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Harmful Algal Bloom Lake Management Guidance

NJDEP HAB Expert Team

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State of New Jersey

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New Jersey Department of Environmental Protection
Water Resource Management
Division of Water Monitoring, Standards and Pesticide Control

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April 2024

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Executive Summary

In 2021, the Division of Water Monitoring and Standards and Pesticide Control (DWMSPC) and the New Jersey Sea Grant Consortium (NJSGC) recruited a team of lakes management and cyanobacterial HAB experts to address the second component of the Governor's HAB initiative focusing on enhancing scientific expertise and building the state's capacity for HAB response. The HAB Expert Team's primary objective is to provide guidance to DEP on HAB prevention, mitigation and management for NJ lakes and other waterbodies. The team has compiled a comprehensive literature review as a resource guide available here: [NJDEP | Harmful Algal Blooms | ET Resources (https://www.nj.gov/dep/hab/et-resources.html)](https://www.nj.gov/dep/hab/et-resources.html).

As a culmination of their research, literature review, and data analysis, this Harmful Algal Bloom Lake Management Guidance provides details to lake managers on how to develop a lake-specific action plan.

The Guidance includes HAB prevention, mitigation, and management for NJ waterbodies that considers short-term and long-term action plan components to characterize lake conditions and lake management actions as needed including:

- **Lake Background:** General description of the lake, lake watershed, water classification, designated uses, existing Total Maximum Daily Loads (TMDLs), and other pertinent information.
- **Public Participation and Outreach:** The importance of outreach, education, public participation and engagement to the success of a Lake Action Plan.
- **Water Quality Monitoring and Lake Conditions:** How to develop a monitoring plan to collect water quality data, including recommended parameters needed to monitor/assess current and changing lake conditions and trends.
- **Identify Existing Data and Data Gaps**: Sources of data including 303(d) List, Water Quality Portal and other sources. Describe any related community monitoring and the need for a QAPP to ensure quality of the data collected.
- **Algae/HABs Summary:** Overview of conditions which cause or contribute to HABs.
- **Pollutant Sources:**
  - Information on identifying and quantifying sources of pollution in watershed.
  - Information on identifying water quality target or goal and pollutant reductions needed to achieve goal.
- **Lake Management / Water Quality Goals:**
  - Information on identifying BMPs and treatment options needed to achieve reductions to meet water quality goal/target and an estimated schedule to implement BMPs identified in plan.
  - The financial and technical assistance needed to implement BMPs.
  - The milestones and estimated time frames for the implementation of BMPs.
  - The criteria that will be used to assess water quality improvement as the plan is implemented.

    - The monitoring plan that will collect water quality data needed to measure water quality improvement.
    - Any lake management actions to date.
- **Selection of Actions –** Guidance for what processes to choose from and how best to select option(s) / activities list for HAB prevention, mitigation, and management.

The detailed guidance incorporates relevant information/BMPs from the ITRC Strategies for Harmful Cyanobacteria Blooms (HCB) Communication, Prevention, and Management document. Additionally, other technical resources from EPA and USGS was reviewed and relevant BMPs included.

TABLE OF CONTENTS

1. INTRODUCTION

Cyanobacteria Bloom

In recent years, the occurrence of known cyanobacterial Harmful Algal Blooms (HABs) in freshwater lakes, reservoirs, rivers and streams has become more common in NJ. In 2019, there were 74 suspected and 35 confirmed harmful algal blooms at 35 waterbodies, representing a significant increase since the HAB Response Strategy was implemented in 2017. This trend of increased HAB occurrence throughout the State has continued to present day with most recent data showing a significant increase of waterbodies with confirmed HABs (Watch Alert or above) by nearly 40% since the program began. Exposure to harmful algal blooms can result in adverse health effects in humans and animals. Recreational exposure to cyanobacterial cells during bloom conditions can result in allergic-like reactions (e.g. rashes), flu-like symptoms and gastroenteritis. In some cases, blooms may produce toxins at levels that can be dangerous to humans, pets, livestock and ecosystems. When either cell counts or toxins are present above recommended levels set by the State (as per the Recreational HAB Strategy), advisories are issued to reduce potential impacts to the public. Algal blooms can affect not only public health and the ecosystem but also the economy. Beach advisories and closures, while protective of public health, can significantly impact local lake economies. In addition to recreational impacts, HABs can also affect sources of drinking water and, potentially, drinking water quality.

In 2021, the Division of Water Monitoring and Standards and Pesticide Control (DWMSPC) and the New Jersey Sea Grant Consortium (NJSGC) recruited a team of lakes management and cyanobacterial HAB experts to address the second component of the Governor's HAB initiative focusing on enhancing scientific expertise and building the state's capacity for HAB response. The HAB Expert Team's primary objective is to provide guidance to DEP on HAB prevention, mitigation and management for NJ lakes and other waterbodies. The team has compiled a comprehensive literature review as a resource guide available here: [NJDEP | Harmful Algal Blooms | ET Resources](https://www.nj.gov/dep/hab/et-resources.html) (https://www.nj.gov/dep/hab/et-resources.html).

As a culmination of their research, literature review, and data analysis, this Harmful Algal Bloom Lake Management Guidance provides details to lake managers on how to develop a lake-specific action plan.

The Guidance includes HAB prevention, mitigation, and management for NJ waterbodies that considers short-term and long-term action plan components to characterize lake conditions and lake management actions as needed.

2.LAKE BACKGROUND

When developing a HAB management plan it is important to assemble information on the waterbody and surrounding watershed such as geographic location, watershed details, physical description, hydrography, biology, chemistry, HAB history and other pertinent information that provides insight into the behavior of the water in the waterbody under historical and current circumstances. This material provides some insight to locating inputs that could potentially bring nutrients and other pollutants into the waterbody. The following sections provide details on the suggested information that should be included. It is recommended that federal, state and county agencies, university researchers and others be contacted to determine what information is readily available and use that to build a list of items that are needed to create a complete picture.

Administrative Details

Information on the ownership of the waterbody and the governing body responsible for making management decisions related to water quality and designated uses. Contact information for key personnel responsible for oversight of the waterbody should be included. Be sure to include a comprehensive list of any state, county, municipal, commissions, associations, clubs, NGO's, consultants, and any others that may be working on the waterbody or have an interest in protecting and enhancing it.

Physical description

Provide details on the geographic location of the lake surrounding town(s) within the watershed, county and any other information that helps provide the setting. This description should include the physiographic province it is in such as the Ridge and Valley, Highlands, Piedmont, or Coastal Plain. Click here for a map of the Physiographic Provinces (https://www.nj.gov/dep/njgs/enviroed/infocirc/provinces.pdf) and GIS format here GIS Physiographic Data (https://www.nj.gov/dep/njgs/geodata/dgs02-7.htm#:~:text=New%20Jersey%20is%20divided%20into,and%20Coastal%20Plain%20Physiographic%20Provinces). In addition, include information on the drainage and origin of the waterbody (e.g., natural lake, stream impoundment, farm pond, drinking water reservoir)

Include information on the land use within the watershed, including amount of forested versus developed lands (urban, agriculture, etc..), as well as impervious surface. Land uses in the watershed are indicative of the source(s) of nutrient pollution and/or the ability of the watershed to absorb both surface runoff and nutrient pollution. Much of this information may be collected using NJ-GeoWeb (arcgis.com). https://njdep.maps.arcgis.com/apps/webappviewer/index.html?id=02251e521d97454aabadfd8cf168e44d

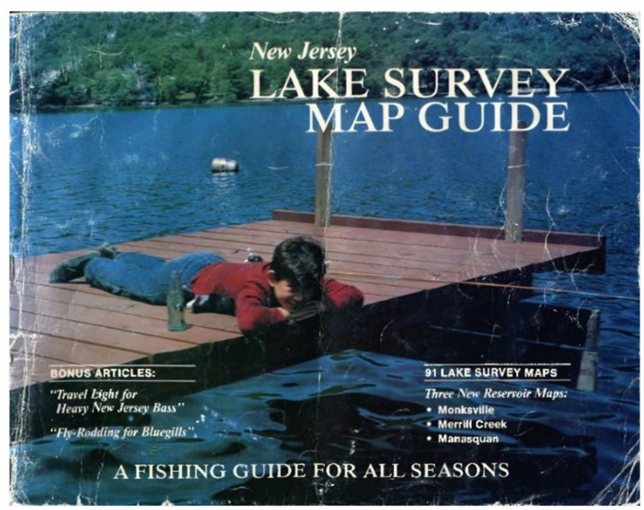
Morphology

Provide key details on the morphology of the waterbody such as length; width; shoreline perimeter; surface area; volume; height above sea level; lake orientation; mean and maximum depth; fetch (the typical distance wind travels over the lake); maximum fetch (the maximum possible distance wind can travel over the lake); and any other pertinent information. Mean depth should be reported as the depth at which half the lake volume occurs above, and half occurs below.

The following are particularly important characteristics to note as they can have a significant impact on mixing:

- Fetch and Maximum Fetch: Waterbodies with a small fetch are less susceptible to turbulence caused by wind and waves and are more likely to experience stratification (exhibit dimixis or polymixis in New Jersey).
- Maximum and Mean Depth: Shallower waterbodies tend to experience greater temperature and nutrient fluctuations due to frequent mixing (polymixis). Shallow waterbodies can generally be defined as those with a maximum depth of less than 20 feet (6m). The occurrence of mixing is influenced by the wind (strength, direction, and time), strength of the thermocline (the difference in density between layers; varies throughout the year in NJ), hydrology (water retention time, relative temperature of lotic inputs), and basin morphometry. There is no specific depth above or below which a lake would be subject to an increased frequency of cyanobacterial blooms.

It should be noted that lakes in the northeastern United States are often classified as dimictic stratifying in summer, inverse stratification in winter, and completely circulated in spring and fall. Lakes in New Jersey may also be polymictic, either mixing completely or partially more often, and this type of mixing may become more common due to climate change. A potential increase in the frequency of mixing is not just due to warming, but also a change in the frequency/severity of storms and ice phenology. Change to mixing dynamics can stimulate cyanobacteria, and lead to change in cyanobacterial growth patterns.



The New Jersey DEP Fish & Wildlife maintains survey maps of most New Jersey lakes and ponds. Maps are in PDF format and range from 30kb-250kb in size and vary in degree of detail. All show depth contours, and many have additional structure or other information. For further information or other waters not listed below contact the Lebanon Field Office at 908-236-2118 or via email at NJFWFish@dep.nj.gov

NJ Fish and Wildlife Lake Maps (https://dep.nj.gov/njfw/fishing/freshwater/lake-survey-maps/)

Hydrologic

Providing key hydrological details on the waterbody such as retention time, flushing rate, listing tributaries along with brief descriptions, describing various inflows/outflows from the waterbody, permitted discharges into the waterbody or its upstream tributaries, and other related information that provides a clear picture of the movement and management of the water. Include currently available climatic data such as seasonal precipitation, air temperature and wind speed and direction in the hydrologic description. In addition, it is important to note areas where sediment can accumulate or has the potential to. In addition, sediment type of the lakes (or lake-bottom sediments) should be noted in consideration of water-sediment exchanges concerning nutrients, organic matter, cyanobacteria, and benthos impacting the bottom layer of water column.

Include figures that depict lake location in state, vicinity to towns, major roads crossing lake, location of storm drains and other important natural and manmade features that could impact the movement of water into and out of the waterbody.

If available for the waterbody details on the Wind Rose -provides prevailing wind direction during a monthly or annual, data from May – November can provide a visual insight into where the likelihood of surface algal accumulating is greatest.

Designated Uses and Existing/Pending Protective Measures

Include a general description of the lake, lake watershed, water classification, designated uses, existing Total Maximum Daily Loads (TMDLs), and other pertinent regulatory information that applies to the waterbody. NJDEP| Bureau of Environmental Analysis, Restoration and Standards | TMDLs (https://dep.nj.gov/wms/bears/tmdls/).

Include information on designated uses such as surface water classification, water supply, recreation activities (boating, fishing, swimming, wildlife viewing. etc.), fish production, fish consumption, and aquatic life uses/designations.

A detailed description of how the homes and businesses on and surrounding the waterbody dispose of sewage is critical to determine whether disposal methods such as septic systems could be potentially contributing nutrients to the system. Are lake community homes and businesses connected to a central sewage collection and treatment system or individually owned and operated septic systems? Are wastewater treatment plants discharging upstream of the waterbody and contributing nutrients? Details may be found from the Water Quality Management Planning Program (WQMP): NJDEP | Water Quality Management Planning | Water Quality Management Planning Program (https://www.nj.gov/dep/wqmp/wqmps.html).

Chemical

Existing water quality monitoring data from the lake and upstream tributaries can be utilized to provide a broad overview of the chemical composition of the waterbody and used to identify trends that need to be addressed or considered when implementing management measures. It is recommended that data on minerals, nutrients (total nitrogen and total phosphorus, including speciated forms when available), silica/silicate, dissolved and particulate organic matter (C, N and P), pH, suspended solids, dissolved oxygen, alkalinity, and conductivity. It should be noted many cyanoHAB species have physiological features to utilize organic nitrogen and phosphorus which is advantageous in competing with other algae for nutrients especially during growth seasons. Contained in the *Identifying Existing Data Gaps* section is a comprehensive list of where available water quality data for New Jersey lake can be found. A summary of this data along with appropriate figures will provide a general characterization of the lake and overall conditions.

Biological

Current biological data can help provide a clear picture of the overall health of the waterbody. It is also important to include historical information to understand if conditions are improving or deteriorating and in combination with current data can help provide insight into the direction the ecosystem is heading. It is recommended that current information be provided on phytoplankton, particularly cyanobacteria, zooplankton, fin fish, shellfish, plants, epiphytic cyanobacteria, aquatic vegetation, and invasive species that inhabit the waterbody. If available, include detailed data on cyanobacteria such as species, cell counts and presence/absence of cyanotoxins. Information on chemical treatments (algicide, herbicide, phosphorus inhibitors) and weed harvesting are useful in assessing the natural vs treated biological condition of the water body. Including a description of relative scale of littoral (plant zone) versus pelagic (open water zone) as lakes can "switch" between productivity states- plant dominance vs. phytoplankton dominance. The NJ Bureau of Freshwater and Biological Monitoring (https://www.nj.gov/dep/wms/bfbm/)is good source for available biological information on NJ waterbodies.

3.PUBLIC PARTICIPATION AND OUTREACH

An important component of preventing Harmful Algal Blooms (HABs) is to educate the public about the ecological impact and health risk of HABs. This may include causes and effects that excess nutrients can have on HABs and provide information on how they can take an active role in helping reduce the occurrence of HABs. A well-informed public will be more likely to actively support and participate in the development and implementation of a HAB management plan. Through a well-planned outreach and communication campaign, it will be possible to identify key stakeholders that you can build relationships and establish partnerships with that will contribute to the overall success of the effort to reduce the occurrence and severity of HABs. In order to effectively address the issue of HABs, the HAB management plan should include a multi-tier outreach and communication component designed to:

- Educate the community surrounding the waterbody and user groups about the causes of HABs and potential environmental, health, and economic impacts they can cause, as well as actions the community can do to reduce HABs;
- Provide actions that individuals, homeowners, associations, businesses, government entities, and others can take to reduce nutrients; and
- Identify key stakeholders that will help develop and implement the HAB management plan.

Through a concerted effort to develop and disseminate information and educational materials the public will become aware of the potential adverse impacts of excess nutrients, HABs and learn to minimize problems through the implementation of Best Management Practices (BMPs). As a result, the community surrounding the waterbody and those with an interest in it will become active participants in contributing to improvements in water quality and enhanced recreational opportunities by reducing the occurrence of HABs and the potential adverse impacts that are often associated with them.

Education and Information

Ultimately, emphasis must be placed on providing education and information materials to all the stakeholders of the entire waterbody community about the importance of reducing HABs. Education efforts should be directed toward homeowners, lake associations, businesses, local and regional sewage authorities, governmental agencies, and organizations located in the community surrounding the waterbody. Reaching visitors that utilize the waterbody for recreation purposes should be included in your audience as well. Educational materials and methods to be employed should be designed and developed in a manner that makes them applicable and useful for educational efforts with each of these audiences throughout the surrounding area. Wherever possible and appropriate new, and innovative ways of educating the target audiences should be utilized.

Outreach Example

Educational materials that can be developed and distributed should include an appropriate mix of hard copy and electronic format materials. Many outreach materials are available for download and use from DEP's website: [NJDEP | HAB | Outreach Material](https://www.nj.gov/dep/hab/outreach-material.html) (https://www.nj.gov/dep/hab/outreach-material.html)The use of social media campaigns, direct email campaigns, videos and other electronic forms of communication can help to reach a larger audience and reduce printing/dissemination costs associated with traditional brochures and fact sheets. Consider partnering with municipalities to provide education messages in billing inserts and other communication materials they distribute to residents of the town. Informative posters and interpretive signage can be utilized to reach visitors to the waterbody. Educational materials can also include presentations at meetings, shows, educational courses and other special events. Consider including the use of infographics as they can be eye catching powerful tools that can be used to convey an often-complicated issue.

Dissemination of educational materials can be accomplished through a variety of methods including social media posts, direct mailings, workshops, meetings, participation at environmental and outdoor expos, educational videos, and radio and television public service announcements. Participation in school programs, stream/lake clean ups, and engaging volunteer monitoring groups is a great opportunity to engage individuals and organizations that already have a vested interest in the waterbody.

