Harmful Algal Blooms

Prevention, Response, and Avoidance Manual

Source: https://www.youtube.com/watch?v=sHnsiS22CB4

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Harmful Algal Blooms:
Prevention, Response, and Avoidance Manual

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Glossary of Terms

Algae: Algae are autotrophic aquatic organisms that can conduct photosynthetic activities due to the presence of chlorophyll.

Algal Bloom: The rapid proliferation of algae in an aquatic system.

Algaecide: Chemical(s) used to kill or prevent the growth of algae in aquatic systems.

Best Management Practices (BMPs): Structural and non-structural practices in a watershed to manage soil and water effectively to minimize downstream impacts.

Blue-Green Algae (BGA): Although referred to as algae, BGA are classified as photosynthetic bacteria, otherwise known as Cyanobacteria.

Chlorophyll-a: Chlorophyll-a is the photosynthetic pigment used by plants during photosynthesis. The concentration of chlorophyll-a in water is used as an indicator for a harmful algal bloom.

Cyanobacteria: Photosynthetic organisms with the properties of bacteria that are capable of producing toxins that can negatively impact the environment and the ecosystem. Previously known as blue-green algae.

CyanoHAB: A harmful algal bloom that is dominated by cyanobacteria.

Cyanotoxins: The toxins produced by cyanobacteria, which can impact human, animal, and aquatic ecosystem health.

Diatoms: A single-celled algae.

Eutrophic: A body of water with elevated nutrients that support a dense plant population.

Harmful Algal Bloom: The rapid growth of algae that can impact the use of a water body due to physical interference, production of compounds that cause taste and odor issues, or production and release of toxic compounds.

Geosmin: Naturally occurring compound, produced by cyanobacteria and other bacteria, that gives water an earthy or musty smell.

Lyse: To rupture an organism's cell wall, killing the cell and releasing any toxins that may be present inside the cell.

Nutrients: Nutrients such as nitrogen and phosphorus are essential for plant growth. In the case of water bodies, excessive nutrients cause algae and aquatic plants to proliferate.

Runoff: Excess water after a storm event (or irrigation event) that does not infiltrate through the soil or evaporate and instead flows over the land and into surface waters.

Trophic Status: Describes the degree of pond aging and typically uses various characteristics (chlorophyll a concentrations, phosphorus concentrations, turbidity, etc.).

1.0 Harmful Algal Blooms

Harmful algal blooms (HABs) are the over-abundant growth of algae or bacteria that may interfere with use of water or a waterbody. HABs include several types of blooms:

- Large nontoxic blooms that can interfere with physical movement (e.g., swimming) in the waterbody or can clog a water intake/outlet structure (Figure 1).
- Blooms that produce problematic compounds that can interfere with taste and odor of the water, causing it to be unpalatable for drinking.
- Cyanobacterial blooms that are capable of producing toxins that can harm fish, wildlife, livestock, pets, and humans.

Cyanobacteria were previously referred to as "blue green algae" and that term is still sometimes used. Since cyanobacteria are technically not algae, they will be referred to as cyanobacteria or cyanoHAB throughout this Manual.

Figure 1. In 1999, excessively thick algal bloom in Lake Greenwood physically interfered with industrial facilities' water intakes (Image Credit: Dave Hargett).

HABs occur throughout South Carolina's (SC) freshwaters and sometimes cause taste and odor issues in local drinking water (Figure 2). HABs are most likely to occur in slow-flowing or stagnant waters with elevated nutrient levels – conditions that are common in ponds. HABs are most common during summer and fall, warm temperatures and little rain often support heavy aquatic plant growth in shallow ponds that are typically rich in nutrients, though they can occur throughout the year. Waters protected from the wind with little to no aeration frequently support excessive growth of cyanobacteria (Olkowski, 2009). HABs are rarely seen in flowing streams in the southeastern US.

The Post and Courier
COLUMBIA

Unclear how much longer Columbia's smelly, earthy-tasting water will last

BY TYLER FEDOR TFEDOR@POSTANDCOURIER.COM
MAY 31, 2022

Figure 2. Headline about problems caused by a HAB (Image Credit: *The Post & Courier*).

