheduled visits to de-foul and correct malfunctions so that data loss is minimized. Data from the continuous water-quality monitors will be telemetered via the GOES satellite system and publicly served on NWISWeb in near-realtime along with the streamgage data.

Discrete Water-Quality Sampling

Discrete water-quality sampling will be conducted by USGS staff monthly and during targeted stormflow conditions (fig. 3) at the two tributary load monitoring stations to generate the data needed to compute constituent loadings to the lake. Manual collection of water-quality samples will be accomplished following published USGS sampling methods (U.S. Geological Survey, 2018), consistent with other USGS-DEQ collaborative monitoring programs such as the River Input Monitoring (RIM) and Non-Tidal Network (NTN). Basic field parameters – temperature, pH, specific conductance, dissolved oxygen, and turbidity – will be measured directly in stream using a multi-parameter instrument. Alkalinity will be measured for all samples using field titration.

Monthly samples will be collected on a fixed-schedule basis, representing a random sampling of hydrologic conditions. Stormflow samples will be collected for up to 12 stormflow events each year. This number of stormflow samples is needed to support an accelerated timeline for surrogate approaches for load computation (described below) and will provide a rich dataset that can be leveraged to better understand relations between water chemistry and hydrology.

All samples will be analyzed to determine major ion, nitrogen, phosphorus, stable isotopes in nitrate, and suspended-sediment concentrations as detailed in table 1. Nutrient analyses will include filtered and total analyses to inform evaluations of potential changes in fractionation. Major ion analyses are included both because these may represent essential micronutrients to algal communities and may have a role in regulating toxin production (Bacsi and others, 2006, Mailcht and others, 2013). Nutrient, major ion, and suspended sediment concentration analyses using published methods with appropriate reporting levels for these streams (table 1). Nitrate isotope analyses, useful for the determination of nutrient sources (*i.e.* manure, artificial fertilizer, atmospheric deposition), will be provided by the USGS Reston Stable Isotope Lab.

Table 1.List of analytes and DCLS lab codes (in parenthesis) to be collected at the tributary load and tributary synoptic monitoring stations.

Nutrients and Sediment (BAYR2, CNTF4, TPLL, DOCFF, SSC-C2)	**Major Ions** (IONTR)
Turbidity	*Specific Conductance*
Total Suspended Solids	*pH*
Volatile Suspended Solids	*Total Alkalinity*
Fixed Suspended Solids	*Dissolved Nitrate*
Total Nitrogen	*Dissolved Calcium*
Particulate Nitrogen	*Dissolved Magnesium*
Total Dissolved Nitrogen	*Dissolved Sodium*
Total Dissolved Phosphorus	*Dissolved Potassium*
Particulate Phosphorus	*Dissolved Chloride*
Particulate Inorganic Carbon	*Dissolved Sulfate*
Particulate Carbon	*End Point pH*
Dissolved Organic Carbon	**Photosynthetic Pigments** (FCHLR)
Total Phosphorus	*Pheophytin*
Dissolved Ammonia Nitrogen	*Chlorophyll A*
Dissolved Nitrite	**Stable Isotopes in Nitrate** (USGS LAB)
Dissolved Nitrate	$^{15}N/^{14}N$
Nitrite + Nitrate	$^{18}O/^{16}O$
Dissolved Orthophosphorus	
Dissolved Silica	
Suspended Sediment Concentration	
Suspended Sediment % <0.0625 mm	

Computation of Concentration and Load Timeseries

Upon the completion of the first year of data collection, preliminary statistical models, commonly termed surrogate relations, will be developed to utilize the relations between continuously measured parameters and the manually sampled constituents in support of load calculation. In subsequent years the surrogate relations will be formally developed and continuous concentration and load timeseries will be computed. These continuous load timeseries will be used to compute total loads over various periods of interest, including monthly, annual, and individual event.

Tributary Synoptic Monitoring

In addition to the intensive monitoring on the two main tributaries, it is necessary to sample other tributaries to the lake to 1) determine transferability of constituent yields (or per acre loads) and 2) determine if there are any “hot spots” that require further investigation. To maximize cost efficiency, ongoing DEQ sampling efforts will be leveraged to inform this element. Nine anticipated locations for this sampling are indicated in Figure 2. Quarterly sampling (fig. 3) of the nutrient and major ion schedules identified in Table 1 (BAYR2, CNTF4, TPLL, IONTR) is required, though monthly sampling may be conducted if resources permit. Measurement of hydrologic conditions at the time of sampling are necessary. Preferably, concurrent streamflow measurements will be made using standard approaches. Alternatively, measurements of water level from a fixed reference point would provide minimally acceptable information.