Education and information messaging on HABs should raise public awareness, educate on BMPs, and encourage participation in the implementation of actions to restore and improve water quality. It is important for messaging to provide definition of key terms used when discussing HABs and nutrients and relevant project specific parameters.

The key to this is to ensure the public understands the issues and causes related to HABs. It is important to define vital components of HAB development and local conditions pertaining to the waterbody. Consider including key definitions such as harmful algal blooms, cyanobacteria and algae (phytoplankton), water quality, nutrients, stormwater runoff, and other influences of HABs.

Although the development of HABs is often the result of numerous factors acting together, providing factors specific to the waterbody in question will help relate the problem at a local level and provide an understanding as to why a specific action must be taken/implemented. The solutions often include changes in behavior and the adoption of management practices, many voluntary by those residing and doing business in the area surrounding the lake. It is important for them to understand the project area and link causes and effects of their actions on HABs to ensure the success of the HAB management plan, and most importantly encourage changes in behavior that will help to achieve overall HAB management goals.

It is important to provide information on actions that can be implemented at the individual, business, and government level and how they can become involved in the development/implementation of the HAB management plan.

Educational Messages

Target Audiences

Ultimately, to be effective outreach and communication efforts must be directed toward the community surrounding the waterbody and within the watershed. Level of effort should reflect the location of targeted audience with the greatest effort being focused on those individuals and groups located within the watershed. However, thought should be given to the audience that may reside outside of the watershed as many will have a personal stake in the quality of New Jersey's waters. The need to inform, educate, and involve all these groups is critical to successfully reducing HABs. The following are categories that can help group your audience, and focus education and communication efforts:

- Local Level: homeowners, lake associations, municipal officials including department of public works, chamber of commerce, local business owners, park operators, anglers, boaters and outdoor enthusiasts;
- County/Regional Level: regional sewage authorities; governmental agencies and organizations; and
- Statewide Level: anglers, boaters and outdoor recreation enthusiasts, general public; non local entities

Public Engagement and Building Partnerships

Prior to engaging the public on the development of the HAB management plan it is important to determine what is needed and the role they will play in the various tasks that must be completed. It is not possible or productive for the public to be involved in every decision that will need to be made. This should be clearly stated and provided to the public at the onset of the engagement process. Key items to define before engaging the public include:

- Existing protection measures in place for the waterbody and any ongoing management measures currently to address HABs.
- Information needed such as water quality data, HAB history, condition of waterbody, recreational use, etc.
- Skills needed such as data analysis, public education, facilitation, technical expertise, etc.
- Funding needs.

It is important for the developer of the HAB management plan to establish contact and build relationships with key stakeholders. These relationships will be key to forming partnerships and successfully implementing the plan. Using the list of stakeholders identified for the education effort, identify the key stakeholders that reside or work within the area surrounding the lake. Develop a list of stakeholders that you will invite to participate in the development of the plan and attempt to match them with the skills you will need.

Some broad categories that stakeholders can be broken into include decision makers; land, business owners and others that could be impacted; individuals and organizations that can provide assistance; researchers, consultants and others that are knowledgeable about the lake and can provide technical assistance; and government and private entities that can provide funding assistance.

Have stakeholders identify problems, issues of concerns, provide input on current conditions from a historical perspective and provide details on ongoing and planned actions. Do they see conditions improving or worsening? This information will help shape overall goals for managing HABs and determine what is needed to reach those goals. It is important to incorporate ongoing and planned actions into the plan. Provide input on long term goals they would like to see such as reduced swimming beach closures resulting from HAB events, increases in fish populations, reduced plant growth, etc. Goals can result in both economic and environmental benefits.

Overall, the planning process should be simple and transparent to keep the public engaged and move the development of the plan forward quickly and efficiently. In addition, inform the public of successes, failures, and the opportunity to provide input in revisions to plan. The following sites provide additional information and resources on how to include and plan for public participation in the HAB management plan process.

NJDEP | HAB | Outreach Material (https://www.nj.gov/dep/hab/outreach-material.html)

NJDEP Watershed Based Plans (https://www.nj.gov/dep/wms/bears/wbplans.htm)

USEPA Public Participation Guide (https://www.epa.gov/international-cooperation/public-participation-guide-process-planning)

USEPA Handbook for Developing Watershed Plans (https://www.epa.gov/sites/default/files/2015-10/documents/2008_04_18_nps_watershed_handbook_ch03.pdf)

Water Quality Planning
The NJDEPs Water Quality Management Planning program originates from the Federal Water Pollution Control Act, commonly referred to as the Clean Water Act (33 U.S.C 1251 et seq.). Sections 201, 208 and 303 of the Clean Water Act provided a framework for water quality planning in the State. One of the tools the NJDEP utilizes to assure that both current decision making, and future planning adequately take into account protection of water quality and quantity is the Water Quality Management Planning rule, N.J.A.C. 7:15.
Water Quality Management Plans (WQMPs) may address issues that can prevent HABs. Therefore, it is important that the HAB management plan include pathways to educate the developers of the WQMP on current HAB issues and provide input on protective measures to prevent HABs. In addition, any measures addressing HABs in the WQMP should be considered while developing a HAB management plan.

[NJDEP | Water Quality Management Planning | Water Quality Management Planning Program (https://www.nj.gov/dep/wqmp/wqmps.html)](https://www.nj.gov/dep/wqmp/wqmps.html)

4. WATER QUALITY MONITORING AND LAKE CONDITIONS

In response to the increase in HABs, the NJDEP has worked with the Harmful Algal Bloom (HAB) Expert Team to develop the following water quality monitoring recommendations as guidance for lake managers, environmental consultants, lake organizations, municipal officials, non-profit organizations, and other similar groups working to identify, monitor and manage HABs in New Jersey. The guidance contained in this document is the result of various analyses the HAB Expert Team conducted on the NJDEP HAB water quality dataset collected from 2017-2019.

The information has been carefully selected to provide a basic understanding of water quality, developing a water quality monitoring plan for HABs along with useful technical information to help non-experts understand their options for HABs related to identifying conditions that can lead to the development, identifying species, toxin production and extent to which it exists within the waterbody.

It should be noted that the guidance for water quality monitoring in this document is in addition to response monitoring necessary, per the NJDEP Cyanobacterial Harmful Algal Bloom (HAB) Freshwater Recreational Response Strategy (Response Strategy) to protect immediate public health.

Water Quality Monitoring for HABs

Water Quality

Water quality is a description of the condition of the water at a given location or a waterbody at a certain point in time or over longer periods of time such as months and years to identify and track trends. The condition of the water is based on observations and analysis of physical, chemical, and biological parameters. Based on the condition of the water it is designated as supporting recreational activities such as swimming, fishing and boating, shellfish harvesting, trout production, drinking water and other similar use designations. Degraded water quality that persists over longer periods of time can result in the development of public health and ecosystem concerns that when not addressed can result in economic impacts to the local and regional areas. Certain conditions such as increases in nutrients, temperature and changing weather patterns can lead to the proliferation of HABs.

HAB Water Quality Monitoring

Water quality monitoring is an effective tool to track the development of HABs, including contributing factors such as nutrients, changing climate conditions, measuring the success/failure of management measures, providing direction for changes that need to be made to the HAB management plan and regulatory purposes. This differs from Diagnostic Monitoring being conducted by an expert in the field to track water quality conditions through time (physical, chemical, biological) to determine trophic conditions, identify causes of water quality problems, and forcing factors for blooms.

Recommended Monitoring Parameters

It is recommended that monitoring be conducted weekly from March through late-October. If weekly is not possible, it is recommended that sampling be conducted twice per month for lakes that have a history of cyanobacteria blooms and once per month for lakes where the goal is long term tracking. Monitoring conducted over longer periods of time will capture conditions prior to, during and after HAB events and analysis of this data will reveal the conditions that lead to the development of the HAB.

It is recommended that the following physical, chemical and biological parameters are monitored to track the overall condition of the waterbody and health of the ecosystem. It is recommended that samples be collected weekly from March to late October. The section on Sample Frequency provides detailed information on the recommended frequency.

Physical Parameters

Physical parameters that are recommended to measure include water temperature, water clarity, precipitation, and lake levels.

- Water temperature readings can be collected at the surface and vertically. Vertical readings are recommended whenever possible, to determine the presence/absence of thermal (density) layers.
- Water Clarity/Transparency (Suspended Solids/Turbidity) – Measuring transparency with a Secchi disc is a cost-effective method that can be easily incorporated into monitoring plans. It provides a measurement of the depth that available sunlight can penetrate. The depth at which light can penetrate is impacted by algae, sediment, and the color of the water. A reduction in transparency can be an indicator that excess algae growth is occurring due to an overload of nutrients in the system and/or an increase of sediment inflows from the surrounding watershed. Secchi depth is also the basis for calculating some trophic state indices that allow comparisons of lakes with each other.
- Precipitation - The amount of rainfall input in the watershed measured on a daily, weekly, monthly, and annual basis. Sources, such as runoff and streams, should be considered as well and can provide essential information on the type and quantity of freshwater flowing into the waterbody. Rain events followed by periods of relatively dry weather have the potential to suddenly increase the nutrient supply to a lake and increase the likelihood of a HAB occurring. Therefore, it is recommended to collect rainfall data (or utilize existing rainfall data) as part of a HAB monitoring plan. A resource for rainfall can be found at https://njdep.rutgers.edu/rainfall/ and provides near real-time rainfall for locations across the state.
- Lake levels – Documenting the lake level is important as it provides a picture of where the level is at a given point in time relative to the mean lake level. Low levels have the potential to expose sediments and increase erosion, elevate temperatures, and impact recreation activities.

Chemical Parameters
Chemical characteristics that are recommended to be measured include pH, dissolved oxygen, nutrients, and specific conductivity.

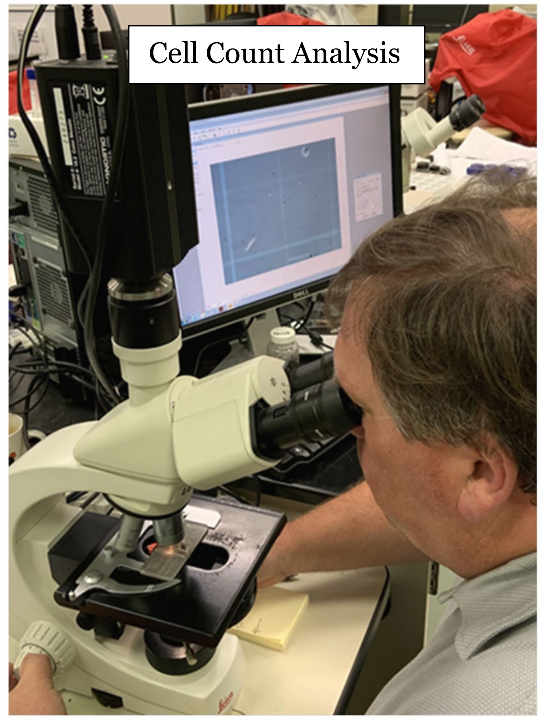
- Increased pH in a waterbody can lead to release of excess nutrients from the sediment. Rises in pH can be a leading indicator for the likelihood of a bloom to occur and can be used to trigger additional monitoring.
- Dissolved oxygen provides details on the ability of the waterbody to support fish and other aquatic organisms that need oxygen to survive. DO swings (extreme highs and lows) are indicative of algae production. Low dissolved oxygen levels can occur when HABs and other algae blooms respire and/ or begin to die off and can cause problems for the organisms dependent on oxygen for life.
- Nutrients are essential for plant and animal life but at excessive levels can contribute to the development of HABs and create other problems in the ecosystem. Recommended nutrients to monitor include Total Phosphorus, Total Nitrogen, Fe (important when conditions are anoxic), inorganic N (nitrate and ammonium) and inorganic P (phosphate) (others?).
- Specific Conductivity is a measure of the water's ability to conduct an electrical current. Waterbodies with elevated levels of dissolved materials will have high specific conductivity levels.

It should be noted that anoxia doesn't cause increased internal nutrient loading, subsequent anaerobic respiration does. When sampled waters are devoid of dissolved oxygen it is critical to measure anaerobic respiration products (esp. Fe, Mn, and hydrogen sulfide in some lakes) as well as Ammonia-N (due to the lack of nitrification).

Biological Parameters
Biological characteristics that are recommended to measure include cyanobacteria and the cyanotoxins which they can produce; phycocyanin a pigment indicative of cyanobacteria, and overall algae production through the measurement of chlorophyll *a*. In addition, an examination of the whole phytoplankton community should be considered.

- Cyanobacteria can produce toxins that are dangerous for humans, pets, livestock and wildlife. The toxins produced by the cyanobacteria are referred to as cyanotoxins and can be produced by a wide variety of cyanobacteria. (NJDEP)
    - Cyanobacteria should be measured through cell counts, preferably with community breakdown, i.e. Natural Units when possible.
    - Phycocyanin is a measure of the pigment found in cyanobacteria and can be used as an indicator for the level of HABs in freshwater. This can be measured through extraction and 'wet chemistry' in the lab or estimated by the use of handheld phycocyanin fluorometers in the field. NJ state criteria for HAB determination is based on total cyanobacterial cell counts, and it is important that each lake establish its own relationship between phycocyanin fluorescence measurements and cell counts.
    - Measure cyanotoxin levels to determine if the bloom is producing toxins and at what level they are at through a quantifiable measurement. Determining presence/absence is not recommended.
- Chlorophyll *a* is the photosynthetic pigment found in algae and cyanobacteria and can be used to estimate the amount of algae in the waterbody. High levels of chlorophyll *a* can be associated with high levels of phosphorus and nitrogen.

Cell counts tend to be conducted at the genus level, but it should be noted that toxin production is determined at the species and strain level. When budget and capability can accommodate it, species level community composition data and toxin producing gene data is preferred to recognize potential toxin producers versus total cyanobacteria density.



Cell Count Analysis

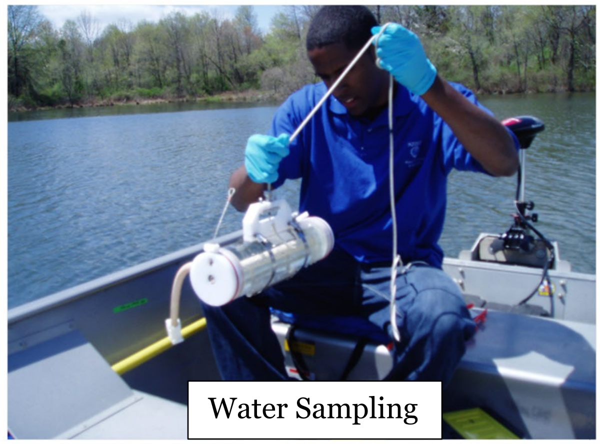
Monitoring programs should also consider alternative ways to quantify cyanobacteria, in addition to “cell count”. The consensus opinion is that the cell count metric, while useful for thresholding management decisions such as beach closures, is not accurate enough for use in constructing predictive models of cyanobacterial density and/or bloom dynamics (growth, areal cover, etc.). Analysis that provides an improved measure of density, as well as measures of biomass and community composition, would be beneficial when the budget allows for it.

Sampling Type, Frequency and Location

The sample types, frequency, and the location where samples are collected are important factors to consider when developing your HAB monitoring plan. Multiple approaches might be needed to meet both regulatory sampling requirements and the goals of your HAB management plan. Below are brief descriptions of sample types, frequency, and locations you will want to consider when developing your HAB Monitoring Plan.

Sample Type

Grab sample – single sample of water collected from a waterbody that can be used to conduct water chemistry analysis or cyanobacteria counts. Useful for characterizing a specific location and grab samples collected at multiple locations and depths can be used to characterize a larger area or an entire waterbody.


Water Sampling

Composite (Integrated) sample – sample comprised of multiple grab samples taken over a set time period, area, or various depths.

Surface water samples are useful for monitoring the development, intensity, and movement of HABs and providing information to assess the health risk from cyanotoxins and establishing advisories. However, while surface water data may give a good indication of overall waterbody conditions, it may miss important causal processes.

When capability and budget allow for it, it is recommended that vertical series sampling be included in the water quality monitoring plan. Vertical series data provides information on the waterbody's susceptibility to a surface water HAB and facilitates the early detection of conditions likely to result in the development of a HAB. For example, several species of cyanobacteria have gas vacuoles that allow them to move through the water column. This movement allows them to access nutrients in deeper water and move to the surface to out compete other algal groups for sunlight at the surface. Vertical sampling can help provide a clearer picture of the condition of the waterbody than a surface sample alone can provide.

Sample Frequency
Short term- range from day to week and provide useful information for a specific point in time.

Long term – can be weekly, biweekly or monthly and are collected over longer periods of time such as a season, annually or even longer depending on the goals and budget. Useful for determining changes from an established baseline and the data can be analyzed to determine trends.

Time of Day- It is recommended that whenever possible, samples be collected outside the typical 10 am - 2pm sampling window to fully understand how a system is functioning in terms of cyanobacteria populations. The use of volunteer monitors can greatly assist with the move away from typical sampling periods and are also useful in reactive sampling such as during a bloom, weather events and other similar instances where spontaneous sampling is needed.

It is recommended that samples be collected weekly from March through late-October. Sampling started earlier in the season is helpful to determine conditions prior to the growing season and to see if there are species that persisted over the winter and at what levels they are at. If weekly is not possible, it is recommended that sampling be conducted twice per month for lakes that have a history of cyanobacteria blooms and once per month for lakes where the goal is long term tracking. This time period encompasses both the primary period during which a significant HAB is likely to manifest and when recreational use (and risk to HAB exposure) is greatest. It also encompasses the period of time during which New Jersey lakes are likely to both thermally stratify and destratify.