1.1 HAB Visual Identification

Visual clues can be helpful in early detection of a potential bloom. As various types of algae and bacteria contribute to a HAB, they can look very different, and a microscopic examination is necessary to confirm the species contributing to the HAB bloom. HABs can occur anywhere in the water column and may cause the water to become opaque (Paerl & Otten, 2013) or to look soapy. Alternately, HABs can be distributed throughout the water body in a way that obscures the presence of the algal biomass.

When present on the surface, a HAB may appear as obvious as thick layers of floating algal mats, may form a scum or look like paint floating on the surface (CDC, 2021a), or can be a bright pea-soup green, blue, red, brown, or a mixture of these colors (USGS, 2019) (Figures 3 to 8). However, color is not a reliable method for identification as many types of algae (such as eukaryotic green algae) and cyanobacteria (e.g., *Dolichospermum* and *Microcystis*) can float to the surface and look similar in appearance. For example, both algae and cyanobacteria can form pea-green and blue paint-like scums on the water's surface. Other species (such as eukaryotic green algae) also form pea-green scums that only aesthetically impair the water.

If a HAB is suspended within the water body, it may exist as suspended globules of various sizes or cause the water to have a turbid green appearance. Blooms can also be 'hidden' as a layer deep enough below the surface not to be visible. If the HAB exists as a benthic mat on the bottom of the water body, it may have a vivid green color or even a dark, almost black, color. Mats of cyanobacteria typically have a characteristic 'musty' smell if brought to the surface.

Figure 3. A cyanobacterial bloom with typical "pea-green" or painted appearance (left). On the left, the cyanobacterial bloom is mixture of species including *Microcystis, Dolichospermum*, and *Aphanizomenon* (Image Credit: left-Sarah White, Clemson Extension; right-Emily Bores, SCDHEC).

Figure 5. Cyanobacteria (*Lyngbya* spp.) bloom (Image credit: Emily Bores, SCDHEC).

Figure 4. Cyanobacteria (*Microcystis* spp.) blooms (Image credit: left-Emily Bores, SCDHEC; right-Zane Knight, Gaffney Board of Public Works).

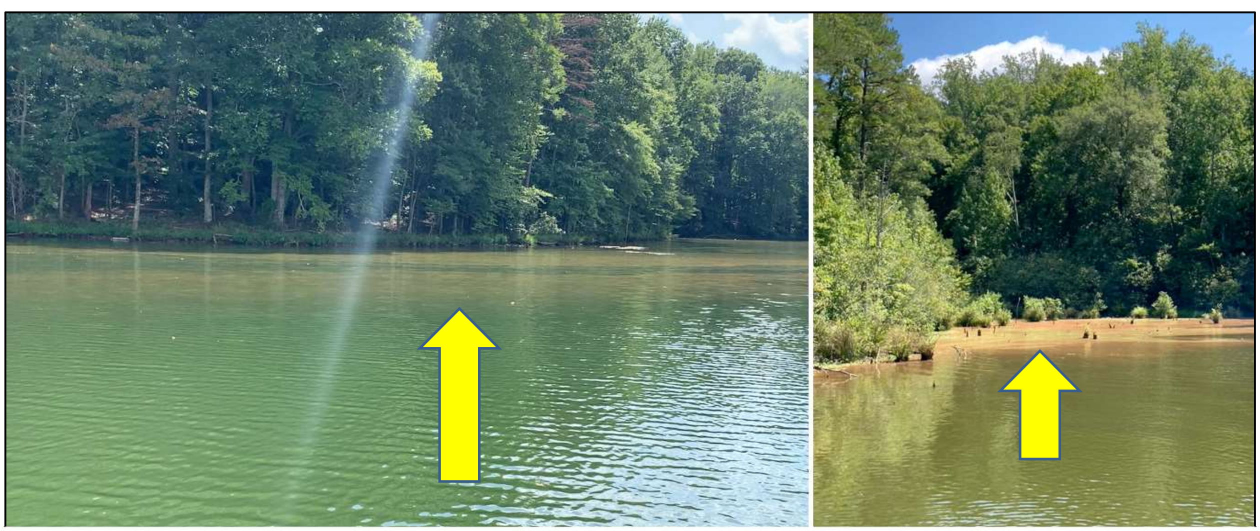

Figure 6. Cyanobacteria (*Euglena* spp.) bloom near the shoreline – note the reddish tint (Image credit: left-Zane Knight, Gaffney Board of Public Works; right-Emily Bores, SCDHEC).