Lake Monitoring

Multiple spatial and temporal scales of lake monitoring are required to satisfy the objectives of this effort. Generally, this will include continuous monitoring of basic water-quality parameters and algal pigments; comprehensive discrete sampling of water-quality constituents, algal community structure, and algal toxins; synoptic sampling to assess stratification and spatial variability of basic water-quality parameters; transect sampling to evaluate potential near-shore sources of nutrients; lake bed-sediment sampling to evaluate potential internal nutrient loading; and wave/wake monitoring to evaluate resuspension of sediment and sediment-bound nutrients. All lake monitoring activities will be conducted upstream of the Route 208 causeway (fig. 2), as this is the primary area of concern for HAB conditions and resources do not permit monitoring of the entire lake.

Continuous water-quality monitoring

Continuously monitoring water-quality characteristics affords the opportunity to observe changes or processes that would go undetected at the temporal scale of most discrete sampling programs. Water quality often changes at daily, hourly, or even finer intervals of time. While discrete sampling can provide detailed snapshots of water quality, continuous water-quality monitoring fills in the gaps between sampling events with valuable, albeit less detailed, data on processes that may be related to changes in the agal ecology of Lake Anna.

Continuous water-quality monitoring stations will be deployed at 3 locations in the lake – one in each of the two arms and a third in the splits or Route 208 region (fig.2). Where possible, these stations will be established at locations accessible from shore, such as bridges or docks. These stations will have similar equipment as the tributary monitoring stations for power and data telemetry, will be operated continuously during the data collection period (fig. 3), and all data will be publicly available online in near real-time. At each station, instrumentation will be deployed near-surface from a suitable structure as available. These stations will include sensors for the measurement of water temperature, specific conductance, dissolved oxygen, pH, and turbidity at 15-minute intervals, year-round. Recording these parameters continuously allow for the detection of changes and observations in patterns related to diel and seasonal cycles. Water temperature and turbidity influence algal community growth and structure. Additionally, diel cycles in dissolved oxygen and pH are commonly related to photosynthetic processes controlled, in part, by algal communities.

In addition to the standard continuously monitored water-quality parameters, a photosynthetic pigment fluorometer (PhycoProbe) will be deployed. The PhycoProbe is a submersible and deployable software to analyze fluorescence to differentiate between major algal classes: green algae, diatoms, cryptophytes, and cyanobacteria, allowing for real-time assessment of algal community composition at a very high taxonomic level. Even at this gross level of taxonomic resolution, the fluorometer will inform our understanding of shifts in community composition and the succession of each class, especially the growth of cyanobacteria. Understanding these compositional shifts will highlight inter-class dynamics and may identify interactions that can lead to cyanobacterial proliferation and toxin production. Deploying these fluorometers at each monitoring station will provide significant data on algal community dynamics and provide a strong linkage between algal communities and the other measured characteristics. Additionally, the patterns in fluorescence measured using the PhycoProbe can be compared to multispectral satellite imagery to assess comparability and possibly relations among the data.

Light, specifically the photosynthetically active segment of sunlight, is a required resource for algal communities. Light availability varies over the year with day length, but also with cloud cover and, in narrow reaches or lake segments, with canopy cover. Photosynthetically active segment of solar radiation (PAR), wavelengths from approximately 400 to 700nm, can be measured using PAR sensor. These sensors will be deployed near water surface at all lake monitoring stations to better understand the role of light as a critical resource driving algal community dynamics.

Depth profiles collected as part of field-measurement synoptic surveys (discussed below) will be used to assess vertical mixing and determine if an additional sensor array (minus PAR sensor and PhycoProbe) will be needed at a greater depth.

