Investigation of Drivers of Harmful Algal Blooms on the Shenandoah River, Virginia

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.

Filamentous algae attached to the stream bottom has been a concern in the Shenandoah River basin for over a decade. Concerns have largely centered on the negative impact that filamentous algal blooms have on stream aesthetics and recreational activities such as swimming, wading, kayaking, and fishing. These blooms have been primarily composed of green algae, which do not produce toxins and thus do not pose a threat to public health. In August 2022, the Virginia State Water Control Board approved final amendments to the Virginia Water Quality Standards (9VAC25 -260) incorporating benthic chlorophyll-a criteria for portions of the mainstem North Fork Shenandoah, South Fork Shenandoah, and Shenandoah Rivers. These criteria are designed to minimize the occurrence of nuisance conditions associated with excessive filamentous algal growth.

In July and August 2021, the Virginia Department of Environmental Quality (DEQ) investigated multiple reports of algal mats in the North Fork Shenandoah that appeared to potentially contain cyanobacteria, which may be toxic. Subsequent laboratory analysis of samples collected indicated that algal toxins were present within algal mats in multiple locations along the North Fork Shenandoah River. While toxins and potentially harmful algal cells were also detected in the water at some sites, concentrations were at low levels and well below Virginia Department of Health (VDH) advisory thresholds for recreational use. However, due to the presence of cyanobacteria in algal mats detected at sites along the river, VDH issued and subsequently extended a recreational advisory for the North Fork Shenandoah River to ensure the public was aware of the presence of these algal mats and to ensure that people, in addition to their pets and livestock, could take caution to avoid contact with visible algal mats and scum. The advisory covered approximately 52.5 miles of the North Fork Shenandoah River. This reach also includes 3 drinking water intakes for the towns of Strasburg and Woodstock and the City of Winchester. Additional testing and treatment were conducted at these plants, and cyanobacteria toxins were detected in both the intake and finished drinking water. In 2022, in response to a recurrence of the benthic mats in the North Fork Shenandoah in the Town of Strasburg, VDH issued an algal mat alert for an 11.5-mile stretch of the river and cautioned the public to avoid algal mats observed along the shoreline or stream bottom.

In 2022, the General Assembly appropriated $3.5 million to the Virginia Department of Environmental Quality to study HABs in Lake Anna and the Shenandoah River basin. These studies are being conducted in coordination with VDH, which has issued swimming advisories for Lake Anna and algal mat alerts for sections of the Shenandoah River basin. The studies funded by the General Assembly will focus on the environmental factors that cause these HABs and management approaches that could be employed to prevent and mitigate their impacts.

Objectives

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

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

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.

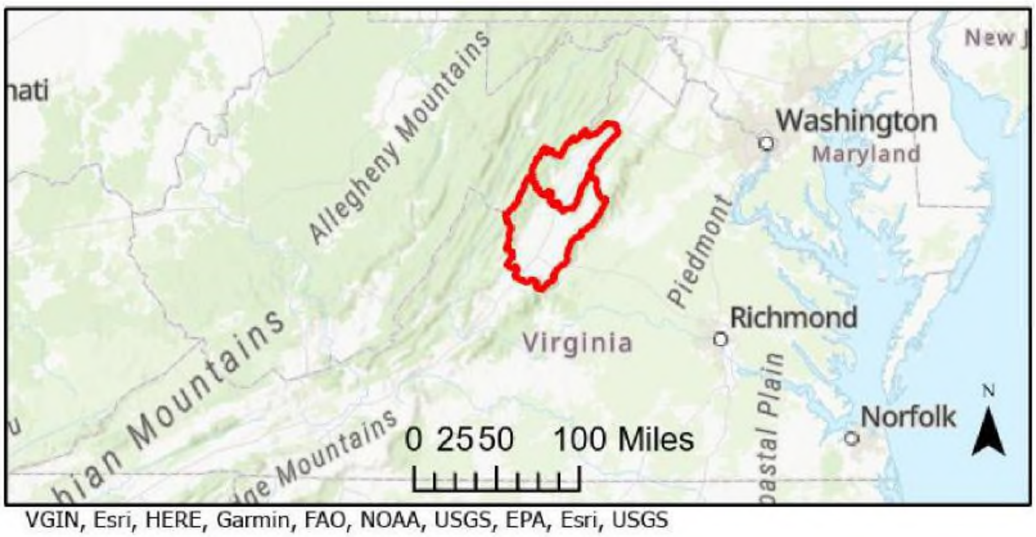

Figure 1. Location of the study area in Virginia.