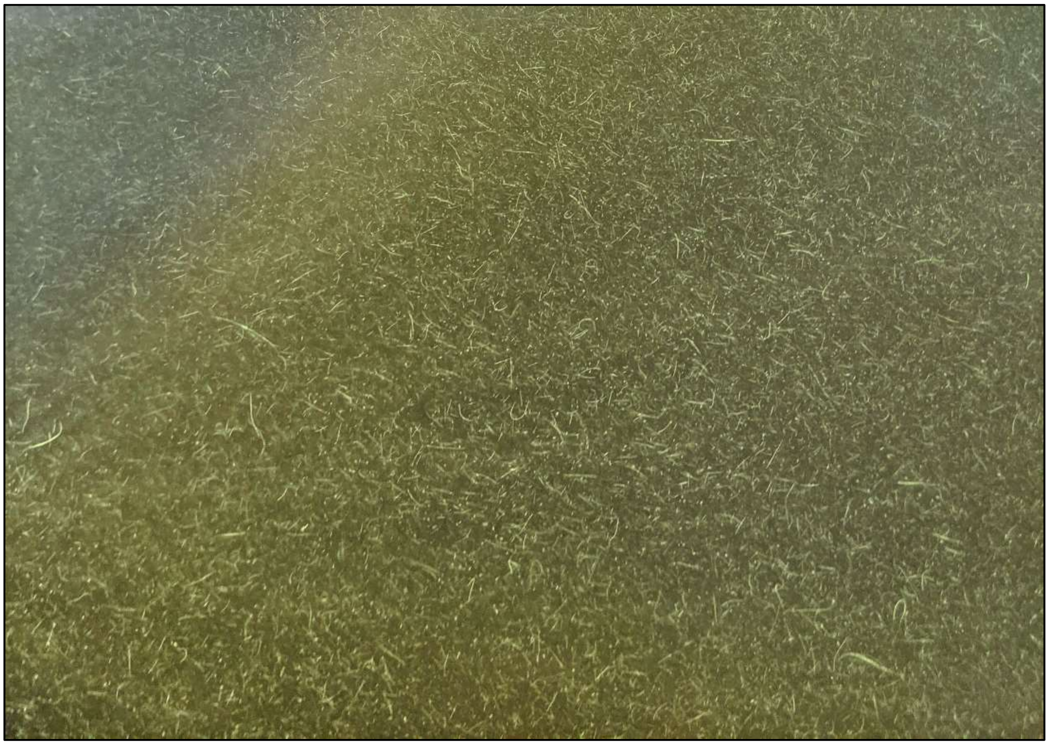

Figure 7. Cyanobacteria (*Aphanizomenon*) bloom (Image credit: Emily Bores, SCDHEC).

Figure 8. Mixed cyanobacteria bloom, including species of dinoflagellate and *Dolichospermum* (Image credit: SCDHEC).

1.2 CyanoHAB Species

In North America, there are 124 genera of cyanobacteria and only microscopic examination can reliably distinguish them. In SC, the most common types of cyanobacteria include *Dolichospermum, Lyngbya*, and *Microcystis*.

Dolichospermum (formerly known as *Anabaena*) is a filamentous species that quickly forms slimy blooms at the water's surface that resemble green paint (Figures 3 and 8).

Lyngbya usually grows in benthic mats on the bottom of lakes and ponds and often has a very dark color and distinctive 'muddy' smell due to the production of geosmin (Figure 4). Geosmin has a disagreeable odor but does not present a threat to animals that drink or come in contact with it. After years of accumulation, *Lyngbya* can produce enough oxygen to form bubbles in the algal mat causing it to rise to the surface. Such accumulations result from long periods of growth of less visible benthic mats.