Discrete water-quality sampling

Although continuous water-quality monitoring provides excellent temporal coverage in measures of water-quality, sensors do not exist for many water-quality characteristics and detailed analyses of discrete water-quality samples are necessary to more fully understand lake biogeochemistry. Understanding lake biogeochemistry is crucial to understanding algal ecology as algal community dynamics are regulated, in part, by the availability of resources. Macronutrients, specifically N and P, are among the resources that exert control on algal communities. Essential micronutrients such as Fe, Mn, and Mo, are required components of critical processes, including photosynthesis. Additionally, recent research has indicated that other trace elements may be important in regulating cyanotoxin production (Facey and others, 2019, Lukac and Aegerter, 1993, Martinez-Ruiz and Martinez-Jerómino, 2016, Polyak and others, 2013). Partitioning of nutrient species, distribution of major ions, metals, and trace elements, the presence of cyanotoxins, and detailed algal community composition can only be determined through the analysis of water samples. Discrete water-quality samples will be collected at the continuous water-quality monitoring stations (fig. 2) on a seasonally variable schedule; monthly samples will be collected from October through April and bi-monthly samples collected May through September (fig. 3). Point samples will be collected from multiple depths using an appropriate sampler (*e.g.*, Kemmerer bottle) and composited using a churn splitter. A depth profile of field measurements, water temperature, specific conductance, pH, dissolved oxygen, and turbidity, will be recorded with each discrete sample. If stratification is noted during collection of field measurements, separate hypolimnetic and epilimnetic samples will be processed and analyzed. The analytical suite will include nutrients, major ions, photosynthetic pigments, metals and trace elements, biomass as ash-free dry mass (AFDM), cyanotoxins, and algal community composition, including taxa identification, enumeration, and density (table 2).

Table 2. List of analytes and DCLS lab codes or responsible lab (in parenthesis) to be for the lake discrete sampling activity.

Nutrients and Sediment (BAYR2, CNTF4, TPLL, DOCFF, SSC-C2)	**Major Ions** (IONTR, HTIT2)
Turbidity	*Specific Conductance*
Total Suspended Solids	*pH*
Volatile Suspended Solids	*Total Alkalinity*
Fixed Suspended Solids	*Dissolved Nitrate*
Total Nitrogen	*Dissolved Calcium*
Particulate Nitrogen	*Dissolved Magnesium*
Total Dissolved Nitrogen	*Dissolved Sodium*
Total Dissolved Phosphorus	*Dissolved Potassium*
Particulate Phosphorus	*Dissolved Chloride*
Particulate Inorganic Carbon	*Dissolved Sulfate*
Particulate Carbon	*End Point pH*
Dissolved Organic Carbon	**Metals and Trace Elements** (DCMET1)
Total Phosphorus	*Aluminum*
Dissolved Ammonia Nitrogen	*Antimony*
Dissolved Nitrite	*Arsenic*
Dissolved Nitrate	*Barium*
Nitrite + Nitrate	*Beryllium*
Dissolved Orthophosphorus	*Cadmium*
Dissolved Silica	*Calcium*
Suspended Sediment Concentration	*Chromium*
Suspended Sediment % <0.0625 mm	*Copper*
Cyanotoxins (VCU Lab)	*Hardness*
Anatoxin	*Iron*
Cylindrospermopsin	*Lead*
Total Microcystins	*Magnesium*
Nodularin	*Manganese*
Photosynthetic Pigments (FCHLR)	*Mercury*
Pheophytin	*Nickel*
Chlorophyll A	*Potassium*
Algal community (VCU Lab)	*Selenium*
Taxa Identification	*Silver*
Enumeration	*Sodium*
Density	*Strontium*
Request Additions to DCLS Lab Schedules	*Thallium*
Biomass as Ash-Free Dry Weight	*Uranium*
Molybdenum	*Vanadium*
	Zinc

Field-measurement synoptic surveys

As reservoirs may stratify and seasonally turn over, essentially creating separate layers of water that may differ in quality, understanding stratification and differences in physicochemical characteristics of the resulting strata is important to understanding algal community dynamics. To assess both stratification regime and how well continuous monitoring stations represent lake conditions, quarterly synoptic surveys (fig. 3) will be conducted to measure variability of water quality characteristics both across the surface of the lake and through the water column. Vertical profiles of water temperature, specific conductance, pH, dissolved oxygen concentration, and turbidity will be recorded at approximately 30 locations evenly distributed across the lake study area. In addition to the vertical-profile measurements, made at 0.5-m intervals from just below the surface to near lake bottom, depth soundings and near-surface measurements of photosynthetic pigments will be recorded. A sampling point will be considered stratified if a stable metalimnetic layer is identified with a thermal gradient of >1.0° C/m (Wetzel, 2001).