Environmental Setting

The headwaters of the Shenandoah River basin begin in Augusta County and flow in a northeasterly direction for approximately 100 miles to the West Virginia state line. The basin averages 30 miles in width and covers 3,384 square miles.

The topography of the Shenandoah River basin is characterized by valleys and rolling hills bordered by the Appalachian Mountains to the west and the Blue Ridge Mountains to the east. The Massanutten Mountain Range divides the Shenandoah River into the North and South Forks. Tributaries of the Shenandoah River exhibit steep profiles as they drain the surrounding mountain ridge. The mainstem of the Shenandoah exhibits a moderately sloping profile with occasional riffles and pools. Approximately 45 percent of the land is forested due to the large amount of federally owned land and the steep topography. Farmland and pasture account for 39 percent of the land area, while 16 percent is urban. Karst geology is a distinctive feature of the Shenandoah River basin.

The South Fork of the Shenandoah and North Fork of the Shenandoah occupy a geologically complex area of the Great Valley section of the Valley and Ridge Physiographic Province. These low-gradient streams traverse broad valleys separated by linear ridges. The valleys are mostly underlain by Cambrian-to Ordovician-aged carbonate rocks and shales and the ridges of either Silurian- to Pennsylvanian-aged sandstones and shales to the west and siliclastic rocks to the east. The high transmissivity of the carbonate rocks that comprise the valley floors and the high-to-moderate base-flows of Valley and Ridge streams (Nelms and others, 1997) indicate a high degree of groundwater-surface water interactions. Structural controls, such as fault planes, can determine where areas of groundwater-surface water interaction occur. Contributions of groundwater enriched in minerals or nutrients can alter stream water chemistry. Research in the Smith Creek basin of the Shenandoah River has demonstrated influence of nitrate, calcium, and magnesium enriched groundwater contributions on the watershed (Hyer and others, 2016).

Potential HAB Factors

The potential factors, and interaction among factors, leading to the development, persistence, and decline of HABS in the Shenandoah River are myriad, as are the potential source(s) of those factors. They include:

- **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 the river 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.
- **Hydrology:** Hydrologic conditions are a controlling factor in the transport of water-quality constituents and habitat conditions that affect algal communities. Quantification of streamflow, and evaluations of patterns in streamflow, are necessary to elucidate the factors affecting bloom formation.
- **Geochemistry:** The geochemistry of the river is the sum of the interactions of the entire watershed and its underlying geology, living components of the watershed, and the waters of the river 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 hydrology and water quality of the two main forks of the river. This monitoring program will be focused in a study area defined by the following bounds: NF Shenandoah River from Mount Jackson downstream to Strasburg and SF Shenandoah River from Lynnwood downstream to Luray (Fig. 2). This study area coincides with the with the river reaches where HAB occurrence has previously been greatest.
The work required to conduct the approach will be conducted under co-leadership by USGS and the Interstate Commission on the Potomac River Basin (ICPRB), with collaborations with Virginia Commonwealth University's Rice Rivers Center (VCU). The description of the approach is grouped according to the organization with primary responsibility.
Generally, USGS activities will focus on the water-column chemical characteristics and hydrology and ICPRB activities will focus on algal mat occurrence and distribution.

Esri, CGIAR, USGS, VGIN, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

Figure 2. Map of sentinel stations defining study area bounds.

USGS-led activities

Sentinel Station Monitoring

The physical and chemical quality of water in the North Fork and South Fork of the Shenandoah River will be quantified to determine how those factors affect the development, persistence, and decline of HAB events. This work will be conducted at four existing streamgaging stations, referred to herein as "sentinel" stations (table 1). These stations define the upstream and downstream extents of the study area on each river.

Table 1.Sentinel stations.