Of these, *Microcystis* is the most common and is sometimes toxic (Figure 5, USEPA, 2021). *Microcystis* can control their buoyancy by forming small gas vesicles inside their cells. The buoyancy helps them move through the water column and often makes their bloom appear scattered; they can also have a pea-soup color and pigpen odor.

Oscillatoria can exist as a layer of cells within the water column that rise to the surface later in the season and sometimes have a red color.

Diatom blooms are found either on the waters' surface or at the bottom, making the color glistening brown and rarely evenly distributed throughout the water column (Kannan & Lenca, 2013). In South Carolina, diatom blooms are rarely classified as a HAB, with the notable exception of *Didymosphenia*, sometimes called 'rock snot' which has not been found in SC (*personal comm.* Dr. John Hains, Clemson University, Emeritus Professor).

1.3 HAB Contributing Factors

The occurrence of HAB and the dominant species contributing to a bloom depends on numerous factors such as temperature, nutrient availability, light availability (sunlight and turbidity), and water motion (turbulence). Warmer temperatures, more intense sunlight, and higher nutrient loads may increase the proliferation of some HAB species (Anderson et al., 2002).

Temperature is one of the most important factors determining habitat suitability for aquatic organisms of all types, including algae and cyanobacteria. In many locations in SC, water in lakes and ponds warms to and may exceed 80-95ºF (30-35°C) at the surface. Winter temperatures rarely approach freezing and, even then, near-freezing temperatures last for only short periods, enabling continued survival of many species that contribute to HABs.

HABs also require light and nutrients (e.g., phosphorus (P) and nitrogen (N)) to grow. Because of the latitude of SC, light is typically abundant, unless water is very turbid or shaded. Light intensity and day length vary seasonally and influence water temperature. Nutrient sources are often abundant and can include external (e.g., fertilizer, stormwater runoff, improper wastewater treatment) and internal sources (e.g., phosphorus released from accumulated sediment).

Upstream land use and activities, as well as pond management practices, are critical factors regulating nutrient availability within lakes and ponds. If a water body has accumulated sediment over time, nutrients - particularly phosphorus - may be stored within those sediments. Under certain conditions (typically anaerobic), these sediments can also become a source of internal P 'loading' into the water body (Varjo et al., 2003). The addition of lime, which may be done to stabilize pH levels, also encourages release of nutrients from sediment. The use of aerators, which pump air to the pond bottom, can slow nutrient release from accumulated sediment and provide water quality benefits.

External loading into ponds is often seasonal and regulated by trends in human activities, precipitation patterns, and stormwater runoff. In deeper ponds (more than 8' deep) (Nix et al, 2021), seasonal patterns of stratification (thermocline – layer of warm water over cold water), or anoxia (decrease in oxygen exchange between thermally-stratified layers decreases) may occur that enable cyclic release of nutrients bound in the sediments (Richardson et al, 2022). Water movement also influences aquatic plant growth – as motion has the potential either to stimulate or to inhibit growth, depending on other conditions. For example, movement of water could potentially increase nutrient cycling, bringing the nutrients from the bottom of the pond to the surface, supporting a HAB. The outcome depends on the unique characteristics of each water body.

1.4 Seasonality and Prevalence of Species

HABs are more common in the summer and fall, although blooms can occur throughout the year. Figure 9 displays a common model of the seasonal dominance of major types of algae and cyanobacteria. Many species are present throughout the year but are likely not as prevalent during certain seasons.

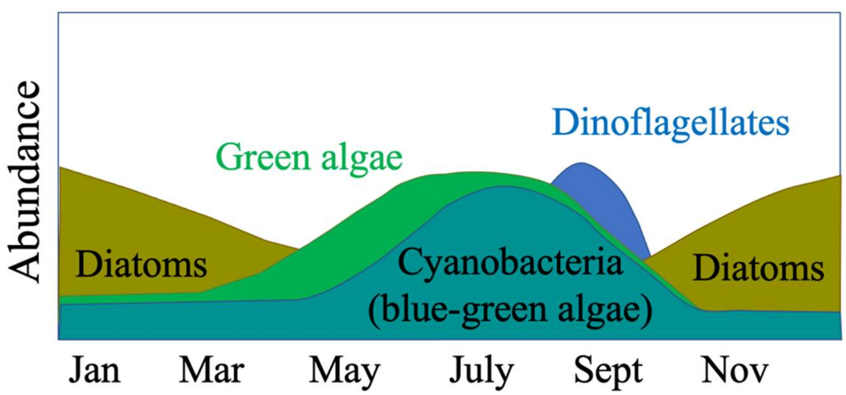

Figure 9. Seasonal dominance of typical species of algae and cyanobacteria found in SC waters (Graphic: SA White).