Near-shore Nutrient Transects

Near-shore sources of nutrients may contribute to proliferation of algal communities. These near-shore sources include, but are not limited to, septic systems, lawn-care fertilizers, and agricultural activities. To determine the extent to which these sources contribute nutrients to Lake Anna, three transects consisting of sampling points spaced 5 m apart and extending from the shoreline to 25 m offshore will be established at sites representing residential, agricultural, and forested land uses (fig. 2). These transects will be sampled during dry/low-flow conditions to accentuate the inputs from baseflow/interflow. All samples will be analyzed for nutrient and major ion concentrations, stable isotopes of N and O in nitrate, which can be used to differentiate between animal/human sources and synthesized nitrate sources, and methylene blue active substances (table 3), the presence of which can indicate human waste streams. Differentiating human/animal and synthetic, *i.e.* fertilizer, sources of nitrate can determine whether the nitrate is from an agricultural or lawn care fertilizer source or a fecal source, such as wildlife or a human waste stream. These transects will be sampled twice during the study, once during typical residential occupancy levels and once during high residential occupancy levels (*e.g.,* a holiday weekend), to determine the effect of occupancy levels on near-shore source influences.

Lake-bed sediment sampling

Lake-bed sediments constitute a labile pool of nutrients and other essential resources that may support algal communities. Nutrients, especially phosphorus, sequestered in lake-bed sediments can be mobilized under certain conditions. Evaluating the distribution of nutrient and major ion concentrations throughout the lake may provide some understanding of patterns in HAB occurrence. As sediment composition is likely less variable than lake water, sediment surveys will occur only once. Samples will be collected at approximately 30 points evenly distributed across the lake study area. The lake-bed sediments survey will be conducted during the first field-measurement synoptic survey. Samples will be collected using grab samplers, an Ekman dredge or petite PONAR dredge as appropriate. Approximately 500 g of each grab sample will be passed through a 2-mm seive before being placed in a container for shipment to the analytical lab. These samples will be analyzed for nutrients (N & P, C), metals and trace elements, and particle size distribution (table 4).

Table 3. List of analytes and DCLS lab codes or responsible lab (in parenthesis) to be for the lake near-shore transect sampling activity.

Nutrients (BAYR2)	**Major Ions** (IONTR)
Turbidity	*Specific Conductance*
Total Suspended Solids	*pH*
Volatile Suspended Solids	*Total Alkalinity*
Fixed Suspended Solids	*Dissolved Nitrate*
Total Nitrogen	*Dissolved Calcium*
Particulate Nitrogen	*Dissolved Magnesium*
Total Dissolved Nitrogen	*Dissolved Sodium*
Total Dissolved Phosphorus	*Dissolved Potassium*
Particulate Phosphorus	*Dissolved Chloride*
Particulate Inorganic Carbon	*Dissolved Sulfate*
Particulate Carbon	*End Point pH*
Waste-Water Indicator (USGS LAB)	**Stable Isotopes in Nitrate** (USGS LAB)
Methylene-Blue Active Substances	$^{15}N/^{14}N$
	$^{18}O/^{16}O$

Table 4. List of analytes and DCLS lab codes or responsible lab (in parenthesis) to be for the lake-bed sediment sampling activity.

Nutrients (USGS Lab)
Nitrogen as bottom material
Phosphorus as bottom material
Carbon as bottom material
Metals and Trace Elements (USGS Lab)
Iron
Manganese
Mercury
Cadmium
Lead
Cobalt
Chromium
Copper
Zinc
Sediment Composition (USGS Lab)
Particle-size distribution

Lake wave action and resuspension monitoring

Recreational boating has been an important activity on Lake Anna since its creation. Boating on the Lake ranges from kayaking to pontoon boats to wake-sport boats such as wakeboarding and wake surfing. Patterns in the amount and nature of boat traffic on Lake Anna may affect sediment resuspension and lakeshore erosion. Wave action, both natural and anthropogenic, may play a significant role in the resuspension of bed sediment and the mobilization of associated nutrients, especially P. Monitoring relations between wave action and turbidity is critical to understanding their influence on nutrient dynamics and changes in algal populations and community composition in Lake Anna. Wave-action monitoring stations, equipped with sensors for high-frequency water-level measurement, will be co-located with continuous water-quality monitoring stations on the lake (fig. 2). Wave height and frequency will be compared to turbidity values to determine if relationships exist between the two values. Additionally, discrete water samples will be collected during periods of both high and low boating activity and analyzed for nutrients and suspended sediment (table 5).