Locations
Consider the use, size, shape and input/outflow locations and locate sampling stations accordingly. A waterbody that is used for drinking water or swimming will require samples to be collected near intakes, bathing beaches, public access locations, etc. It is recommended that spatial sampling be utilized to locate stations that will capture variations in nutrient levels and cell counts that can occur vertically and longitudinally within the lake. Spatial sampling will provide data that is critical to evaluate the entire waterbody and guide the development and implementation of management measures.

Type of Analyses

Field measurements using meters and other methods can be used to obtain an instantaneous or relatively quick measurement in the field or back in the lab. More detailed measurements not obtainable with a meter require collection, proper storage and transportation of samples to a laboratory for analysis.

The type of data needed, or results required should be used to determine if a field measurement or laboratory results are required. Qualitative results provide information that can be helpful to make a decision such as determining if a HAB is present or not present but will not provide numerical results that can be used for regulatory purposes or provide specific levels of chemical, biological and physical properties. Quantitative results provide a numerical result based on analytical standards. Other factors to consider are turn-around time for results, cost associated with sample collection, preparation, storage and analysis, and results needed to determine regulatory actions.

Evaluating Cyanobacteria Presence and Density

Field Measurements

The following list of field measurements is intended to provide basic information to determine which type of field measurement will meet your monitoring needs.

Visual Identification - Provides qualitative, instantaneous results with minimal training that can be used to rapidly assess the presence of a HAB by visually observing the waterbody. Can be a useful first step to determine if there is a HAB and can be used to trigger additional measurements or actions. The costs for these tests are minimal and they can easily be repeated at numerous sites.

A cyanobacterial HAB often looks like a layer of bright bluish-green or white paint on the water surface. Other evidence of a potential cyanobacterial HAB could be discolored or pea-green colored water, parallel streaks, or green dots/globs in the water. It is important to note that some blooms are due to common green algae and not cyanobacteria. Additionally, even when present, cyanobacteria do not always produce cyanotoxin (NJDEP) NJDEP HAB Fact Sheet (https://www.nj.gov/dep/hab/download/HABsFactSheet2020.pdf)

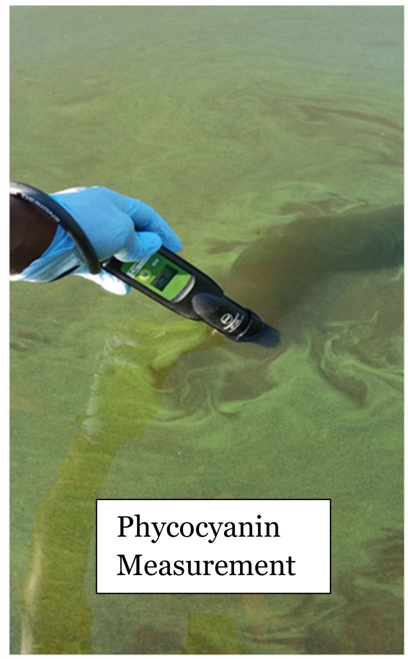
The visual assessment can be further verified by utilizing the stick and jar method while in the field.

Photos of what is and what is not a HAB can be found here: NJDEP | HAB | Photos (https://www.nj.gov/dep/hab/photo.html)

Stick Method - Can easily be conducted by dipping a stick in water where the suspected HAB is forming. A HAB will coat the stick while filamentous algae will lift out in long strands.

Jar Method - A sample of water from the area where the suspected HAB is forming and placed in a clear jar and allowed to rest for 15-30 minutes. Many species of cyanobacteria use gas vacuoles to regulate buoyancy that allows them to form dense blooms at the surface. HABs will typically float to the surface while sediment and other suspended solids will settle to the bottom. It should be noted that this method is not useful for cyanobacteria that do not create surface scums.

Pigments (Chlorophyll a and Phycocyanin) – real time using fluorometric sensors and field measurements. The presence of phycocyanin pigment (unique to cyanobacteria) and density can be determined using a handheld field fluorometer (phycocyanin meter). Fluorometers can provide real time measurements of chlorophyll or phycocyanin and some meters have the capability to do both. It is recommended that periodically samples be collected and sent to a laboratory for analysis to confirm the presence and density of cyanobacteria detected with the meter.


Phycocyanin Measurement

A field phycocyanin meter loan program was implemented by NJDEP in 2020 for partners to screen and monitor HABs at their waterbodies. For more information go to [NJDEP | HAB | Home (https://www.nj.gov/dep/hab/)](https://www.nj.gov/dep/hab/)

Remote sensing with satellites and aircraft to track surface blooms and detect changes in a waterbody over time is an emerging technology. The technology holds great promise and as accuracy increases, interpreting data becomes automated, and cost is lowered it has the potential to be widely used for waterbodies and monitoring budgets of all sizes. NJDEP provides data using some of this new technology which is publicly available.

The NJ Forest Fire Service performs flight (figure 1) surveillance at several larger Northern NJ lakes of concern. Visual observations are recorded as well as remote sensing of phycocyanin pigment. NJDEP developed a customized algorithm that can reliably detect and estimate phycocyanin concentrations in freshwaters through wavelength reflectance signatures. These measurements are not used as a replacement for confirmation analysis, but as a screening and status monitoring tool to detect relative increases and decreases in phycocyanin pigment concentrations. When levels change significantly i.e., indicate a change in alert status, sampling staff are deployed for confirmation laboratory analysis. Data is available to the public at: https://njdep.rutgers.edu/aircraft_phyco/

Figure 1. Flight Surveillance.

Flight Surveillance. are performed once per week during the recreational season at the following lakes (weather permitting). Lake Hopatcong, Greenwood Lake, Musconetcong Lake, Budd Lake, Spruce Run Reservoir, Lake Mohawk, Swartswood Lake, and Round Valley Reservoir (non-HAB control lake). Other lakes are added as needed. Figure 2 shows examples of the flight data.

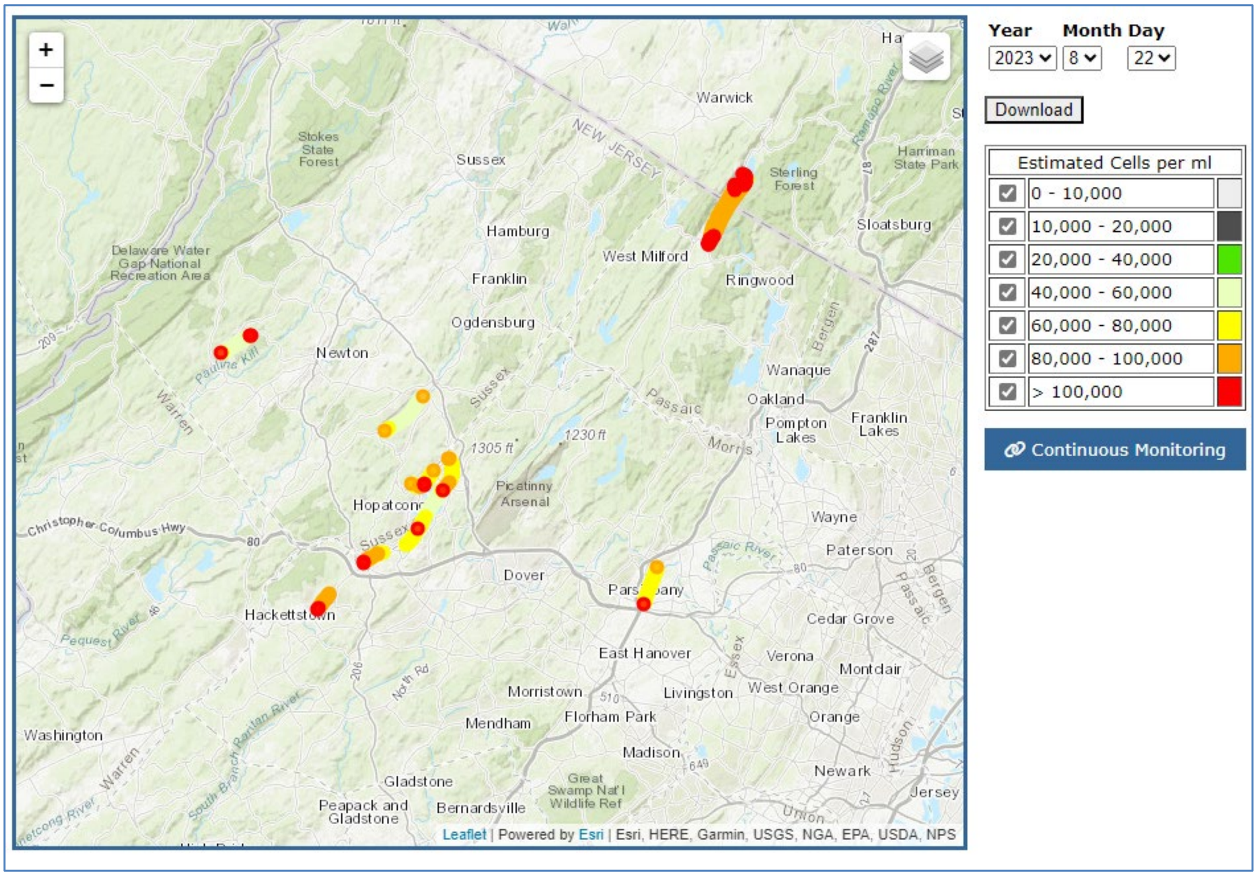
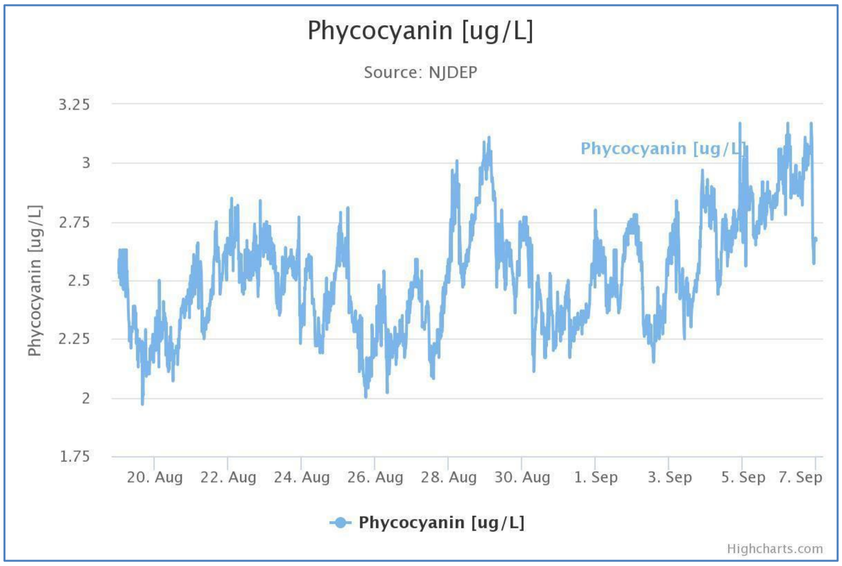


Figure 2. Flight data from northwest New Jersey.

NJDEP deploys buoys equipped with continuous monitoring meters and real-time telemetry technology (Figure 3). Buoys are deployed at select waterbodies. The sites are chosen due to recreational and/or drinking water significance, repeated HAB occurrence, duration, and previous elevated levels of HABs at these waterbodies. The waterbodies have one or more remote monitoring devices to provide best feasible coverage for HAB status monitoring & response. Other continuous monitoring meters are available that collect one or more parameters that may be useful in collecting data over periods of time and multiple depths.

Figure 3. Telemetry Buoys currently in use by NJDEP.

These meters also measure other water quality parameters such as temperature, dissolved oxygen, and pH. As with phycocyanin measurements previously mentioned, this data is used for screening and status monitoring. Water quality data may be used to assess factors that may contribute to or characterize HAB production. Data can be downloaded or viewed in real time at https://njdep.rutgers.edu/continuous/. Figure 4 shows an example of a downloadable graph with phycocyanin measurements at Greenwood Lake.



Cells per ml	Meter
20000	1.15
40000	1.87
80000	3.29
100000	4.00

Figure 4. Buoy data example.

Laboratory Measurements

Having samples analyzed at a laboratory is necessary when seeking quantitative data and a certified laboratory is required to comply with issuing NJDEP Health Advisory Guidance Levels. Water samples can be analyzed using various methods for chlorophyll a, nutrients, cyanobacteria cell counts and species level identification, and to determine cyanotoxin presence and concentration. Analysis of water samples at a laboratory can be expensive and the turnaround time for results can range from a day to several days. It is recommended to check with the laboratory and follow their procedures for collection, preservation, storage and transport. It is recommended that the limit of detection for nutrient analysis of Total Phosphorus and Total Nitrogen limit be 10 micrograms/liter and should not be reported in 10 microgram increments.

Microscopy is recommended to identify cyanobacteria species and quantify abundance. Identification down to the genus and species level is recommended. Citizen science groups can be utilized to conduct this work with the proper training and equipment to keep costs down. Use of a microscope to count cells is helpful to document the extent of a bloom within a waterbody, but it cannot be used to determine the production of cyanotoxins. Other methods discussed in the next section should be used to analyze water samples for cyanotoxins. Montclair University's New Jersey Center for Water Sciences and Technology produces the Freshwater Cyanobacteria of New Jersey (https://sites.google.com/view/njcyanovisualguide/home) and the Interstate Technology Regulatory Council produces A Visual Guide to Common Harmful Cyanobacterial Blooms (https://hcb-1.itrcweb.org/appendix-a/)that can be used to train citizen science groups.

Biomolecular (metabarcoding, amplicon, metagenomics, eDNA) water sample analysis methods are developing at a rapid pace and show promise for various applications in the future. While these methods may not be ready to replace traditional methodologies like cell counting or toxin measurements, genomic techniques can be paired with traditional techniques to great advantage. It is recommended that monitoring programs be designed with some flexibility to allow for integration of genomic methods. As they continue to develop, they will become more accessible and cost effective.

Evaluating Cyanotoxin Presence and Concentration

HABs have the potential to produce toxins, but do not always do so. The most commonly observed cyanotoxins include microcystins, cylindrospermopsin, anatoxin-a and saxitoxin. Investigating the triggers for toxin production is an area that is currently being investigated by researchers in New Jersey and as new information becomes available it is important to build flexibility into your sample analysis plan to accommodate new methods.

Measuring cyanotoxin levels is a critical component of a monitoring program and necessary to implement NJDEP Health Advisory Guidance Levels.

Cyanotoxin Analysis

New Jersey data show that microcystins are the most common cyanotoxin found during a bloom and can routinely be produced at levels above recreational health risk. Because other toxins are rarely detected in NJ, and have not been found above threshold levels unless very high cell counts are present, It is recommended microcystins are analyzed at all times while cylindrospermopsin, anatoxin-a, and saxitoxin should be analyzed under certain criteria:

- Suspected HAB is at a Drinking Water source
- People or animal illness was reported, and/ or
- High levels of cell concentration is measured (approx. >150Kcells/ml)If the presence of microcystins is detected it is recommended that the current NJDEP confirmation laboratory analysis methods be followed, and alert levels be implemented as required.

NJDEP uses, the Enzyme-Linked Immunosorbent Assay (ELISA) method for cyanotoxin analysis of microcystins, anatoxin-a, and cylindrospermopsin. Reporting levels for each toxin are adequate to accurately detect and quantify toxins below NJ Health Guidance.

At this time EPA *Standardized Analytical Method for Determining Total Microcystins by the use of the ELISA Method* (EPA 546) is the only EPA approved ELISA method for toxin analysis.

HAB Monitoring
HABs are complex and have the potential to negatively impact the ecosystem and coastal economy of lakes and other waterbodies used for recreation and drinking water. Establishing an appropriate monitoring program for a waterbody is necessary to determine how nutrient levels and cyanobacteria populations vary seasonally and annually. There are many tools and technologies currently available for monitoring HABs, and factors such as cost, maintenance of equipment, and monitoring location and timing must be considered to ensure the data collected will provide regulatory compliance and the information necessary to understand the current water quality conditions and how they vary seasonally. Carefully collected data will be useful to help identify an algal bloom versus a HAB, forecast when conditions are likely for a HAB event to occur, identify triggers for regulatory action, and identify areas where implementing best management practices will be effective at reducing nutrients and occurrence of blooms.
Reactive monitoring during a HAB event provides useful information about the current conditions. This type of monitoring is necessary for decisions to determine what, if any, protective actions are needed to protect immediate public health. It is also useful for determining conditions after a significant meteorological event such as heavy rain, wind and excessive heat. The NJDEP Division of Water Monitoring, Standards, and Pesticide Control has established HAB response strategies for freshwater. Therefore, monitoring plans should include strategies to meet these requirements. The current response strategy is available at the following website and should be consulted to determine your responsibilities: NJDEP HAB Recreational Response Strategy (https://www.nj.gov/dep/wms/bfbm/response_strategy.html).

Proactive monitoring is routine measuring and can be a single sample or sampling that is repeated over periods of time such as daily, weekly, monthly. Time periods of a day to week can answer short term questions while samples collected at regular intervals over longer time periods such as annually or seasonally can answer long term questions about the water quality condition and presence or absence of HABs. While proactive monitoring costs may initially seem expensive it is important to keep in mind the economic and social costs associated with closures and degradation of the waterbody.