Station Name	USGS ID	Location on River
N F Shenandoah River near Strasburg, VA	01634000	Downstream extent of NF
N F Shenandoah River at Mount Jackson, VA	01633000	Upstream extent of NF
S F Shenandoah River near Luray, VA	01629500	Downstream extent of SF
S F Shenandoah River near Lynnwood, VA	01628500	Upstream extent of SF

Monitoring at these locations will consist of the following:

Streamflow Monitoring

Standard USGS streamgages are currently operated at the four sentinel stations – no additional activity or funding is required to generate the necessary hydrologic data at these locations. Streamflow is measured according to published USGS methods for the operation of streamgages (Sauer, 2002; Turnipseed and others, 2010); this includes 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.

The existing streamgages consist of a water-level sensor, datalogger and satellite telemetry unit, solar-charged DC power supply. The water-level sensors meet USGS requirements for sensor accuracy (0.01 ft; U.S. Geological Survey, 1996). Data telemetry is 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 are 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 provides necessary power to operate all continuous sensors and to support the data logger and telemetry system. All streamside monitoring equipment is housed in a vandal-resistant shelter constructed in accordance with local specifications.

Continuous Water-Quality Monitoring

Continuous water-quality monitoring will be implemented at the two sentinel stations on the North Fork Shenandoah River, NF Shenandoah River near Strasburg and NF Shenandoah River at Mount Jackson. The reach of the North Fork of the Shenandoah between these two gaging stations has consistently been the location of HABs in the past several years. As the more likely location of algal proliferation, this reach has been selected for a more intense monitoring effort with an extensive suite of continuously measured water-quality characteristics. Standard continuous monitoring includes sensors for the measurement of water temperature, specific conductance, dissolved oxygen, pH, and turbidity at 15-minute intervals, year-round. Basic field parameters will be measured with a multi-parameter water-quality sonde such as the YSI-EXO series sonde. These five water-quality characteristics are routinely measured at USGS gaging stations and provide a wealth of information on stream conditions. This sensor array will be augmented with nitrate sensors and *in-situ* fluorimeters, *i.e.* PhycoProbes. 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. PhycoProbe fluorimeters can detect fluorescence from photosynthetic pigments, measure change in concentrations of these pigments, and estimate abundance of algal taxa, including cyanobacteria and green algae.

Light, specifically the photosynthetically active segment of sunlight with wavelengths from approximately 400 to 700 nm, is a required resource for algal communities. Light availability varies over the year with day length, but also with cloud cover. A photosynthetically active radiation (PAR) sensor will be deployed at NF Shenandoah River at Mount Jackson, the upstream gaging station, to measure the portion of spectrum used by photoautotrophs such as algae to produce biomass.

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.

The existing streamgages provide the necessary components for power, data logging, and telemetry, resulting in a substantial cost savings for this proposed study. The above-described sensor package will be added to the exsiting infrastructre at the sites. 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. 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

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 understand biogeochemistry more fully. Understanding 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. Partitioning of nutrient species, distribution of major ions, the presence of cyanotoxins, and detailed algal community composition can only be determined through the analysis of water samples. 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 (tables 2 and 3).

Water-quality sampling will be conducted by USGS staff monthly and during targeted stormflow conditions at the four sentinel stations. 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 4 stormflow events each year. This lesser number of stormflow samples, compared to the RIM and NTN programs, is sufficient because computation of constituent loads is not needed for this effort.

The NF Shenandoah River near Strasburg, VA is currently sampled by USGS as part of the NTN program. This ongoing sampling program consists of monthly and storm event samples for most of the nutrient, sediment, and major ion suite needed (BAYR2, TPLL, SSC-C2, HTIT) for the proposed effort, resulting in a substantial costs savings to this program as much of the labor and laboratory cost is already covered.