Diatoms are a distinct group of algae, identifiable under a light microscope by their yellow-brown coloration. In addition to P and N, diatoms also require silica to grow and reproduce. Silica is rarely a limiting factor in SC. Diatoms can outcompete other aquatic plant species due to their tolerance to low temperature, low light conditions, and ability to survive in turbulent waters (Bellinger & Sigee, 2010). In fact, diatoms are present year-round in most ponds in SC but may be dominant during the cooler seasons (Figure 9) due to their adaptability to cold conditions and ability to extract silica from the water column during abundant precipitation and runoff. Nevertheless, diatoms are rarely, if ever, the cause of a HAB in SC.

Green algae are incredibly diverse with 302 genera described in North America (Wehr & Kociolek, 2015). They are present throughout the year and often display rapid growth during the spring and early summer (Figure 9). Green algae can form nuisance growths and are common in SC ponds and lakes but do not produce toxins. The impairments green algae cause are usually limited to smell (when they decompose) and a disagreeable aesthetic appearance when forming thick surface mats. Green algae dominance throughout much of the summer may be due to elevated N levels available from spring runoff (Bellinger & Sigee, 2010).

Cyanobacteria can survive extremes in temperature and light intensity, including the *absence* of light. Some cyanobacteria species can alter their own buoyancy to optimize light exposure and nutrient availability. When excess P is available, they also absorb and store it in their cells for later growth when P is limited. Most cyanobacteria can also fix N from the atmosphere if dissolved N is not available in the water. Most, if not all, can produce a wide variety of toxins under conditions that we still do not fully understand, making this last capability almost impossible to predict (Paerl & Otten, 2013; New York State Federation of Lake Association, 2020). Cyanobacteria typically become prevalent during late summer and fall (Figure 9). In SC, due to the overall warmer climate, cyanobacteria may become the dominant algal species present even earlier (late spring or early summer) in some ponds. Cyanobacteria are least likely to dominate during winter.

Dinoflagellates are common in all SC lakes and ponds but typically only become the dominant species present during late summer and early fall (Figure 9) when high concentrations of nitrates and phosphates are available (Bhaskar et al., 2020). Dinoflagellates are motile and migrate vertically through the water column each day, swimming towards or away from light to optimize light intensity for growth. In marine systems, dinoflagellates are the primary organisms forming 'red tides,' the original terminology for algal toxins produced by marine dinoflagellates (Sheath & Wehr, 2015). Freshwater dinoflagellates are not known to cause toxic algal blooms. Algal toxins in freshwater lakes and ponds are almost exclusively the result of cyanobacterial toxin production.

1.5 HABs in South Carolina

In 2018, in response to cyanobacteria blooms throughout SC, the SC Department of Health and Environmental Control (SCDHEC) (1) initiated the creation of outreach materials and (2) developed a limited monitoring and reporting program. Due to limited resources, including just two staff members in 2021, monitoring by SCDHEC currently focuses on public-use reservoirs throughout the state.

Report HABs: to Emily Bores (WTR_asp_hab@dhec.sc.gov; 803.898.8374)

For more information, visit SCDHEC's:

- HAB overview (https://bit.ly/3F4iCIw)
- Algal Bloom Monitoring website (https://bit.ly/3F3k51m): current HAB Monitoring, Watches, and Advisories

- Annual report (https://bit.ly/3vub2Ua): summary of HAB conditions for that year.

1.6 Sampling for Confirmation of a HAB and Species Identification

Confirming the species of cyanobacteria present helps identify if the bloom may produce a specific toxin and determine an appropriate response to reduce potential health impacts. A laboratory can provide species identification, but results typically take a minimum of three days, if expedited, and often longer. In the meantime, there are options for quick, albeit potentially less accurate, results.