Algal blooms can cause harmful effects mainly due to excessive biomass accumulation and/or toxin production. These harmful effects are economic, environmental, and ecological in nature and include deleterious impacts on the health of humans and other species. Most algal blooms do not generate dangerous toxins, but some do. The species composition and development (change in cell density) of the bloom needs to be considered in the context of the specific waterbody, especially when it comes to selecting mitigation and management strategies. In freshwater environments, cyanobacteria are typically responsible for toxin production. However, toxin-production is species and strain specific and depends on favorable environmental conditions. Cyanobacterial blooms are typically composed of toxic- and non-toxic strains of the same species. It is vital to discern if an algal bloom is composed primarily of cyanobacteria (making it a cyanoHAB) and to determine, if possible, if any pre-existing conditions within the waterbody favor the development of cyanobacterial toxins. Therefore, it is recommended that species level analysis be conducted when the budget permits.

The development and implementation of a water quality monitoring plan for HABs is critical to define the HAB for a waterbody, measure nutrient inputs, selecting managements measures that will be effective at reducing HABs, conducting outreach, predicting blooms, and evaluating the success or failure of restoration, mitigation, management measures.

Developing a Water Quality Monitoring Plan for Managing HABs
A water quality monitoring plan should be developed that focuses on three key points which include meeting regulatory requirements, identifying the causes leading to the development of a HAB and providing guidance needed to identify solutions that will help meet the established long-term goals of the plan. It is important to establish goals that are achievable. Prior to developing a water quality monitoring plan, it is important to document both observable problems and any issues that have been documented by previous monitoring efforts. Observable conditions, both good and bad, should be recorded for the waterbody such as surface algal blooms, aquatic plant growth for both nuisance and invasive species, poor drinking water quality, fisheries issues, and sedimentation. It is important to note where possible land uses are in the watershed that could be potential sources of nutrients, thermal inputs and sediment.

Establish Objectives – Tracking HAB development for regulatory action or investigative purposes such as identifying trends/problems to guide decisions and management measures.

Are conditions improving or worsening? Are there times during the year when conditions are better or worse? How does it compare to other similar lakes in the region? Is it the result of other problems such as sedimentation, stormwater inputs, etc. or is it causing the problems? Through a review of observable conditions and documented HAB occurrences you will be able identify the end goals and design the monitoring plan to meet them.

It is important to determine a clear objective, identify data users, the information that will be collected, the quality of the data, and how it will be used. Plan for the use of the data, how it will be analyzed, who will be reviewing the results, will it provide the information to make decisions on determining the most effective management measures and modifying them as needed.

Determine how monitoring will take place before, during and after blooms, and establish protocols based on these determinations. Determining the cost of the monitoring that is planned is critical along with how long you will be able implement the plan with current funding and at what point additional funds will be needed. Resources needed such as people, equipment, laboratory services, etc. Also, plan for continued monitoring to be able to track progress of implemented management measures to determine effectiveness and make necessary changes.

Develop sampling plans that include details on items such as location, frequency, equipment, methodology.

Assess Existing Water Quality Data and Collect New Data
Determine what monitoring may already be taking place, find out what data exists and design your monitoring plan to complement existing data and reduce redundancies. When available, the results from previous monitoring efforts should be reviewed for occurrence of HABs and any regulatory actions that had to be taken to protect public health, address excessive nutrient levels, thermal inputs, sedimentation, etc.

NJDEP HAB Dashboard - NJDEP Harmful Algal Bloom (HAB) Dashboard (arcgis.com) (https://njdep.maps.arcgis.com/apps/dashboards/49190166531d4e5a811c9a91e4a41677)

NJDEP Water Quality Data Acquisition - https://www.nj.gov/dep/wms/data_acquisition.html

TMDL Look Up Tool - https://www.nj.gov/dep/dwq/msrp-tmdl-rh.htm

USGS Water Resources Real Time Data https://waterdata.usgs.gov/nj/nwis/rt

Quality Assurance Project Plan

A critical and necessary component of a HAB Monitoring Plan is a Quality Assurance Project Plan (QAPP) that is developed to ensure the data collected as part of a monitoring effort is useful and defensible. A QAPP is a key tool to address potential uncertainties that may affect the quality of data, such as how staff and volunteers are trained; how samples are collected, handled and stored; or how data are analyzed, and reports written. A QAPP is a document which outlines all procedures that will be followed by those conducting a monitoring project to ensure that the data they collect and analyze meet project requirements. It also serves as a record of methods, goals, and procedures that current and future volunteers will follow and that potential users of the data can consider. NJDEP has a policy that all environmental data collection activities be conducted under a QAPP approved by the NJDEP Office of Quality Assurance (OQA). The OQA has developed a template to facilitate the development of the QAPP. In addition, the United States Environmental Protection Agency (EPA) provides guidance to organizers involved in developing QAPPs that address the specifications listed in EPA Requirements for QA Project Plans (QA/R-5). Links to both documents can be found below.

NJDEP QAPP Guidance (https://dep.nj.gov/dsr/oqa/quality-assurance-program/)

EPA QAPP Guidance: (https://www.epa.gov/quality/guidance-quality-assurance-project-plans-epa-qag-5)

Other Resources

Montclair Phytoplankton Lab (https://www.montclair.edu/water-science/phytoplankton-lab/)

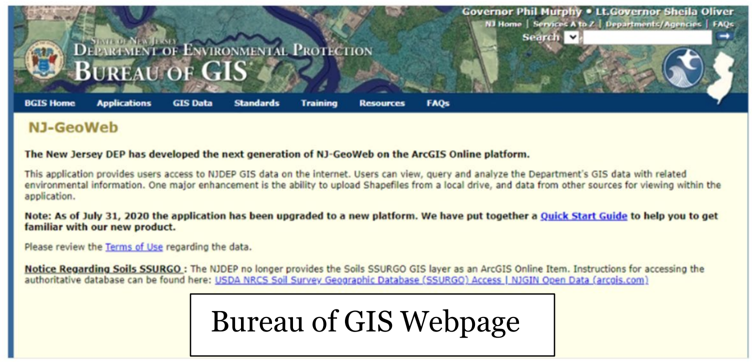
US EPA HAB Information (https://www.epa.gov/habs)

USGS Why study Lakes? (https://pubs.usgs.gov/fs/fs06303/#heading174165920)

ITRC HAB Monitoring (https://hcb-1.itrcweb.org/monitoring/)

5. IDENTIFYING EXISTING DATA AND DATA GAPS

The development of a HAB Management Plan will require data on the physical, morphological, hydrological, chemical, and biological characteristics of the waterbody. Conducting an assessment to locate existing data on the waterbody and surrounding watershed along with any ongoing water monitoring efforts is a crucial step in the development of a HAB Management Plan and has the potential to provide significant cost savings that can be redirected to complete other tasks. Locating data that is sufficient to characterize the waterbody and identify causes and potential triggers of HABs should be a priority. This assessment should be undertaken prior to making plans for the collection of new data and conducting a diagnostic study of the waterbody.



Bureau of GIS Webpage

Gathering Existing Data

A thorough search of government agencies, consultants and volunteer monitoring groups that may have worked on or are working on the waterbody or in the watershed should be conducted. Coordination with all these groups will help identify data gaps, gain access to the data and in turn they should be recognized for their efforts. It is also an opportunity to identify potential partners that can contribute financial and staffing resources when implementing water quality monitoring to collect additional data. The focus should be on collecting data that will ultimately guide steps to reduce nutrients and the occurrence of HABs in the system.

The following are important parameters to look for in existing datasets:

- Internal and external sources of nutrients such as nitrogen and phosphorus at the surface and depth profiles when available;
- Temperature, DO, pH, conductivity;
- Volume flows in and out of the waterbody;
- Information on past HAB events including cyanobacteria cell counts and species composition data;
- Prior algae and cyanobacteria treatments along with results of these treatments;
- Land use data such as percent of wetlands, open water, agriculture, forest and developed land; and
- What types of potential nutrient transport mechanisms exist such as stormwater outlets, stream inputs, groundwater flow, etc.

The following are important metadata that should be collected along with the data:

- Was the sample analysis conducted by an NJDEP certified laboratory, university or a volunteer monitoring group;
- Are detections limits acceptable for the planned analysis;
- Were the samples collected under the guidelines of a Quality Assurance Project Plan;
- Type of sample (grab or integrated sample, surface or depth);
- Location, time, date;
- Contact information;
- Constraints related to use of the data; and
- Information on why the sample was collected (ongoing, responsive, regulatory, research).

It should be noted that data not meeting established detection limits or sampling protocols can still be valuable to help identify trends and provide a relative overview of the water quality in the waterbody.

Data Tools and Resources

- **New Jersey Department of Environmental Protection**
  - *NJDEP Water Quality Data Acquisition* https://www.nj.gov/dep/wms/data_acquisition.html
  - *Office of Water Quality Division*
    - Total Maximum Daily Load Look-Up Tool: This tool allows for stormwater program coordinates to easily identify TMDL information for their waterways.
  - *Bureau of Geographic Information System*
    - NJ-GeoWeb NJ-GeoWeb (arcgis.com) (https://njdep.maps.arcgis.com/apps/webappviewer/index.html?id=02251e521d97454aabadfd8cf168e44d)uses NJDEP's Geographic Information System (GIS) data to allow users access to water quality and environmental data. For those unfamiliar with the GIS platform please view their Quick Start Guide.
  - *Division of Water Monitoring, Standards and Pesticide Control*
    - The Bureau of Freshwater Biological Monitoring Data Inventory has a number of river/stream, lake, and groundwater data including the Integrated Water Quality Assessment Report (Integrated Report), Surface Water Quality Standards (SWQS) development, Statewide Statistical Surveys, Water Quality Trends, Water Quality Research. HAB data, continuous buoy data, and flight data, can be accessed via the HAB Dashboard. NJDEP Harmful Algal Bloom (HAB) Dashboard (arcgis.com) (https://njdep.maps.arcgis.com/apps/dashboards/49190166531d4e5a811c9a91e4a41677)
- **United States Geological Survey Sources (USGS)**
  - National Water Information System: Web Interface allows users to search for information about sites and respective real-time or recent surface-water, groundwater, or water-quality data. Users can also search by category of data.
  - USGS Water Resources Real Time Data https://waterdata.usgs.gov/nj/nwis/rt
- **United States Environmental Protection Agency**
  - The Watershed Index Online (WSIO) is a downloadable watershed data library and analysis tool for comparing watershed characteristics throughout the United States.
  - Surface Water Quality Modeling creates quantitative models on how surface waters change in response to pollution and how to implement proper management plans.
  - EnviroAtlas Data provides geospatial data and other resources related to ecosystem services, their chemical and non-chemical stressors, and human health.
  - Integrated Water Analysis Tools

    - Hydrologic and Water Quality System is a water quantity and quality modeling system that evaluates the impacts of management alternatives, pollution control scenarios and climate change scenarios.
    - The Watershed Assessment, Tracking & Environmental Results System integrates data from National Hydrography Dataset (NHD), National Elevation Dataset (NED), and the Watershed Boundary Dataset (WBD).
  - *Ambient Water Quality Tools*
    - The Assessment, Total Maximum Daily Load (TMDL) Tracking and Implementation System (ATTAINS) is a way to access information on surface water conditions in the US. Water quality assessment and Total Maximum Daily Loads (TMDL) information are required every two years under Clean Water Act Sections 305(b) and 303(d).
- **Montclair University's** NJ Center for Water Science and Technology (https://www.montclair.edu/water-science/) provides harmful algal bloom assessment including cyanotoxin testing and cyanobacteria identification and enumeration. Community members are encouraged to visit NJCWST HAB Data Dashboard https://www.arcgis.com/apps/dashboards/a31267af4ab84fb297e6cf7072fc9c7e
- **National Aeronautics and Space Administration** collects remotely from sensors aboard satellites and aircraft or deployed in and under water including Ocean Color, Photosynthetically Available Radiation, Water Surface Temperature, Precipitation, Soil Moisture, Runoff, Turbidity, and Human Impacts/Socioeconomic data.
- **County Health Departments**: Contact your county health department to find out what data they may have previously collected or any ongoing effort they are currently undertaking on the waterbody.
- **New Jersey Sea Grant Consortium Database:** Get in touch with researchers working on HABs, water quality and stormwater BMPs in NJ by searching the NJSGC Expertise Database (https://njseagrant.org/experts/).

Identifying Stakeholders

It is important to recognize government agencies, consultants, citizen groups, and waterbody owners that have worked on the waterbody or in the watershed. The NJDEP asks partners such as parks and local health departments to visually survey confirmed HABs. In addition, NJDEP has a limited supply of phycocyanin meters for additional monitoring that are available to partners.

6. ALGAE AND HARMFUL ALGAL BLOOMS SUMMARY

The NJDEP Division of Water Monitoring and Standards has developed an extensive HAB management program that includes a mechanism for reporting and documenting HABs along with a tiered alert system that is based on data (such as cell counts and toxin production) from a cyanobacteria bloom. The 2021 Cyanobacterial Harmful Algal Bloom Freshwater Recreational Response Strategy was developed to provide a unified statewide approach to respond to HABs in freshwater recreational waters and drinking water. The HAB Alert Levels (Figure 5) and signage (Figure 6) developed by the NJDEP can be found below. Documenting HAB events and the environmental conditions leading up to, during and after the event with as much detail as available is an important step in the development of HAB Management Plan. Compiling and reviewing the details of HAB events and accompanying water quality data can provide insight into the overall health of the waterbody and give an indication as to whether conditions are improving or deteriorating.

HAB Alert Levels	Criteria	Recommendation
HAB Not Present	HAB reported and investigated. No HAB present.	None
WATCH *Suspected or confirmed HAB with potential for allergenic and irritative health effects*	Suspected HAB based on field survey **OR** Confirmed cell counts ≥20k - ≤80k cells/mL **AND** No known toxins above public health thresholds	**Public Bathing Beaches Open** Waterbody Accessible: Use caution during **primary contact (e.g. swimming) and secondary (e.g. non-contact boating)** activities Do not ingest water (people/pets/livestock) Do not consume fish An *Alert* is initiated at beaches if cell counts are 40K to < 80K. An *Alert* begins actions to monitor the beach more frequently due to increasing potential for toxin production and to ensure the HAB has not elevated to a higher risk Tier.
ADVISORY *Confirmed HAB with moderate risk of adverse health effects and increased potential for toxins above public health thresholds*	Lab testing for toxins Microcystins: ≥2 µg/L Cylindrospermopsin: ≥5 µg/L Anatoxin-a ≥15 µg/L Saxitoxin-a ≥0.6 µg/L **OR** Confirmed cell counts ≥80k ug/L	**Public Bathing Beaches Closed** Waterbody Remains Accessible: Avoid primary contact recreation Use caution for secondary contact recreation Do not ingest water (people/pets/livestock) Do not consume fish
WARNING *Confirmed HAB with high risk of adverse health effects due to high toxin levels*	Toxin (microcystin) ≥20 - ≤2000 µg/L	**Public Bathing Beaches Closed** Cautions as above May recommend against secondary contact recreation
DANGER *Confirmed HAB with very high risk of adverse health effects due to very high toxin levels*	Toxin (microcystin) ≥2000 µg/L	**Public Bathing Beaches Closed** Cautions as above. Possible closure of all or portions of waterbody and possible restrictions of access to the shoreline.

Figure 5. NJDEP HAB Alert Tiers.

Figure 6. NJDEP Recommended Signage.

HABs History

Historical information and data related to reported, suspected or confirmed HABs along with the corresponding NJDEP HAB alert when available is important information that should be compiled on the waterbody and included in the HAB Management Plan. It is recommended that the following information be included in the HAB history to document and provide an overview of the HAB situation in the waterbody.

Aquatic Plants and Cyanobacteria

The HAB history should include a detailed description of the current aquatic plants and cyanobacteria situation in the lake along with any historical information that may be available such as previous herbicide treatments or removal efforts and past plant surveys. Details such as aquatic plant growth, presence or absence of invasive aquatic plant species, cyanobacteria species present and other pertinent information that help describe the conditions of the lake. Engage stakeholders that have a long history utilizing the waterbody for recreation and other purposes for anecdotal evidence on how they may have seen conditions of the lake improve or deteriorate during the time for which they have experience with the waterbody that the HAB Management Plan is being developed for. In addition, it is recommended that any information that could be contributing to HABs such as excess nutrients, shallow water, invasives, significant aggregations of waterfowl, etc. is included in the section.

Documenting Previous HAB Events
It is recommended that the following details be included when documenting previous HAB events.

- Summary of total occurrences, annual summary along with months event occurred, and include NJDEP Alert Levels when available.
- How the bloom was confirmed, test type and results.
- Spatial extent of bloom- small localized, widespread, lake wide.
- Bloom location - shoreline, lake wide, open water, isolated to a particular area.
- Rainfall data prior to the event.
- Wind speed
- Cell counts along with presence/absence of toxin production and species composition when available.

When water quality data is available it is recommended that a summary of the conditions leading up to, during and after a major HAB event be provided. Information on nutrients, DO, pH, water temperature and other available parameters can be included. While phosphorus is generally considered to be the nutrient that limits the extent of a HABs, the Total Nitrogen: Total Phosphorus ratio may provide information on the dominant species as well as toxin production. It is important to look at all the factors involved to help understand why a particular cyanobacteria species flourished. Including information on the lack of water circulation, floods, drought, etc. before and during the event can also be helpful to reveal conditions that have the potential to lead to a HAB event. In addition, climate change can have a warming effect on lakes that can lead to altered seasons that impact thermal stratification and seasonal succession of phytoplankton groups that can influence the conditions of the lake the next year. This can lead to cyanobacteria persisting through a warmer, shorter winter that has the potential to result in higher cell counts going into the warming season. This is especially important when blooms are severe or occur frequently in the waterbody and will be useful to determine cause and effect.