Table 5. List of analytes and DCLS lab codes or responsible lab (in parenthesis) to be for the wave action sampling activity.

Nutrients and Sediment (BAYR2, SSC-C2)
Turbidity
Total Suspended Solids
Volatile Suspended Solids
Fixed Suspended Solids
Total Nitrogen
Particulate Nitrogen
Total Dissolved Nitrogen
Total Dissolved Phosphorus
Particulate Phosphorus
Particulate Inorganic Carbon
Particulate Carbon
Suspended Sediment Concentration
Suspended Sediment % <0.0625 mm

Products

This effort will result in numerous deliverables on varying timelines. These deliverables include datasets, reports, and web products, as detailed below.

The most immediate product will be the data, which, in the case of continuous data will be publicly available in near realtime (within ≈1 hour of collection), via NWISweb. Water-quality sampling results will be available on NWISweb upon receipt from the laboratory.

A website will be developed at the beginning of the program to communicate objectives, approaches, monitoring locations, and links to data collected by the program. This website will be updated to communicate findings and publications as they are released.

Quarterly progress reports summarizing the operation, maintenance, issues, and anomalous observations (if any) will be provided for the duration of the effort. Annual progress reports synthesizing the data collected and providing updates on program status and interim findings will be provided as presentations to DEQ and VDH staff each winter.

The capstone product from this program is a USGS Scientific Investigations Report (SIR). This report will detail all aspects of the program described herein and the results of analyses to be completed in support of the stated objectives. A comprehensive, peer-reviewed, and professionally published SIR is a preferable product for a program of this size and scope because the numerous findings will be communicated without the constraints of fitting the information in a journal article.

Timeline

The work proposed will be accomplished within 3 years, as depicted on the timeline below:

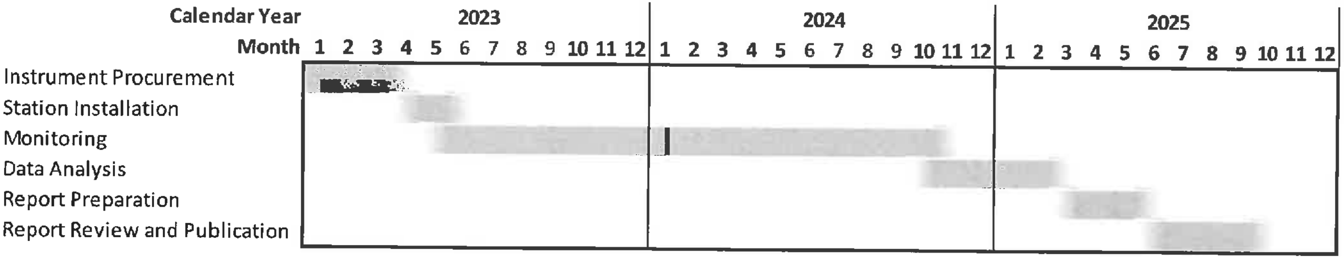


Figure 4. Timeline for proposed activities.

Collaborations

Collaborations with other entities, such as universities and non-governmental organizations, are anticipated. These collaborations may fill some of the needs identified in this scope and budget, and therefore may result in changes to the budget. These collaborations have yet to be fully defined. However, algal toxin determination and taxonomic analyses will be completed by laboratories at the Virginia Commonwealth University's Rice River Center.

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Supplemental Information

Table of total counts of laboratory analyses to be performed by DCLS, by lab schedule.

DCLS Schedule	Count
BAYR2	385
CNTF4	247
TPLL	247
DOCFF	247
SSC-C2	274
IONTR	274
HTIT2	0
FCHLR	164
DCMET	88