Test results vary in accuracy based on improper collection or handling of samples. The most protective response is to assume the bloom is toxic and immediately limit access by humans, livestock, and pets while conducting a further evaluation.

1.6.1 Sample Collection

Collecting a sample will involve the risk of exposure to the potentially toxic bloom. Appropriate safety measures should be taken to avoid skin contact, inhalation, and ingestion.

- Waterproof gloves should be worn while collecting and handling the sample.
- Thoroughly wash hands, gloves, and the outside of the sample jar after collecting the sample.
- Avoid leaning over the waterbody while collecting the sample to reduce potential for falling into the water or breathing airborne toxins.

Typically, samples can be collected in a plastic or glass container, but some tests or laboratories may have specific requirements. Be sure to leave space at the top of the sample jar to allow for gas formation during transport.

1.6.2 Do It Yourself: The Stick Test for Cyanobacteria

Cyanobacteria can form a scum at the water surface and can sometimes resemble filamentous algae. At the pond in question, use a sturdy stick (or rake/shovel handle, etc.) to try to lift the plant out of the water; if the stick looks like it has paint on it, it is likely cyanobacteria. If the stick lifts out strands of material (which may look like green threads or hair), filamentous algae are more likely present. Please see Clemson Extension's HGIC Fact Sheet: DIY Visual Indicators, Stick Test, and Jar Test for Cyanobacteria (https://hgic.clemson.edu/factsheet/do-it-yourself-visual-indicators-stick-test-and-jar-test-for-cyanobacteria/) for complete instructions.

1.6.3 Do It Yourself: The Jar Test for Cyanobacteria

Many species of cyanobacteria can regulate their movement within the water column and often rise to the surface when the water is calm. Collect a water sample (as described above), cap the sample, and take it to a cool, dark location (e.g., refrigerator) where it can sit undisturbed for 8-16 hours. If a scum forms on top, it is likely cyanobacteria. If the sample remains well mixed or material settles to the bottom, it is unlikely to be a cyanobacteria bloom. Please see Clemson Extension's HGIC Fact Sheet: DIY Visual Indicators, Stick Test, and Jar Test for Cyanobacteria (https://hgic.clemson.edu/factsheet/do-it-yourself-visual-indicators-stick-test-and-jar-test-for-cyanobacteria/) for complete instructions.

1.6.4 Professional Testing: Clemson University Plant and Pest Diagnostic Clinic

Clemson University's Plant and Pest Diagnostic Clinic offers professional identification of cyanobacteria to the species level. This option will provide accurate species identification and control recommendations, typically within about five business days. A sample must be collected and transported to the lab. Please see Clemson Extension's HGIC Fact Sheet: Submitting an Algae Sample For Identification (https://hgic.clemson.edu/factsheet/submitting-an-algae-sample-for-identification/) for complete instructions.

2.0 Harmful Effects of Cyanobacteria

Increased cyanobacterial biomass indirectly harms aquatic ecosystems via increased competition for nutrients among aquatic organisms. Direct harm from cyanobacteria is caused by production and release of toxic substances, otherwise known as cyanotoxins. Cyanotoxins can cause serious health issues or even death.

Even if the algal biomass is obvious and massive, there is no way to visually determine if the algal bloom is toxic or 'harmful' beyond the smell or aesthetic appearance. Laboratory evaluation and expert proficiency are required to confirm if toxins are being released. For this reason, when such blooms are observed or even suspected, caution is warranted. Use caution when approaching a water body that may be experiencing a HAB and avoid potential exposures through skin contact, breathing inhalation, or ingestion.

2.1 Cyanotoxin Exposure and Categories

Cyanotoxin exposure routes include skin contact, ingestion of contaminated water, and sometimes through inhalation of airborne cyanotoxins. Exposure can occur through surface water bodies (e.g., ponds or reservoirs), water used for drinking or dialysis, or contaminated nutritional supplements. The exposure route, dose (concentration), and mixture components involved in exposure determine the overall impact. Cyanotoxins can be divided into several categories based on their toxic effects (Table 1, van der Merwe 2015).