Impacts of HAB Events
Include a general description of any impacts that occurred due to HAB events to drinking water advisories, recreational activities such as bathing beach closures, fishing and boating restrictions, fish consumption advisories, restrictions for contact by humans, pets, livestock, and other impacts. Economic impacts when available should be included.

Previous Actions

Determine what treatments or other steps have been taken to reduce the occurrence and severity of HABs and include a summary of these items. Some key actions to include in the summary are BMPs (e.g., for septic systems, livestock and stormwater), nutrient inactivation, aquatic pesticide applications, circulation and aeration techniques, weed harvesting and other similar methods to reduce the occurrence of HABs. Information such as when the action item was implemented, location, ongoing, results and other information pertinent to the action item.

Resources

NJDEP HAB Summary Reports
(https://www.nj.gov/dep/wms/bfbm/response_strategy.html)

7. POLLUTION SOURCES

A critical step in the development of a HAB management plan is to identify nonpoint and point sources of pollution not only at the time the plan is being developed, but also consider how climate change along with continued development in the watershed could create new sources or increase contributions from existing sources. Changes in the intensity and occurrence of rainfall events have the potential to rapidly increase nutrients that can lead to an increase in the occurrence of HABs. Input from stakeholders with local knowledge can be extremely helpful in identifying sources and prioritizing the process of investigating and documenting them.

Pollutant sources include point sources that are permitted through the New Jersey Pollutant Discharge Elimination System (NJPDES) and nonpoint sources such as agriculture, atmospheric deposition, internal loading, landscaping practices, septic systems and urban land use that enter the waterbody and can be readily available to cyanobacteria. Nutrients can also be deposited in the lakebed sediments and stored there until environmental conditions occur that allow them to be released into the water column and become readily available to cyanobacteria. This is referred to as internal loading and has the potential to be a significant source of nutrients. It is important to identify sources that contribute dissolved nutrients and focus management efforts that reduce or eliminate these sources.

Types of Sources

Point Sources

The NJPDES protects New Jersey's ground and surface water quality by ensuring the proper treatment and discharge of wastewater (and its residuals) and stormwater from various types of facilities and activities. To accomplish this, permits are issued limiting the mass and/or concentration of pollutants which may be discharged into groundwater, streams, rivers, and the ocean. The types of regulated facilities can range from very small users such as campgrounds, schools, and shopping centers to larger industrial and municipal wastewater discharges and municipal collection systems. Information on permitted sources can be found in the NJDPES Permit Database (https://dep.nj.gov/dwq/permitting_information/data_access_and_reports/).

Nonpoint Sources

Nonpoint sources include run-off carrying fertilizer from residential and agriculture use, oil, grease, sediment from construction sites and shoreline erosion; bacteria and nutrients from animal waste and atmospheric deposition. Detailed information on the NJDEP Nonpoint Source Program along with the NJDEP Nonpoint Source Program Management Plan can be found at NJDEP Nonpoint Source Plan (https://www.nj.gov/dep/wms/bears/nps.htm#/).

Water Sampling

Types of Pollutants

Based on the work of the HAB Expert Team the focus should be on identifying, reducing and eliminating sources that contribute to the occurrence of HABs including nitrogen, phosphorus, sediment, and temperature. Phosphorus is a nutrient of concern, but not the sole nutrient regarding HABs. Effort and funds dedicated to investigating sources of pollutants should be focused on the sources of pollution and conditions that are enabling the HAB.

Early in the process of identifying pollutant sources, it is important to document both observable problems and any issues that have been documented by previous monitoring efforts. This presents a good opportunity to engage residents and other stakeholders that have a long history with the waterbody. Observable conditions, both good and bad, should be recorded for the waterbody such as surface algal blooms, aquatic plant growth for both nuisance and invasive species, poor drinking water quality, fisheries issues, and sedimentation. It is important to note where developed and agricultural land use areas are as they are often sources of nutrients, thermal inputs and sediment. This information can be extremely useful and help you pinpoint sources.

It is important to document the proximity of pollution resources to sensitive areas and this will help to prioritize the order in which sources need to be addressed and guide the selection of management measures. Ultimately, the focus should be on sources that contribute high levels of pollutants and have a high likelihood of being transported into the system.

External Pollutant Sources

Check with state agencies, researchers and consultants to determine what previous water quality monitoring has been completed on the waterbody to identify pollutant sources. The NJDEP TMDL Look Up Tool (https://dep.nj.gov/njpdes-stormwater/municipal-stormwater-regulation-program/tmdl/) and NJDEP Bureau of Freshwater and Biological Monitoring (https://www.nj.gov/dep/wms/bfbm/index.html) are good places to start. It is recommended that all available information and resources be used to identify sources of pollution. Use of volunteers and anecdotal evidence from local residents to identify occurrence of surface blooms, discharge pipes, shoreline erosion, etc…can be helpful to verify the source.

Stormwater Outfall Pipe

Stormwater runoff has the potential to be the primary source of nutrients to waterbodies in New Jersey. GIS data for land use types, stormwater outfall pipes, septic systems data, and other potential pollution sources maps can be used to find potential sources. Stormwater runoff from agriculture, septic systems and outfalls are generally good places to begin investigating and focus effort. In addition, it is important to identify any point sources such as wastewater treatment plants that may be located upstream and contributing pollutants to the waterbody. Permitted point sources can be found at NJPDES Permit Holders (https://dep.nj.gov/dwq/permitting_information/data_access_and_reports/).

The Clean Air Act of 1970 required measures to be implemented to reduce the amount of pollutants in the air. The USEPA reports that for more than 40 years the Clean Air Act has fostered steady progress in reducing air pollution. Nutrient contributions from atmospheric deposition have been decreasing and are likely a minor contributor of nutrients when compared to land sources of nutrients that enter the waterbody through surface and groundwater input. However, nutrient contributions from atmospheric deposition should still be taken into account when calculating loading. It should be noted that the potential exists for waterbodies with a large surface area to volume ratio to receive higher levels of nutrient contributions from atmospheric deposition. While nutrient contributions from atmospheric deposition are a source beyond control it is important to take them into consideration when calculating nutrient loads and note that changes in weather patterns resulting from climate change have the potential to vary contributions seasonally and annually.

Internal Pollutant Sources

Internal Loading (especially P and Fe)

Reducing the input of nutrients (especially N and P), and maintaining an adequate N:P ratio, is the best long-term practice for controlling harmful cyanobacteria blooms. Exchanges between the sediments and the water column are also a stimulating factor for cyanobacteria blooms. Internal loading is greatest during the summer thermal stratification season when cyanobacteria blooms occur most frequently.

Most associate increased internal nutrient loading with the depletion of dissolved oxygen in deep over-sediment strata. However, oxygen depletion doesn't cause internal loading, subsequent anaerobic respiration does. When dissolved oxygen is exhausted respiration continues using alternates to oxygen as the electron acceptor, and the alternates are used in order of decreasing redox potential (Figure 7). The first alternate used is nitrate (denitrification, nitrate to N_2 gas), which is performed by facultative anaerobes (they use oxygen when available and switch to nitrate when oxygen is depleted). If nitrate serves as the alternate to oxygen, release of sediment phosphorus doesn't increase. Unfortunately, nitrate is exhausted rapidly by both assimilative uptake and denitrification in most lakes and reservoirs. Once nitrate isn't available, anaerobic respiration occurs using metals, especially iron (Fe). Insoluble oxidized ferric iron complexes are usually what binds phosphorus in the sediment. When used as an electron acceptor the iron is reduced to ferrous iron, which is soluble. When that occurs Fe, and any P that had been bound to the Fe, are released from the sediment, and accumulate in deep anoxic waters. Fe is an important micronutrient and is a stimulating factor for blooms of cyanobacteria. Fe is an enzyme cofactor in photosynthesis, electron transport, energy transfer, and N assimilation. Fe is required for nitrogen fixation by cyanobacteria. If oxidation-reduction potential decreases even further sulfur is used as an electron acceptor in anaerobic respiration, producing hydrogen sulfide (which is highly toxic to aerobic organisms).

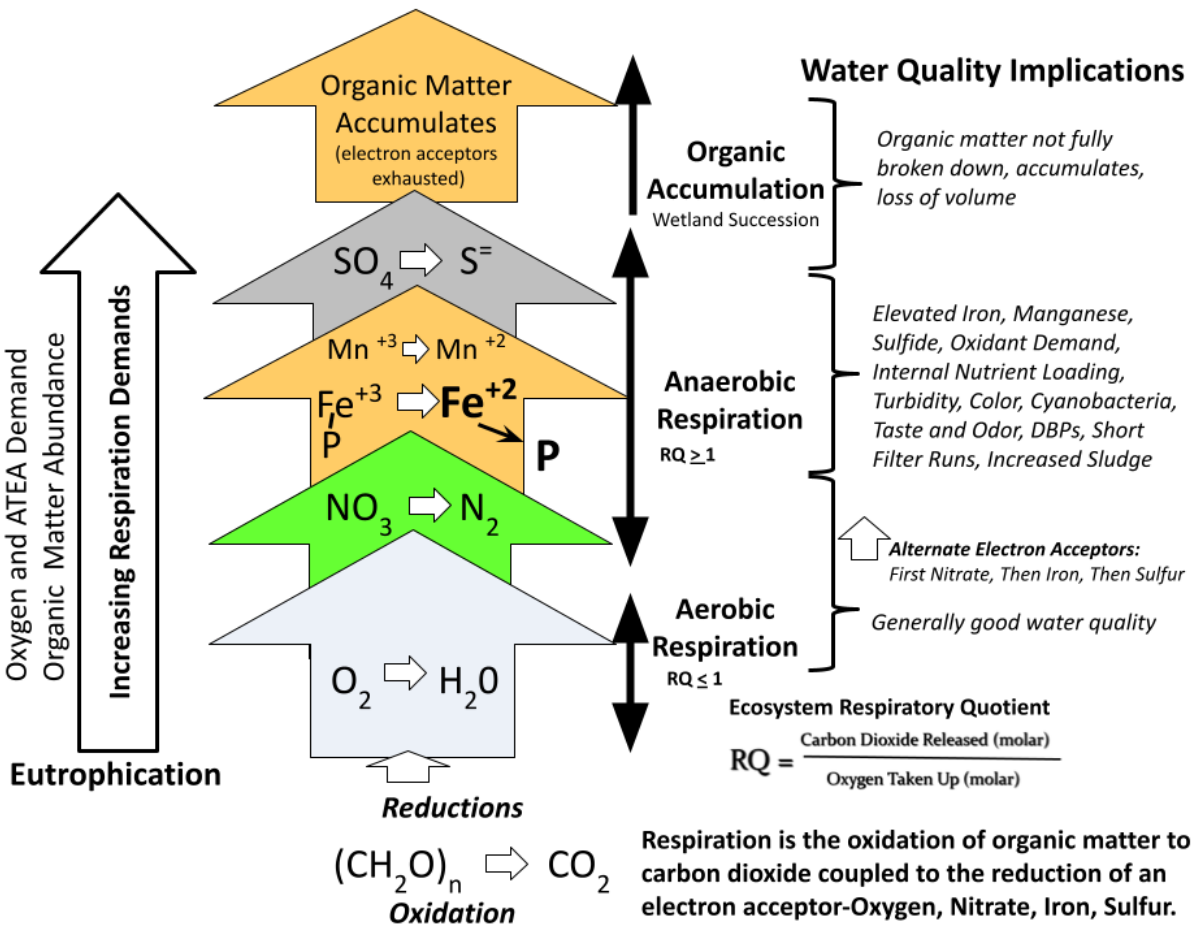


Figure 7. Organic loads, whether produced within the lake or detritus coming from the watershed, affects the respiration system in the lake or reservoir.

In some lakes (especially hardwater systems) carbonate complexes also bind P in sediments. Respiration (aerobic and anaerobic) produces carbon dioxide which accumulates in deep strata, decreasing pH. The decrease in pH causes dissolution of the carbonate complexes which release bound phosphorus. Both mechanisms (Fe and Carbonate) are driven by respiration. Monitoring dissolved oxygen alone isn’t adequate for evaluating the internal loading contribution to bloom stimulation. Monitoring of anaerobic respiration products should be included when water becomes anoxic. Ammonia nitrogen also accumulates in deep anoxic water because oxygen isn’t available for nitrification to nitrate. The accumulated P, Fe, and ammonia can become available to phytoplankton following Fall turnover, following a storm mix-down event, or if the anoxic boundary ascends high in the water column (e.g., above the thermocline). Some bloom forming cyanobacteria can regulate their buoyancy, descending to obtain nutrients, ascending to obtain light (PAR).

Tools

GIS based tools can provide a visual representation of outfalls including MS4 inventory, land uses such as natural areas, developed land, roadways along with septic system density to help find potential hot spots.

NJDEP GeoWeb (https://www.nj.gov/dep/gis/geowebsplash.htm)

Rutgers Center for Remote Sensing and Spatial Analysis (https://crssa.rutgers.edu/)

8. LAKE MANAGEMENT/ WATER QUALITY GOALS

When developing lake management and water quality goals for your waterbody it is crucial to understand that not all waterbodies have the same water quality dynamics and not all HABs have the same characteristics. Size, shape, depth and drainage are important characteristics that can result in variability within the waterbody. Therefore, goals, BMPs and control measures should be carefully selected. It is imperative that the hydrologic and morphological characteristics, water chemistry, and biological conditions of the waterbody be taken into consideration, along with the HAB composition and development, when establishing goals, selecting measures to meet them and the timeframes for evaluating progress. Selecting BMPs and control measures that are effective at reducing nutrients and provide long term benefits should be a priority.

Goals and Actions

The focus should be on identifying broad goals to improve the lake water quality that will reduce the occurrence and/or severity of HABs, and meeting TMDLs if they have been established for the waterbody. Objectives should be developed that address the water quality problems identified in the review of existing data and new data collected as part of the HAB Monitoring Plan that have the potential to lead to the development of HABs.


Spring Lake

While phosphorus is generally considered to be one of the main the nutrient that limits the extent of a HABs it is important to look at all the factors involved to help understand what the conditions were that enabled a particular cyanobacteria species to exploit them and develop a plan to simultaneously reduce all the factors. The cyanobacteria species that exploit a given water quality condition and the factors that lead to the release of toxins vary from waterbody to waterbody. It is critical that any objectives that are developed and the corresponding measures taken to meet them be selected based on the cyanobacteria species composition found in the waterbody.

The NJDEP Bureau of NJPDES Stormwater Permitting and Water Quality Management has developed a tool to identify Total Maximum Daily Loads (TMDL). The tool can be accessed through the following link [TMDL Look Up Tool (https://dep.nj.gov/njpdes-stormwater/municipal-stormwater-regulation-program/tmdl/)](https://dep.nj.gov/njpdes-stormwater/municipal-stormwater-regulation-program/tmdl/). The TMDL document for the pollutant of concern should be reviewed for valuable information such as current restoration work, treatment of invasives, dredging activities, reference to diagnostic studies that have been completed, and other pertinent information that will help select BMPs and management measures as well to avoid duplication of efforts.

In addition, it is important to gather public input to identify priority goals for the lake such as HAB reduction, reduced bathing beach closures reduced impacts to recreational activity, etc.

BMP and Control Measure Selection

Provide a detailed description of the problem and the BMP, control measure or combination of strategies that has been selected to address it. Include details on the effectiveness of the strategy, previous experience with it, possible intended or unintended consequences, why it was selected and information to support the location where it will be implemented. Utilize the information in the Selection of Actions chapter to help guide the decision process. The description should also include the details outlined below.

Financial and Technical Assistance

The description should include details on the amount of financial and technical assistance needed to implement each BMP and/or control measure that has been selected. The following are recommended items that should be included:

BMPs

- Assistance developing new outreach materials and/or use of existing information;
- Assistance delivering the message. Rutgers Water Resources Program, County Agricultural agents, watershed groups, lake associations, municipalities, environmental commissions, chambers of commerce and other similar organizations can help disseminate information; and
- Distribution costs.

Control Measures

- Engineering plans;
- Licensed pesticide applicator;
- State and local permits, including Pesticides and/ or NJPDES;
- Is maintenance required? Who? How often? How long? Cost?; and
- Landowner cooperation.

Milestones and Timeframe

Include a description of the milestones associated with each BMP and control measure that will be implemented along with the criteria that will be used to assess water quality improvements as the plan is implemented. An estimated timeline should be included for the implementation of the selected strategies that includes short, medium and long term deliverables.

HAB Monitoring Plan
Provide a brief explanation of how the HAB Monitoring Plan supports the goals for reducing the occurrence of HABs and improvements in water quality. Include a description of how the proposed monitoring will be integrated with refining the goals and objectives as new data becomes available and measuring the results of any BMPs and control measures implemented.

Ongoing actions
Provide a description of any ongoing BMPs and control measures already being implemented to improve water quality and reduce the occurrence of HABs. Include information on where it is in the implementation process, who implemented it, when and where, outcome, etc. It is recommended that a description of how it fits into the overall HAB Management Plan and the cost savings benefit it may provide.