Table 2. List of analytes and DCLS lab codes 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	**Other Analytes of Interest**
Total Phosphorus	*Molybdenum, total recoverable*
Dissolved Ammonia Nitrogen	*Biomass as Ash-Free Dry Weight*
Dissolved Nitrite	
Dissolved Nitrate	
Nitrite + Nitrate	
Dissolved Orthophosphorus	
Dissolved Silica	
Suspended Sediment Concentration	
Suspended Sediment % <0.0625 mm	

Table 3. List of analytical determinations and taxonomic services to be provided by George Mason University

Cyanotoxin Analyses	Photosynthetic Pigments
Microcystins (ELISA)	*Chlorophylls a, b, and c*
Nodularin (ELISA)	*Phycocyanin*
Anatoxin (ELISA)	*Phycoerythrin*
Cylindrospermopsin (ELISA)	
Saxatoxin (ELISA)	**Taxonomic analyses**
LC/MS procedures to further identify congeners and concentrations as needed	*Relative abundance of all algal forms (green + cyanobacteria) using SWAMP procedures*

Intensive Studies in Bloom Areas

The lower reaches of the North and South Forks of the Shenandoah River have seen the most regular and extensive algal blooms in the Shenandoah River basin. More intensive examinations are warranted to discern which factors lend themselves to making these river reaches more susceptible to HAB formation.

Surface-water/Groundwater Interactions

The influence of upwelling groundwater or hyporheic water on algal communities will be examined by establishing surface-water/groundwater interaction study areas in the previously identified HAB occurrence zones in the lower reaches of both the North and South Forks of the Shenandoah River. The study zones, two each in both the North and South Forks, will initially be delineated through geospatial analysis based on the intersection of geologic features, faults, bedding planes and lineaments, conducive to upwelling groundwater and the occurrence of algal proliferations. Inflows of groundwater will be confirmed by thermal imagery and point measurements of water temperature and specific conductance during reconnaissance. Study reaches will be selected from confirmed areas of upwelling groundwater with the highest recurrence frequency of algal mats and strongest groundwater signature as indicated by water temperature. Where possible, shallow, temporary monitoring wells or piezometers will be established in areas of upwelling groundwater identified through TIR imagery and point measurements of water quality characteristics. Additional piezometers will be established in nearby areas without a thermal signature of upwelling water to serve as a comparison environmental setting. The piezometers will serve two purposes: to verify the upwelling of groundwater and to sample hyporheic/groundwater. Upwelling groundwater can be verified by differences in water level in a stream bed piezometer and stream water surface, this difference indicates the vertical hydraulic gradient (VHG). At each study area a set of three samples will be collected; one from a piezometer in a zone of upwelling groundwater, one from a piezometer in a zone not identified as a source of upwelling groundwater, and a representative stream sample collected using standard depth- and width-integrating methods. Water from the hyporheic zone will be collected by purging the piezometer before collecting an aliquot of water to be analyzed for nutrients and major ions. These data can be used to verify areas of upwelling groundwater identified using TIR imagery, understand nutrient inputs from groundwater, and relate algal patches to areas of positive VHG.

ICPRB-led activities

Task 1: Monthly Longitudinal Transects (ICPRB)

Lotic ecosystems are complex and variable, changing over the length of a stream. Capturing this variability and the patchiness of habitats, including algal habitats, requires a greater spatial density of measurements than is possible through fixed data collection stations alone. Longitudinal transects, collection of data from multiple locations along a length of stream, provide detailed snapshots of the changes in water quality occurring over that length of stream. These observed changes in water quality can, in turn, be related to changes in land use, geology, and geomorphology along the stream. Additionally, the occurrence and persistence of benthic algae and algal mats can be noted and related to local water quality and environmental setting. To sufficiently describe algal coverage in the Shenandoah study reaches:

Monthly surveys at 11 sites (1-7, North Fork Shenandoah sites, 8-11, South Fork Shenandoah sites, Figure 3. and Table 4) will be conducted through the algal growing season. The algal growing season will be operationally defined as May – October. Operations throughout this period will capture early growth phases, algal community shifts, and population senescence. Additional opportunistic transects may be added if early blooms are noted or dense growths persist later in the season. Data collected during longitudinal transects will consist of; 1.) at least 5 points across the river width, 2.) field measurements (including water temperature, pH, dissolved oxygen, specific conductance, and turbidity), 3.) total algal coverage will be estimated for a 100-yard reach, 50 yards above and 50 yards below point of entry or where site is deemed most representative of algal composition, and 4.) Proliferations of benthic algae or extensive floating mats encountered during longitudinal transects will be sampled for analysis of cyanotoxins and community composition. Samples will be collected using appropriate methods, such as those described for benthic algae in Porter and others (1998) or for floating mats described in Fetscher and others (2010). Methodologies for benthic mat collections, and the arrangement and number of benthic algae samples may be altered based on lab requirements and field conditions encountered during the investigations.