Resources
How's My Waterway was designed to provide the general public with information about the condition of their local waters based on data that states, federal, tribal, local agencies and others have provided to EPA. https://mywaterway.epa.gov/

Diet for a Small Lake: http://www.dec.ny.gov/chemical/82123.html

9. SELECTION OF ACTION ITEMS

The results obtained from water quality monitoring and observing physical changes that take place on a seasonal or annual basis will identify problems and causes that need to be addressed to reduce the occurrence of HABs. These problems can be addressed through the selection and implementation of management techniques at the lake and watershed level. Excess nutrients are a primary factor that lead to the development of HABs. It is important to note that while excess phosphorus can be a primary driver of HABs, it is imperative to select management measures that reduce overall nutrient inputs while maintaining an adequate N:P ratio so as not to cause a shift in cyanobacteria species that favor one nutrient over the other. A combination of short term strategies to reduce the severity/occurrence of HABs and long term strategies to reduce nutrients that cause the HABs will be needed to help you meet your long term lake use goals. In addition, climate change impacts on the frequency and severity of weather events can further complicate nutrient inputs and impact effectiveness of management strategies. Water quality conditions have the potential to improve significantly when the correct actions are implemented in areas where the pollutant source has been identified and reducing or eliminating it.

Action Items Overview

These resources are intended to provide general information that will lead to informed decisions on management strategies to provide cost-effective long-term reductions in HABs. The focus should be on selecting strategies that will provide long term sustainable benefits to the waterbody. It is important to check with the NJDEP to determine if TMDLs have been developed for the waterbody and if nutrient sources may have already been identified by the NJDEP or other groups working in the watershed. In addition, gathering information on action items that are currently being implemented will help to identify potential partnering opportunities and reduce the chance of duplicating efforts.

At a minimum, the following should be considered when selecting a strategy to reduce the occurrence of HABs: estimated effectiveness and over time (long/short term), timing for implementation, possible intended or unintended consequences, cost (including implementation and maintenance costs), regulatory/permitting restrictions, length of time that it will take benefits to become noticeable, is the strategy acceptable to the landowner and/ or community, public and regulators.

Before selecting a HAB strategy or technology for a waterbody, it is crucial to understand that not all waterbodies have the same water quality dynamics, and not all HABs have the same characteristics. There can even be variability from one area of a lake/reservoir to another, or over the course of a season, and part of this is dictated by conditions within specific drainage areas. Therefore, not all HAB prevention, mitigation and management strategies and technologies implemented in one waterbody will produce the same results in another waterbody or across different locations in a large waterbody. It is imperative that the hydrologic and morphological characteristics, water chemistry, and biological condition of each waterbody be taken into consideration, along with the HAB composition and development, prior to selecting a prevention, mitigation and/or management strategy or technology. It is important to be aware that NJDEP permits may be needed to implement certain measures. This not only applies to the use of pesticides/algaecides, phosphorus neutralizing agents, but also to certain preventative measures that could result in a disturbance of the riparian area adjacent to a lake or tributary or the disturbance of the lake bottom. For example, a lake drawdown for dam repair or aquatic vegetation control requires a permit from New Jersey DEP Fish & Wildlife.

Climate Change Impacts

Climate change is affecting lakes and reservoirs in ways that tend to increase the risk of cyanobacteria blooms. The amount of internal loading depends on the area of the sediment-water interface that becomes anoxic, and the duration of anoxia (Anoxic Factor). Climate change is tending to increase the intensity and duration of summer stratification, increasing the anoxic factor and internal loading of P, Fe, and Ammonia-N (Figure 8). Post-turnover blooms are becoming larger, and during some years cyanobacteria are persisting through the warm winters we are experiencing. Climate changes are altering what once was a very regular seasonal succession of phytoplankton groups and these changes should be considered when selecting management strategies.

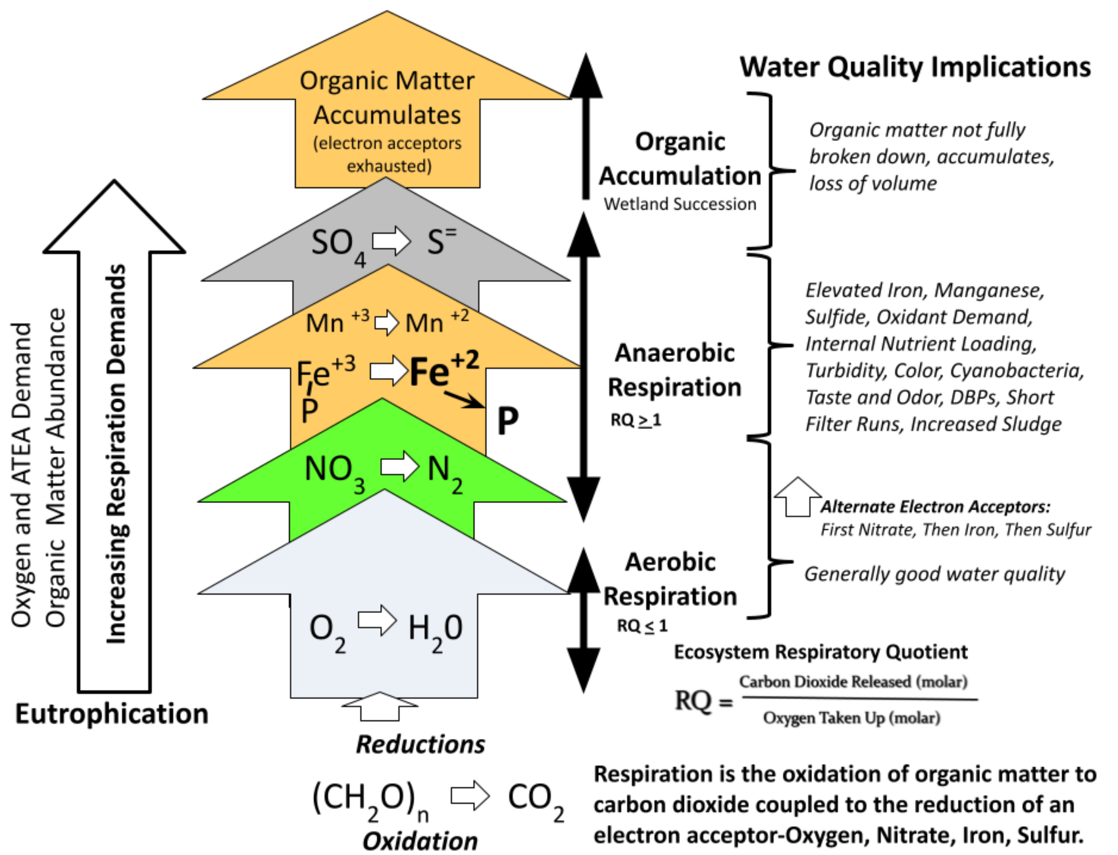


Figure 8. Organic loads, whether produced within the lake or detritus coming from the watershed, affects the respiration system in the lake or reservoir. (Modified from: Kortmann, R.W. and P.H. Rich, 1994. **Lake Ecosystem Energetics: The missing management link.** *Lake and Reservoir Management Journal*, 8(2):77-97.)

Critical Natural Features of the Water Column

There are three critical natural features of the water column relative to the development of cyanobacteria blooms (Figure 9):

1. Mixing Depth: How deep does the well-mixed surface water layer extend?
2. Anoxic Boundary: How high in the water column does anoxia ascend? How much of the sediment-water interface becomes anoxic, and for how long? Does the anoxic boundary ascend above the thermocline?
3. Compensation Depth: How deep does photosynthetically active light penetrate (PAR)?

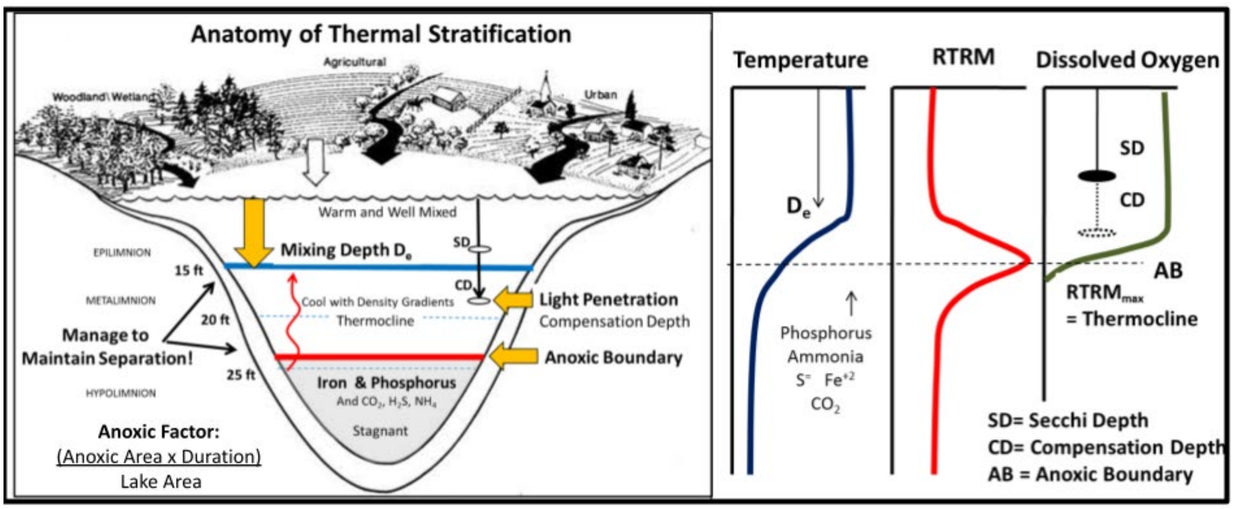


Figure 9. The depth of surface layer mixing (D_e), depth of photosynthetically active light penetration (Compensation Depth, CD), and the depth of ascent of the oxygen loss boundary (AB) are critical natural features of a thermally stratified reservoir. (Modified from: Kortmann, R.W., 2020. **Layer Aeration in Reservoirs: A 35 Year Review of Principles and Practice.** *NEWWA Journal- September 2020.)*

Managing the non-point internal load to reduce blooms involves several principles:

1. Reduce the area and duration of anoxia (decrease the Anoxic Factor).

2. Maintain vertical separation of the Mixing Depth and Anoxic Boundary.

3. Maintain Light Penetration (PAR) below the Mixing Depth.

4. Increase Sediment P-binding Capacity.

Watershed Best Management Practices

The NJDEP defines nonpoint source pollution (NPS) as water pollution that is generated by everyday activities, such as fertilizing the lawn, walking pets, changing motor oil or gasoline, and littering. NPS sources can include septic systems, fertilizers from lawn care, golf courses and agricultural fields, animal/agriculture uses, erosion of soils / streambanks and other similar sources found in the watershed. These pollutants are picked up by stormwater and are transported to the waterbody. There are two main strategies when addressing NPS pollution:

1. **Source Control** - that is, reducing or eliminating the pollutant load prior to it being transported through stormwater.
2. **Reduction of Pollutants** - that is, reducing the magnitude of the pollutant load as it is conveyed by stormwater or as septic leachate. This can include reductions in the quantity and/or quality of the load.

A large component of **Source Control** is associated with educational measures and the implementation of Best Management Practices (BMPs) can be used to effectively address NPS pollutant load in the watershed and land surrounding the waterbody before it is generated. While there is a wide variety of NPS pollution, nutrients (specifically phosphorus and nitrogen), are the ones of primary concern when it comes to the development of HABs. Thus, residents in the watershed that are well informed and educated on the occurrence and causes of HABs are more likely to take steps towards reducing nutrient inputs.

<u>Animals and Agriculture</u>

BMPs designed to reduce water use, and minimize the amount of pesticides, fertilizers, animal waste and sediment from entering the waterbody can contribute toward source control. Of the various sources of stormwater-conveyed nutrients, animal waste tends to be the highest relative to concentrations. For example, as shown below in Table 1, livestock operations produce substantially higher loads of phosphorus and nitrogen in the Chesapeake Bay watershed relative to any other land use.

Table 1: Average Phosphorous and Nitrogen Loads by Land Use in the Chesapeake Bay

Land Use	**Total Phosphorous Loads** (kg/ha)	**Total Nitrogen Loads** (kg/ha)
Forest	0.1	4.3
Pasture	0.4	7.9
Livestock Operations	460.0	2,302.0
Conventional Tillage	2.6	25.2
Conservation Tillage	2.0	20.5
Hay	1.7	11.0
Urban areas Business & Residential	0.9	11.1
Atmospheric Loads	0.7	16.2

Source: Adopted from Shuyler *et al*., (1995) While livestock operations can generate large nutrient loads, there are cost-effective measures that substantially reduce the magnitude of these loads. First, avoid animal waste from flowing into waterways using **animal waste storage structures**.

Animal waste storage structures collect liquid and/or solid wastes, particularly during the non-growing season and temporarily hold these produced in underground or above ground structures. In turn, the waste products (manure) are used to grow plants that are used to feed the livestock. Depending on the design of such systems, such as enclosed vs. open or underground vs. above ground, additional design structures such as fans and pumps may be required to reduce the development of anaerobic conditions and remove the products for use.

Other livestock based BMPs that can be considered for nutrient reduction strategies include:

- Riparian / Forested buffers between grazing livestock and waterways.
- Using fences to keep livestock out of streambeds and off streambanks.
- Providing livestock with a source of freshwater that is not the existing stream.
- Design / install environmentally friendly stream crossings for livestock.

In addition to livestock associated with agricultural lands, the two additional major animal-based sources of nutrients for fueling HABs are pets and Canada Geese (*Branta canadensis*). Thus, educating the communities and watershed stakeholders to pick up pet waste and not to feed Canada geese is extremely important.

Canada geese are essentially "cows with feathers;" they are constantly feeding on vegetation, so they are constantly defecating. On average, a single Canada goose defecates about 28 times a day. Thus, they generate a lot of phosphorus that can be easily transported into receiving waterways through stormwater runoff. In fact, Canada geese produce some of the highest amounts of phosphorus of all waterfowl, second only to the cormorant. One Canada goose is estimated to generate about 0.5 lbs. of phosphorus per year and translated into wet algae biomass one goose has the potential to produce 550 lbs. of wet algae biomass. Thus, communities should be educated on preventing the establishment of a large, year-round population of geese at waterbodies and areas that may transport waterbodies via runoff or stormwater. These efforts include not feeding the geese, the establishment of vegetative buffers around waterways, 2-3 feet in height and egg addling programs (permitting through US Fish & Wildlife). The following link is a resources for MANAGING CANADA GOOSE DAMAGE | NJ.gov (https://www.nj.gov/agriculture/pdf/managingcanadagoosedamage.pdf).

As previously mentioned, pets can also be a source of nutrients such as nitrogen and phosphorus. Thus, picking up pet waste is another important means of minimizing sources of phosphorus that are transported to the waterbody via surface runoff. To put this into context, a 44 lb. dog typically produces approximately 2 lb. of TP per year associated with its waste. In turn, 2 lb. of TP has the potential to produce 2,200 lb. of wet algae biomass. Thus, “pooper scooper” ordinances are another effective means of controlling phosphorus from a source control perspective.

Fertilizer Management
New Jersey's "Healthy Lawns, Healthy Water" law enacted in January 2011 required that all fertilizers sold in New Jersey contain no phosphorus and contain a minimum of 20% slow release nitrogen. The law does not permit homeowners to apply fertilizer after November 15th and before March 1 in any calendar year and commercial applicators must complete late fall nitrogen or phosphorus fertilization by December 1 and cannot be applied again until March 1. In addition, professional fertilizer applicators and lawn care providers are required to undergo training and become certified through the NJ Agriculture Experiment Station
Outreach to homeowners and commercial applicators on the specifics of law and fertilizer management including timing of applications, application methods and importance of applying the correct amount of fertilizer can be effective at reducing nutrients that have the potential to reach the waterbody from stormwater.
Steps that can be taken to reduce fertilizer use include minimizing lawn space on lakefront properties, using native plants near the water edge to capture runoff and nutrients, sampling soil to determine what nutrients and amounts are needed and use of cover crops on farmland to prevent erosion.

Septic
Many lake communities and areas where HABs have occurred in the past utilize septic systems for sewage treatment and disposal. Septic systems, when functioning properly, can provide a cost effective method to treat wastewater and provide the benefit of recharging the groundwater. However, septic systems that are not maintained and functioning properly can contribute to the nutrient load of the waterbody. Education and outreach efforts that promote proper management, design and maintenance of these systems can be an effective tool to reduce nutrient loading and introduction of pathogens into the waterbody.

Specification on the design and placement of septic systems can be found at NJDEP Septic Standards (https://dep.nj.gov/wp-content/uploads/rules/njac7_9a.pdf). In addition, the NJDEP has prepared A Homeowners Guide to Septic Systems (https://www.nj.gov/dep/dwq/pdf/septicmn.pdf) that can be used as an education tool. Check with the township(s) surrounding the waterbody to see if funding for septic upgrades is available.

Stormwater
Stormwater runoff has the potential to be a major contributor of nutrients and sediment to waterbodies in New Jersey. It is important to identify pollutant transfer mechanisms and implement BMPs and controls that treat the water through treatment devices and green infrastructure practices, reduce the volume of runoff, increase retention time and infiltration into the groundwater. The NJDEP maintains the website NJStormwater.org (https://dep.nj.gov/stormwater/) that is a clearinghouse for everything related to stormwater. Information such as the NJ Stormwater Rule, permitting, BMP Manual and guidance for maintaining stormwater control measures. It is recommended that the BMP Manual be used to guide the selection of stormwater control measures. Collaboration/ coordination with municipalities is essential.

Control Measures

Biomanipulation

Given the lack of scientific information on bioaugmentation treatments the NJDEP's position is that there is too much potential harm in causing ecological shifts to either planktonic or benthic communities through the introduction of these products, and thus they are not supported by the NJDEP. NJDEP has reached out to national and international experts from both the federal and state level on the use of these products, with states including Vermont and Michigan taking similar stances to NJDEP and recommending against their use. .

Such products rely on an ecological premise known as microbial augmentation, sometimes known as microbial supplementation, which is the process of adding microbial species (such as bacteria or fungi) in concentrations higher than they may be found naturally and/or introducing them to aquatic or semi-aquatic environments where they are not typically found. Adding any foreign biologic constituent or most chemicals into lake ecosystems without fully understanding all the potential impacts, positive or negative, is not recommended. There are concerns that any introduced species could become invasive and destructive, even among microorganisms. Additional peer reviewed studies at a variety of scales are needed to sufficiently determine lack of harm from bioaugmentation treatments.

Ultimately, it is the responsibility of the applicant to prove that the use of any product will not negatively impact the ecosystem or create a human health concern. Additionally, any person or business applying a substance, or mixture of substances to a NJ aquatic site to enhance and improve water quality and clarity should refer to the NJDEP Compliance Advisory #2021- 04 issued: 03/23/2021.

Floating Wetland Islands

Floating Wetland Islands (FWIs) are structures that are placed in a lake or pond where the plants and microbes associated with the Island assimilate nutrients from the water column that would otherwise fuel the growth of cyanobacteria. While alone FWIs will not eliminate cyanobacteria and associated HABs, they will certainly contribute toward reducing the availability of nutrients. In turn, FWIs can be incorporated into a larger lake / watershed management plan to reduce nutrients, which in turn will reduce the magnitude and frequency of HABs. The advantages of FWIs are it is another non-chemical management measure and can also provide structural habitat for favorable species such as gamefish. Typically, no permits are required for the installation of FWIs in New Jersey and it is strongly recommended they be installed in near-shore areas, within the no-wake zone. Since they tend to be most effective in treating water with elevated nutrient levels (for example, total phosphorus concentration of at least 0.1 mg/L), they are frequently positioned in front of stormwater outlet pipes or swales to receive stormwater and surface runoff.

Limitations associated with the FWIs include potential issues associated with the anchored structures breaking free and floating away. They are typically anchored in near-shore areas but depending on local wind and wave activity, the FWIs may also need to be tethered to the shoreline. Also, for maximum success it is strongly recommended that the FWIs be positioned where they will receive full sunlight over most of the day. While there is some maintenance involved after the installation of a FWI, most of this is conducted over the first year after it's installation. This is to ensure that the goose netting is intact, and the plants are well established. After the first full year of being installed, maintenance is to periodically inspect the FWIs for any invasive species or damage.

The FWIs typically have a lifespan of 15 years and a 250 square foot FWI can remove approximately 10 lbs of phosphorus per year, which translates into approximately 11,000 lbs of wet alga biomass per year. Finally, the planting of the FWIs can be conducted with volunteers, which helps to reduce costs but also educates local stakeholders on the value of the FWIs and the need to reduce nutrient availability to limit the development of HABs.

Nutrient Inactivation
The release of bio-available phosphates stored in-lake sediments is often a major factor supporting the mid-summer occurrence of a HAB. Commonly referred to as internal phosphorus recycling, this release is triggered by oxidation-reduction reactions occurring under low oxygen (strongly hypoxic to anoxic) conditions. Under oxygenated (oxic) conditions, sediment release of bio-available phosphates tends to be slow and minimal, as much of the phosphorus is present in a chemically bonded state with various metals and minerals; primarily iron. However, this weak covalent phosphorus:iron bond breaks down very quickly under anoxic (oxygen depleted) conditions, resulting in the rapid and significant recycling of interstitial, sediment bound phosphorus back into the water column. Such conditions are typically the result of thermal stratification, which inhibits the vertical mixing of the water column, subsequently leading to the development of deep water anoxia. If a lake is sufficiently deep, the depth and volume of the anoxic hypolimnion limited, and water column stratification strong, most of the recycled phosphorus will remain segregated in the unlit hypolimnion and be unavailable for algal and cyanobacteria uptake and assimilation. However, conditions that result in the vertical transport of the recycled phosphorus from the unlit hypolimnion into the metalimnion or epilimnion, where there is enough light to support photosynthesis, most often triggers a bloom. It should be noted that internal phosphorus recycling is not limited to only deep lakes with a large hypolimnion and a dimictic pattern of stratification/destratification. Internal phosphorus recycling can also occur in lakes and ponds that are relatively shallow, polymictic waterbodies that are only weakly stratified but experience anoxia, even if only for a relatively short amount of time. This is the case for many of New Jersey's lakes.

A means by which to address this internally recycled phosphorus is to utilize products, commonly referred to as "nutrient inactivants", to elicit a chemical reaction resulting in the binding of dissolved forms of phosphorus and/or the stripping of particulate forms of phosphorus from the water column. The three most commonly used products are iron, aluminum or lanthanum based; with aluminum products the most commonly employed.

Iron is a natural phosphorus binder. In fact, much of the phosphorus present in lake sediments is bound to iron. However, as previously noted, the iron-phosphorus bond is a relatively weak covalent bound that quickly breaks down (dissociates) under anoxic conditions. Thus, it is not that effective a means of inactivating phosphorus. As such, it is not routinely used. There are essentially three types of aluminum nutrient inactivants:

- Aluminum sulfate – commonly referred to as alum
- Sodium aluminate, and
- Polyaluminum chloride– commonly referred to as PAC.

Of the three, alum is the most commonly used product. While aluminum is a highly effective binder of phosphates, both aluminum sulfate and sodium aluminate will cause changes in the pH of the treated lake. Alum will cause the pH to drop (become more acidic) whereas sodium aluminate will cause the pH to increase (become more alkaline). PAC tends to have far less of an effect on the pH of the treated waterbody. The pH effect can be significant for lakes having limited buffering capacity (low alkalinity and hardness). This can be problematic because at low (< 5.5 spu) and elevated (>10 spu) the aluminum in these products transition from an insoluble to soluble state. In the soluble state, aluminum is toxic to fish, primarily affecting oxygen transfer via the epithelium of the gills. Therefore, before using any aluminum based nutrient inactivant bench testing must be conducted to ensure the prescribed treatment dose does not trigger a major alteration of the pH of the subject lake or pond.

Lanthanum products are gaining more widespread use as they are as effective as aluminum products but do not elicit the above noted pH changes. Lanthanum is a rare earth element. Most lanthanum based products are particulate. For such products, the lanthanum is combined with bentonite clay.

The iron, aluminum and lanthanum nutrient inactivators can be applied directly to the surface of a lake or injected below the surface at a specified depth. In most cases, the products are introduced as a liquid that may be created on site by tank mixing a granular product with lake water. But iron, aluminum and lanthanum nutrient inactivators can also be applied in a granular form, especially with respect to the lanthanum products.

Applications are conducted using a boat or barge capable of handling the required volume and weight of the product. Proper application also requires the use of specialized metering equipment to ensure the product is applied in a uniform manner and at the correct dose rate, regardless of the speed of the treatment vessel. This is critical to the success of the project given the goal is typically to evenly apply the product over the sediments within the targeted lake bottom area.

When introduced into lake water, the nutrient inactivant product will produce a “floc”, an amorphous precipitant. The floc settles through the water column within minutes to hours. With the aluminum and iron products, the settling floc will strip particulate material and chemically bind dissolved phosphates. The floc produced by the lanthanum products does not have the same stripping effect as the iron and aluminum products but will chemically bind in a similar manner with any dissolved phosphorus present in the water column.

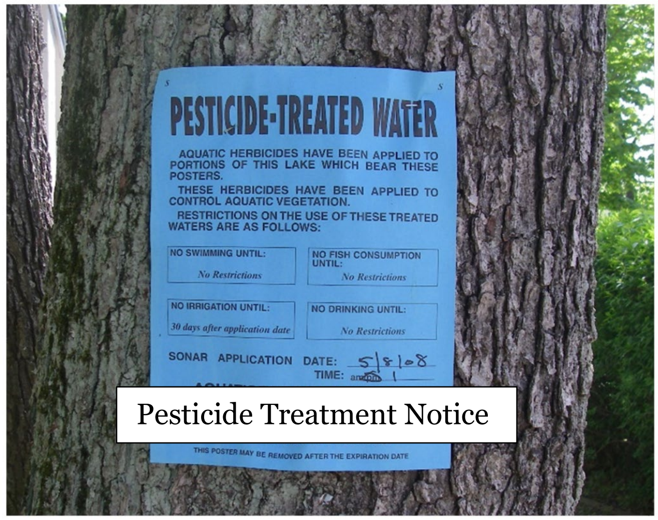
The residual floc that settles to the bottom of the lake becomes incorporated into the upper 10 – 20 cm of the fine bottom sediment layer. The residual inactivant associated with the settled floc in turn over time will bind phosphates released from the sediment under both anoxic and oxic conditions. In effect this will significantly decrease the amount of recycled phosphorus that would otherwise be available for biological assimilation, thus decreasing the potential amount of phytoplanktonic primary productivity. The longevity of the sediment treatment will be primarily determined by the nutrient inactivant application dose, the amount of interstitial phosphorus present in the sediment, the physical properties of the sediment, and sediment redox rates. It is not uncommon for a single sediment treatment to mitigate and decrease internal phosphorus recycling for as long as 5-7 years. An excellent nutrient inactivant review paper is Huser et al. (2016), which reviews 114 nutrient inactivant treatments. As summarized, for shallow lakes the beneficial longevity of a single treatment averaged 6 years whereas for deeper, dimictic that experience prolonged thermal stratification, the beneficial longevity of a single treatment averaged approximately 20 years. The longevity of the treatment may be compromised if the external phosphorus load is not well controlled. Additionally, the efficacy of nutrient inactivation may be lower for lakes with high flushing rates (>30-45 days) as compared to slow flushing lakes.

Ideally, nutrient inactivation should be used to manage lakes demonstrated to have at least 30% of their annual phosphorus load internally generated, especially if most of that load is generated during the peak of the annual phytoplankton "growing season", May through August. As noted, it can be used to manage the internal load generated by either dimictic or polymictic lakes. Due to the potential for the aforementioned aluminum toxicity issues, care needs to be taken in treating soft water, low alkalinity lakes with alum or sodium aluminate; such is not the case with either iron or lanthanum products. While the majority of the reviewed treatments focus on the control of phosphorus released from the sediments, more recently treatments have been implemented to primarily inactivate water column phosphorus. Additionally, some of the more successful lake treatments in New Jersey have involved the metered, daily, low dose introduction of alum as opposed to a single large-scale application. Nutrient inactivants are also being used in some cases to meter dose stormwater discharges, thereby decreasing the amount of phosphorus introduced during every storm event.

Overall, when properly utilized nutrient inactivation helps decrease the potential for HABs. Similar to other nutrient management techniques, this is accomplished by decreasing the amount of bioavailable phosphorus present in the lake. This reduction in "food" in turn decreases the potential for excessive phytoplankton primary production, thus helping to lessen the likelihood of a HAB.

Pesticide (Algaecides) Applications

Aquatic pesticides (algaecides) are a "reactive" as opposed to a "proactive" means of controlling, managing or mitigating a harmful algae bloom (HAB) and should not be considered a prevention strategy. This is because while the application of an algaecide may effectively decrease the severity or lessen the duration of a HAB, it does not actually prevent a HAB from occurring in the first place.



Pesticide Treatment Notice

In New Jersey any aquatic pesticide product used to control a HAB must be registered with and approved by both the USEPA and NJDEP. Equally important, the application of the aquatic pesticide must be conducted by a NJDEP licensed aquatic pesticide applicator. Furthermore, the application must be implemented under an NJDEP issued pesticide application permit and the product applied in a manner fully consistent with any limitations or stipulations set forth by the NJDEP in the permit. Thus, algaecide applications should never be conducted by an individual property owner.

Algaecide treatments should be coordinated on a whole lake basis and conducted as part of a comprehensive lake management plan. Additionally, it is better to implement a treatment during the developing stages of a HAB rather than after a bloom has fully peaked. To successfully manage a waterbody in this manner requires a good understanding of the conditions responsible for the development of a HAB. This includes, but not limited to, an understanding of:

- The magnitude, sources and timing of nutrient inputs;
- The role and impact of internal versus external nutrient loading;
- The seasonal succession of algal groups over the duration of the growing season;
- Algal and HAB development under wet versus dry weather conditions; and
- The structure of the lake's food web.

Treating a HAB that has peaked should be avoided and will result in the rapid water column release from the dying cyanobacteria of organic phosphates and cyanotoxins, both of which favor the quick "rebound" bloom of cyanobacteria. For water supply lakes and reservoirs, treating high density blooms may also result in the release of substantial amounts of taste and odor compounds (e.g., Metho-Isoborneol (MIB) and Geosmin). Treatment of a fully manifested HAB with copper-based algaecides, having a large amount of water column biomass, will more than likely result in the rapid depletion of dissolved oxygen concentrations increasing the chance of a fish kill. Therefore, it is always best to plan and conduct algaecide treatments during the earlier stages of HAB development rather than once the bloom has peaked.

Prior to conducting an early-spring algaecide treatment, sampling should be conducted to confirm the phytoplankton community is dominated by cyanobacteria and not beneficial phytoplankton such as diatoms and chrysophytes. Treating a bloom dominated by diatoms and chrysophytes is not recommended by the HAB Expert Team. They typically dissipate naturally and applying an algaecide to a beneficial bloom often sets the stage for an early season HAB.

Determining the status of a bloom, and the responsible species, requires the frequent collection and review of key water quality data; at a minimum phytoplankton assemblage data and cell count data. Other data that can be useful to evaluate the potential for a bloom and the need for a treatment include secchi clarity, chlorophyll *a,* total phosphorus and soluble reactive phosphorus, pH profile, and dissolved oxygen and temperature profile.

It may be possible to use a combination of the above data to set threshold values for a lake that can be used to determine if an algaecide treatment should be planned or is warranted. For example, this could be:

- Dominance (>50%) of the phytoplankton assemblage by cyanobacteria,
- Secchi clarity of less than 1 meter (3 feet), and
- Chlorophyll *a* concentration greater than 20 µg/L

Tracking and using these types of data should enable a lake community to be in a better position to forecast a HAB and then implement, should the data warrant, an algaecide treatment to control the bloom before it has peaked. Such planned algaecide treatments typically result in much more effective HAB control, require the use of less algaecide, and are far less likely to trigger the disruptive secondary post-treatment environmental and ecological impacts.

In general algaecides can be divided into three main types of products: copper based, sodium carbonate peroxyhydrate (peroxide) based, and endothall-salts (Hydrotholl™)

Of the three, the copper based products are the most widely and commonly used group of algaecides. All three types of algaecides have a similar mode of action, that being destruction of the cell wall of the individual algal cells. The copper based products affect the integrity of the cell wall by binding to proteins in the cell wall. This causes the cell wall to lyse (burst). While peroxide based products also cause the cell wall to lyse, the breakdown of the cell wall is the result of a strong oxidation process. Endothall salts also work mostly by impacting the integrity of the algal cell wall but also disrupt algal protein synthesis. Collectively, all three products primarily cause the die-off of algae, phytoplankton and cyanobacteria by degrading the cell wall and causing the cells to breakdown. The balance of this review focuses on the use of the copper and peroxide based products, as these two groups of algaecides are the most commonly used in the management of HABs.

Copper Based Algaecides
The appropriate rate for copper based algaecides is a function of the type of cyanobacteria being targeted and the existing severity of the bloom. As per the manufactures' label, for granular/crystal formations of standard copper sulfate (Cu_2SO_4), dose rates can range from 0.2 ppm to as much as 2.0 ppm, but typically are between 0.2 and 1.0 ppm. Again, following the manufacturers' label for the liquid, chelated formulations of copper based algaecides, dose rates typically range from 0.2 ppm to 1.0 ppm (or from 0.6 gallons/acre-foot to 3.0 gallons/acre-foot).

The three primary negative consequences of copper algaecide treatments are: copper accumulation in the sediments, dissolved oxygen depletion and fish kills.

Sediment copper accumulation occurs as the result of residual post-treatment, dissociated copper settling out of the water column. Because copper is elemental, this residual copper does not break down and over time builds up and concentrates in the sediment. While this is unlikely to result in any appreciable acute environmental impact, it is a consequence of long-term use of copper based algaecides, especially for lakes and ponds that conduct frequent, high dose copper based algaecide treatments.

Copper precipitates more rapidly in hard water lakes than in soft water lakes, but the rate of precipitation can be decreased by using chelated copper algaecide products. Regardless of water hardness, an even more important attribute of the chelated products is that their efficacy is greater as compared to non-chelated copper algaecide. The longer active copper "contact time" associated with the chelated forms increases treatment effectiveness even at lower dose rates. Thus, although more expensive, the chelated copper based algaecides are usually far more effective (especially in hard water) than the non-chelated copper based algaecides. Their use can therefore theoretically decrease copper accumulation in lake sediments.

Although fish kills caused directly from the application of copper based algaecides are rare, they do occur. Copper has the potential to impact the gill epithelium of fish, thereby disrupting oxygen transfer. Trout, carp, goldfish, and koi, and trout are especially susceptible. As such, particular care needs to be taken when treating lakes and ponds supporting these fish. However, copper toxicity may also occur in very soft (low alkalinity) water. As such, it is imperative before conducting a copper based algaecide treatment to measure dissolved oxygen, alkalinity and hardness and use these data before applying the copper product to guide the treatment and determine the correct dose rate.

The most significant and common secondary environmental impact resulting from copper based algaecide treatments is the rapid depletion of dissolved oxygen (DO). This impact is not directly due to the application of the copper product, but rather is the result of the bacterial decomposition of the dead and decaying algae. This can cause DO concentrations to drop enough to trigger a lake-wide fish kill (DO < 4 mg/L). The likelihood of such an impact occurring increases in the summer when lake water temperatures are warm.