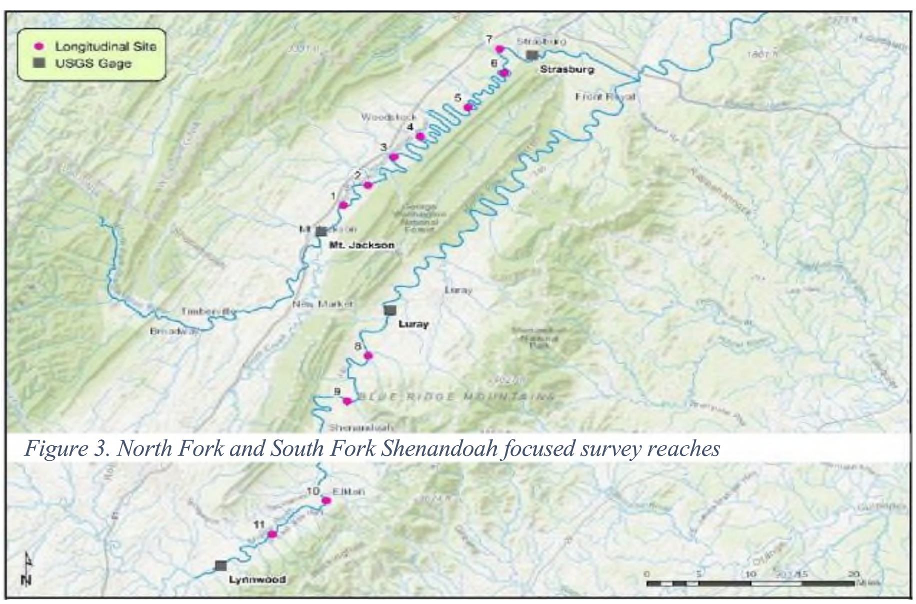

Figure 3. North Fork and South Fork Shenandoah focused survey reaches

Table 4. Site descriptions and locations for the 11 HAB observation sites.

ID	Name	Latitude	Longitude
1	NF Shenandoah Bridge @ Rt 707	38.7823259	-78.60042925
2	NF Shenandoah Bridge @ Rt 698	38.8084439	-78.5660327
3	NF Shenandoah Park @ Chapman Landing Rd	38.84527646	-78.52958983
4	NF Shenandoah Park @ Lupton Rd, Rt 667	38.87162439	-78.4927559
5	NF Shenandoah Bridge @ Rt 600	38.90957591	-78.42625834
6	NF Shenandoah Bridge @ Rt 744	38.95440548	-78.37549297
7	NF Shenandoah Bridge @ Rt 11	38.98540376	-78.38198763
8	SF Shenandoah Park @ River Rd	38.58626305	-78.56571635
9	SF Shenandoah Park @ Rt 650, Grove Hill	38.52719821	-78.59479338
10	SF Shenandoah Park @ M St, Riverside Park	38.39745358	-78.62418031
11	SF Shenandoah Park @ Rt 650, Island Ford	38.35320897	-78.69955195

Task 2: Coordination of Shenandoah Water Chemistry (VADEQ, No funds to ICPRB)

VADEQ will collect water column samples at six of the 11 locations listed in Table (3 on the NF Shenandoah, 3 on the SF Shenandoah) in conjunction with the longitudinal sampling conducted by ICPRB. Coordination of USGS sentinel station site visits, ICPRB algal monitoring longitudinal surveys (Task 1), and VADEQ water chemistry sampling will provide the most complete temporal snapshot of river conditions leading up to, during, and post HAB event. All water quality measurements will be collected following protocols and quality assurance measures described in the Virginia DEQ ambient water quality monitoring plan QAPP. The standard suite of water chemistry parameters that will be collected alongside the other agencies' efforts are listed in Table 5.

Table 5. VADEQ coordinated water monitoring parameters.

Parameters
Total Dissolved Phosphorus/Orthophosphate
Total Phosphorus
Nitrogen (Nitrate, Nitrite, TKN)
Dissolved Organic Carbon
Total Organic Carbon
Iron
Calcium
Magnesium
Alkalinity ($CaCO_3$)
Total Suspended Solids (TSS)
Suspended Sediment Concentration (SSC)

Task 3: Event Based Intensive Surveys

Observations from the sentinel gaging stations, longitudinal transects, VADEQ monitoring, and the VDH HAB reporting portal will all be used to inform field crews of the temporal and spatial presence of HABs within the Shenandoah River. In previous years of study, the extent, frequency, and duration of HAB events have been inconsistent and difficult to respond to via a regular, site-based monitoring strategy. For this reason, an "event bank" of 12 events spread over the two growing seasons will be used to respond to the most impacted reaches when conditions allow. Additional intensive surveys can be added as needed for additional cost.

Detailed longitudinal transects, conducted by watercraft, will be used to collect further information to support investigations on factors contributing to HABs in the Lower North Fork and South Fork of the Shenandoah River. The watercraft surveys will aim to cover roughly 10 miles, which allows time for data and specimen collection as well as timely delivery of specimens to the lab for processing. All parameters measured as part of the routine longitudinal transects described above will be collected in the detailed transects but in more closely spaced cross sections. Furthermore, rapid visual habitat assessment (geomorphic channel unit, substrate size, etc.), and locations of algal proliferations or floating mats will be recorded and sampled for taxonomic identification and enumeration, pigment analysis, and determination of cyanotoxin concentration. Identification of algal proliferations will be recorded throughout the reach, regardless of whether it coincides with a regularly spaced measuring point along the longitudinal transect.

Task 4: Coordination and Oversight of Drove Aerial Surveys

Although the monthly longitudinal (Task 1) and intensive surveys (Task 3) will provide taxonomic and toxin analyses with precision and accuracy, spatial coverage estimates will remain qualitative and spatially limited. There are currently no ground-based methodologies developed that can rapidly and quantitatively calculate benthic algal composition and area coverage. The purpose of this task is to explore the use of drone based hyperspectral technology in rapidly quantifying spatial coverage of a benthic community. A drone fitted with a hyperspectral camera will survey the middle 80% of a targeted 600-foot river reach every three weeks during the 6-month observation season. An aerial survey will be conducted in both observation years for a total of 12 months of HAB hyperspectral surveillance.

ICPRB will coordinate with an aerial technology team prior to the algal growing season and select three static locations from the longitudinal site list for continued surveillance. These sites will be selected based on input from all partners and should be located within historically problematic bloom locations that regularly and predictably experience benthic HABs. Once locations are determined, ground control points (GCPs) will be used to define the sites. The drone team will fly these three sites every three weeks May – October in hopes of defining baseline conditions, the growth phase, peak HAB, senescence period, and return to baseline.

Complementary to the static locations, the drone team will reserve three additional sites per field visit for dynamic response. Due to unpredictable nature of HAB blooms, both spatially and temporally, these dynamic sites will allow researchers to identify conditions on an as needed basis to make control and test data sets more robust.

ICPRB Deliverables and Schedule

The outcome of this work will be two annual summaries of field data including HAB characterizations, ambient water chemistry, and drone surveillance as well as contributions to a final multi-agency report including USGS, ICPRB, VADEQ, and others. The annual summaries are intended to provide a centralized citable source of data and analysis for all non-sentinel station-based datasets. ICPRB will also maintain an online data depository for project data. The work schedule is provided in Table 6.

Table 6. Work schedule by task and quarter. (Q1= start of project, Qx = a quarter is 3months relative to start date)

Short Title	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Project Kickoff/Equipment Procurement										
Year 1 Field Monitoring/Project Coordination										
Year 1 Annual Summary, Data QA/QC										
Year 2 Field Monitoring/Project Coordination										
Year 2 Annual Summary, Data QA/QC										
Final Document										

USGS 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 USGS 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.

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