All of the above affect pre- and post-treatment DO concentrations. Post treatment DO impacts can be avoided by:

- Never treating more than ½ the surface area of the lake;
- Never treating if pre-treatment DO concentrations are less than 4 mg/l;
- Treating in accordance with recommended algaecide label dose rates; and
- Treating well before a HAB has peaked and HAB biomass has maximized.

Another consideration relative to the use of copper based algaecides is that copper is much more toxic to zooplankton and fish larvae than to cyanobacteria. Additionally, the amount of time it takes for zooplankton, fish larvae and even desirable types of phytoplankton to rebound following a copper treatment is longer than the time it takes for the cyanobacteria to rebound. As previously noted, cellular lysing has the potential to quickly release into the water column high concentrations of cyanotoxins and organic phosphate, thus creating conditions that are favorable for cyanobacteria development. This can even happen at the sediment-water interface following the treatment of benthic HABs (Anderson, et al. 2021). Thus although it may appear counter intuitive, copper based algaecide treatments may promote post-treatment conditions that favor more cyanobacteria development. Therefore, the HAB Expert Team does not recommend the use of copper based algaecides as either the primary means or as a routine management strategy for dealing with a HAB. While copper based algaecide treatments can be beneficial, an expanding field of data shows the risks associated with reliance on such treatments as neither an effective nor environmentally sound approach to HAB management. Thus, although copper based algaecide treatments can be a part of a lake community's HAB management toolbox, they should not be viewed as a primary HAB control option.

Peroxide Based Algaecides
An alternative to the copper based products is the sodium carbonate peroxyhydrate products, referred to herein as peroxide (H_2O_2) based algaecides. These strong oxidizers not only kill cyanobacteria and other algae but have also been demonstrated to have the ability to oxidize and breakdown taste and odor compounds and cyanotoxins. The ability to do so gives this group of algaecides a large advantage relative to the copper based algaecides. Additionally, a growing number of peer reviewed papers report peroxide algaecides, when used correctly and at appropriate dose rates, may be capable of selectively controlling cyanobacteria while sparing eukaryotic phytoplankton, zooplankton, and macrofauna (Matthijs, et al. 2012). The advantage of the peroxide based products appears to be related to the biochemical composition of the cell walls of photosynthetic prokaryotes (cyanobacteria) as compared to photosynthetic eukaryotes (phytoplankton) as well as the mode of action (oxidation). Another advantage of the peroxide based algaecides is there is no post-treatment residual given that the peroxide based products break down rapidly into oxygen and water, and oxygen is generated rather than consumed avoiding the aforementioned DO sag which can occur following the copper treatment.

The two main negative attributes associated with the peroxide products are cost and material handling safety requirements. Presently, the treatment of a lake with a peroxide product can cost as much 10-fold more than a similar treatment conducted with copper based products. This is a function of not only differences in the base costs of the peroxide products, but the need for higher dose rates (resulting in the need for more product) as well as added handling and application costs (discussed below). It may also be necessary to conduct more treatments using peroxide products rather than copper products. Thus, although the peroxide products may have greater treatment and environmental benefits as compared to the copper products, the price differential is often great enough to limit their selection.

Proper handling and application of the peroxide based products are an issue of note. Given their strong oxidative properties more care needs to be taken by the applicator when handling and applying these products to avoid skin and eye burns. The strong oxidizing properties of these products requires the use of dedicated application equipment as the presence of any other residual organic material in the application mixing tanks and/or spray equipment could trigger a strong and potentially destructive oxidative reaction.

As per the manufacturer's label, the application dose for granular peroxide algaecide treatments can vary from 2 lbs. to 100 lbs. per acre-foot, depending on the severity and density of a bloom. The typical maintenance dose or application rate to control an emerging or low density bloom is in the 2-10 lbs. / acre-foot range. Similar to copper algaecide treatments, the peroxide algaecides should be used before a HAB has fully manifested and has reached peak densities. Treatments should once again be limited to less than ½ total lake surface and always conducted in accordance with the manufacturers label guidance and NJDEP permit limitations.

In summary, all algaecide treatments, regardless of the product used, represent short-term, "quick fix" HAB control solutions. Algaecide treatments should be considered lake maintenance as opposed to lake management strategies. The HAB Expert Team recommends algaecide treatments be conducted sparingly. Property owner applications of contact aquatic herbicides are of specific concern and information that discourages this practice should be included in education materials. Algaecide treatments should not be the primary means of HAB control but rather should be conducted as a supplementary means of HAB control. Maximizing the effectiveness of algaecide treatments, while minimizing possible negative environmental and ecological impacts, requires their integration into a comprehensive long-term lake management plan. Also, as is the case for determining the effectiveness of any lake management technique, post-treatment monitoring should be part of an algaecide treatment program. The resulting data can be used to confirm the effectiveness of the treatment and assess if it caused any environmental impacts, as well as build a forecast model to predict when during an expanding bloom is the best time to treat and the proper level of treatment needed for effective HAB control.

Circulation, Aeration, and Oxygenation Methods to Control Internal Non-Point Loading

Circulation, Aeration, and Oxygenation

There are many physical in-lake management methods for decreasing internal loading and vertical transport of P, Fe, and Ammonia-N (Figure 3). There are also several chemical methods to keep phosphorus in the sediments despite anoxia, especially when watershed loading is under control and reducing the recycling of legacy P is needed. Chemical nutrient inactivation is the subject of another section.

Artificial Circulation (aka destratification)

Maintaining surface-to-bottom mixing can be accomplished by diffused air systems that use compressed air to create a bubble plume air-lift pump which circulates the water column and prevents the development of thermal stratification. (Although many call that "aeration", it is more accurately called artificial circulation). Diffused air artificial circulation can be accomplished with line diffusers or clusters (modules) of diffusers. Sizing (CFM) is based on surface area, heating, stratification dynamics to be overcome, and selected air-lift plume mechanics.

Maintaining surface-to-bottom mixing can also be accomplished by mechanical systems (which can circulate the water column in a downward direction). Systems are available powered by solar power (either on the water or lakeside).

In some cases, partial artificial circulation (enhancing the depth of mixing) can be an effective method for reducing the bottom area that experiences anoxia, decreasing the anoxic factor and internal loading. However, in designing this approach Mixing Depth and Anoxic Boundary should be maintained and care should be taken to avoid extending the mixing depth close to the anoxic boundary.

Artificial circulation should be limited to relatively shallow systems (<7m) in which over-bottom anoxia leads to internal loading in close vertical proximity to the mixing depth. System design and sizing are critical to effective management by artificial circulation. If adequate dissolved oxygen is not maintained at the sediment-water interface this approach can result in increased transport of bottom-generated constituents to surface waters where blooms occur. Bottom temperatures increase due to increased transport of heat, which can increase respiration rate and oxygen consumption rate at the sediment-water interface.

Seasonal full or partial artificial circulation has been useful for adapting to climate change at several lakes and reservoirs. Artificial circulation during the spring-summer transition can ensure a more normal spring circulation period, avoid early stratification and anoxia, and enhance diatom productivity (reducing and delaying subsequent cyanobacteria increase). Artificial circulation following fall overturn can enhance the return of diatoms to dominance over cyanobacteria, decreasing the likelihood that cyanobacteria persist through the winter to the next growing season.

Aeration Methods that Preserve Stratification
Hypolimnetic Aeration aerates and circulates the deep-water layer below the thermocline. It preserves stratification, and cold water habitat, while reducing the anoxic factor and internal loading. If a large bottom area experiences anoxia in the depth range of the metalimnion, hypolimnetic aeration will not affect that zone and anoxia can continue to ascend close to the mixing depth. "Classic Hypolimnetic Aeration" can be a suitable alternative if the anoxic boundary hasn't ascended above the top of the hypolimnion.

Layer Aeration is similar to hypolimnetic aeration but was developed for situations where maintaining aerobic and stratified conditions in the 4-10m mid-depth range was most cost-effective. It could be described as a depth-selective artificial circulation technique. The apparatus takes water in at a warmer, shallower, oxygen-rich depth, and a colder oxygen-deficient depth, blends and aerates the water, and returns it at an intermediate depth between the aerator intakes. Returned water is at an intermediate temperature and density and stays in the layer depth range. The resulting temperature and dissolved oxygen content of an aerated layer can be predicted from examining temperature and oxygen depth profiles and lake morphometry information. The method distributes available ambient dissolved oxygen deeper, to offset demand (not dependent on solute phase input). Layer aeration is useful at water supply reservoirs that have multiple depth raw water intakes, for maintaining separation of the mixing depth and anoxic boundary, for restoring cold water habitat, and reducing the anoxic factor and internal loading.

Diffused Air vs. Oxygen
Any of the above "airlift pumping by bubbles" approaches can be performed using compressed air (21% oxygen content), pure oxygen, or "enhanced air" (> 21% oxygen) by increasing the oxygen content of the compressed air (e.g., by including an oxygen generator in facility design). Enriching the oxygen content of the gas to hypolimnetic or layer aerators reduces the amount of in-lake apparatus required, but also increases land-based mechanical systems.

Oxygenation Methods
In recent years, oxygenation methods have been developed and are especially useful tools for maintaining dissolved oxygen conditions. In-lake oxygenation, which maintains stratification structure, can be accomplished using specially designed line diffusers, or in-lake conical gas contactor apparatus. Oxygenation systems can also be side stream, where lake water is pumped from the lake to land, super-saturated with pure oxygen, and returned to the lake. Such systems can be designed to be very depth-selective if stratification dynamics are considered.
Avoid intensive aeration (mixing of the water column top to bottom) during the application of a nutrient inactivant, as that could impact the ability of the floc to settle, thus impacting the success of the treatment designed to bind to nutrients.

Weed Harvesting

Removing noxious plant biomass through harvesting will remove nutrients that could eventually contribute toward potential HABs regardless of when they are being removed. Hydroraking requires a permit from the NJDEP and applications that propose to remove all or excessive amounts macrophytes will not be approved. Care must be taken not to disturb sediments during hydroraking to avoid creating widespread turbidity and depositing fine sediments on the plant surfaces. The sediment coating the plants or suspended in the water column will impact the effectiveness of many herbicides. Some products will adhere to the suspended sediment, thus decreasing the effectiveness or efficacy of the treatment. Also, sediment coating the plants will decrease the effectiveness of contact herbicides that must come into direct contact with the plant in order to impact the plant. Weed harvesting can also impact fish populations through direct killing of young and juvenile fish species inhabiting weeds which provide important nursery areas, and also from the removal of habitat. Spreading weed fragments may cause establishment in other areas of the lake.

Avoid hydroraking for weed control after nutrient inactivation. Disturbing the sediment can compromise the intended effect of the nutrient inactivator by releasing the nutrients back into the water column.

Drawdowns

A review of the literature has identified a number of potential mechanisms that may influence how drawdowns may trigger a HAB event. Summer drawdowns definitely have the potential to produce HABs by reducing the flushing rate of a waterbody, increasing water temperatures, modifying the structure of thermal stratification and increasing the availability of nutrients, particularly phosphorus from the sediments. Thus, for this reason as well as others (e.g., impacts on fishery and recreational use) summer drawdowns are only permitted under a very narrow set of circumstances.

In contrast to summer drawdowns, it is very unlikely that a HAB will occur as a result of a winter drawdown. However, subsequent to such winter drawdowns, HABs have been known to occur later in the spring or summer. When such situations occur, they tend to be the result of a reduction in submerged aquatic vegetation, switching the lake from a clear-water, macrophyte-dominated state to a turbid algal-dominated state (Cooke, et. al., 2005). Another mechanism that may trigger a HAB subsequent to a winter drawdown is an increase in the mobilization of phosphorus and nitrogen after the lake is refilled. Additionally, such conditions seem to be more common in eutrophic waterbodies with sediments / hydrosoils that have a high organic content (Cooke, et. al., 2005). It should be noted that winter drawdowns only produce marginal reductions in aquatic weed growth as the organic sediments exposed do not freeze sufficiently with New Jersey's mild winters. One recommended suggestion:

- The phytoplankton community should be closely monitored under pre- and post-drawdown conditions. Monitoring parameters should include cyanobacteria cell counts, measurements of phycocyanin and chlorophyll-*a* and phosphorus concentrations.

The occurrence of HABs has been further complicated by climate change, especially warmer winters and a higher level of variability in storm frequency and intensity. From a long-term perspective, there is a need to consider how climate change will impact the water quality of a lake and, in turn, the management of it. Integrating how a waterbody will respond to a dry versus wet/normal year should be considered in management plans. Also, the State and lake / watershed stakeholders need to continue focusing on efforts that control the sources of nutrients (in particular phosphorus) from both external / internal sources, to minimize these impacts. Drawdowns are part of a constellation of factors that could increase the risk of a cyanobacterial bloom at a given waterbody. Therefore, it is prudent to consider the timing, duration, and severity of drawdowns as cyanoHAB risk-factors in developing a lake management plan.

Ecosystem Specific Approaches to Internal Nutrient Load Reduction

In some cases, unique natural features of a lake or reservoir ecosystem can be used to reduce nutrient availability to bloom-forming phytoplankton.

Depth-selective Outflow

When a lake or reservoir has a healthy water budget compared to volumes at depth a portion of lake outflow can be induced to come from deep strata to reduce oxygen loss and internal loading by enhancing the deep flushing rate. That has been accomplished at some lakes by designing a simple apparatus that fits into existing flashboard slots to have some of the flow over the spillway come from a selected depth (Hydrologic Discharge Control Assembly). The approach tends to be most applicable to run-of-river reservoirs with a healthy water budget, and lakes that have been raised by a low dam with flashboard slots for seasonal lake level management.

Use of Lake-Generated Iron as a Coagulant for Phosphorus Removal

A Clean Lakes Section 314 diagnostic study at a New England Lake identified internal loading of P and Fe as a major stimulus for intense cyanobacteria blooms. It was also determined that there was much more Fe release from the sediments than P (not all the iron that became reduced and soluble had bound P). Iron, in its oxidized ferric state, is a particularly good coagulant for phosphorus. A system was developed to harvest iron mobilized by anaerobic respiration in the lake, re-oxidize it, and return it to precipitate phosphorus from the water column (P that came from internal or external loading).

Flow-Routing and Reservoir Partitioning

Run-of-river reservoirs offer some unique opportunities for managing water quality. In several water supply reservoirs longitudinal reaches were compartmentalized (riverine, transition, and lacustrine reaches) and managed individually by an aeration or artificial circulation method. In other cases, water flow from up-reservoir to the dam was induced to be through the middle of the water column, containing surface phytoplankton and deep anoxia in upper reaches. In some reservoirs the hypolimnion was contained up-reservoir by a submerged weir curtain and the supply withdrawal basin by the dam was maintained in an aerobic condition by hypolimnetic aeration (reduced scale due to reduced area and volume to be aerated).

Suggested Best Management Practices for Implementing Chemical and Mechanical Strategies

- Avoid combined timing of a weed and algae treatment (using herbicide/algaecide). This combination may cause a major dissolved oxygen (DO) drop due to the rapid increase in bacterial decomposition and associated oxygen demand. DO is a measure of the amount of oxygen in the water and is the amount available to living aquatic organisms.
- Allow sufficient time for a herbicide treatment to impact the plant prior to moving forward with removal or other treatments.
- While it is not uncommon to follow up a systemic herbicide treatment with a contact herbicide treatment, these treatments are spaced apart with the latter treatment intended to complement the former by controlling any residual plant growth not addressed by the systemic product.

Conducting two or more herbicide treatments over a short time frame may cause a rapid die-off that elicits a high Biological Oxygen Demand (BOD) resulting in a fish kill. Similarly, disturbing the sediments via mechanical control enough to depress DO concentrations and then conducting a large-scale herbicide treatment that causes a rapid die-off should also be avoided. The combination of the depressed starting DO and the added DO demand owing to bacterial decomposition of the dead weeds could drop in-lake DO concentrations enough to trigger a fish kill.

The Bottom-Line regarding managing internal loading to reduce cyanobacteria blooms:

Reducing the non-point internal loading source can accomplish a significant decrease in the availability of constituents that stimulate cyanobacteria blooms (P, Fe, N). Each of the above-described in-lake management methods is applicable to specific cases. None is a “cure all”. Sometimes maintaining a “continuously stirred tank reactor- CSTR” function by an artificial circulation approach is most cost-effective for improving the capacity of a lake to deal with elevated nutrient content while not experiencing problematic cyanobacteria blooms. If the eutrophication process is identified early enough, when the anoxic boundary ascends no higher than the top of the hypolimnion, hypolimnetic aeration or oxygenation could be the best practice. If the anoxic boundary ascends higher, or if maintaining separation of the Mixing Depth and Anaerobic Boundary is most important, a specific layer aeration or oxygenation design approach might be best. Recognizing the effects of climate change to date, and expectations for the future, hybrid systems incorporating several operational alternatives for seasonal deployment might be best in some lakes and reservoirs (providing adjustability to adapt to changing climatic conditions). In some cases, the natural features of a specific lake or reservoir provide an opportunity to manage water quality cost-effectively by a customized approach. Reducing external loading, watershed loading, is always prudent for managing a lake or reservoir long-term. However, well selected, designed, implemented, and monitored in-lake management approaches can also be particularly useful for managing ecosystem structure and function and water quality, especially while watershed management is implemented. Selection of in-lake management methods should be ecosystem specific.


Absegami Lake

10.References

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