Table 1. Overview of types of cyanotoxins.

Type of Toxin	Main Impact	Reaction Timing	Toxin
Dermatoxin	Skin Reactions Rashes	Hours or days	Lynbyatoxin-a Aplysiatoxin
Hepatotoxin	Liver function	May act slowly (days or weeks later)	Microcystin Nodularin Cylindrospermopsin
Neurotoxin	Paralysis of skeletal and respiratory muscles	Rapid (minutes to hours)	Anatoxin Saxitoxin BMAA Microviridin J

2.1.1 Hepatotoxins

Hepatotoxins damage the liver. Low to mild exposures are characterized by irritation to the skin, respiratory, and gastrointestinal systems. Early symptoms of exposure include lack of appetite, depression, and diarrhea (van der Merwe 2015). Higher exposures result in severe liver damage. Symptoms include dehydration, electrolyte imbalances, vomiting, acidosis (too much acid in body fluids), and hypovolemic shock (the heart cannot pump enough blood throughout the body due to fluid loss) (Osswald et al. 2007).

Examples of hepatotoxins include:

- Microcystin which is produced by *Microcystis, Planktothrix (Oscillatoria),* and *Dolichospermum* (*Anabaena*) (Babica et al. 2006). Microcystin is primarily dominant in regions characterized by intensive agriculture, industrial development, and urbanization.

- Nodularins are mainly produced by *Nodularia spumigena* and possess the same effect mechanism as microcystins (Chen et al., 2013).

- Cylindrospermopsin is produced by *Cylindrospermopsis, Aphanizomenon, Anabaena, Lyngbya, Umezakia,* and *Raphidiopsis* (Guzmán-Guillén et al. 2013).

2.1.2 Neurotoxins

Neurotoxins impact nerve tissue and can cause paralysis. Harmful effects can occur rapidly – sometimes within minutes of exposure.

Examples of neurotoxins include:

- Anatoxins are produced by several genera of cyanobacteria, including *Aphanizomenon*, *Arthrosporic*, *Cylindrospermum*, *Dolichospermum*, *Microcystis*, *Nostoc*, *Oscillatoria Phormidium*, *Planktothrix*, and *Raphidiopsis* (Osswald et al. 2007). Harmful effects of anatoxin occur rapidly, and mortality is quick due to the fast absorption rate. Symptoms of exposure include loss of muscle coordination, muscle tremors, and respiratory distress; terminal symptoms include convulsions, shock, and heart failure (van der Merwe 2015).

- Saxitoxins are produced by *Aphanizomenon*, *Cylindrospermopsis*, *Dolichospermum*, *Lyngbya*, *Planktothrix*, and *Scytonema* (Smith et al. 2012). Saxitoxins in freshwater can accumulate in tilapia and shellfish (e.g., mussels). Low-level exposure to this toxin causes a tingling sensation around the mouth, and high exposure can cause mouth and throat numbness, extremities, acute muscle paralysis, and respiratory failure (Osswald et al., 2007).

2.1.3 Cyanotoxins and exposure limits

At the state level, the SCDHEC adopted cyanotoxin water quality standards for primary recreation in 2020 (Busari et al, 2022). Rather than a regulatory approach, the US Environmental Protection Agency (USEPA) published a Health Advisory for cyanotoxins (USEPA, 2015) and the World Health Organization published suggested limits (Table 2).

Cyanotoxin levels can vary throughout a pond. For example, water body mixing (controlled by wind, temperature, or aeration) can influence exposure levels and the relative risk of contact with the water body (Figure 10).

Table 2. Suggested and regulatory cyanotoxin standards for SC waters.

Cyanotoxin	SC Water Quality Standard	USEPA Drinking Water Health Advisory (10-day)	World Health Organization (WHO)

	(SC Code, 2020)				
	Freshwater (for recreational use)	Bottle-fed infants and pre-school children	School-age children and adults	Suggested limit Drinking Water	Suggested limit Recreational Water
Cylindrospermopsin	15 µg/L	0.7 µg/L	3.0 µg/L		
Microcystins	8 µg/L	0.3 µg/L	1.6 µg/L		
Microcystin-LR				1.0 µg/L	10 µg/L

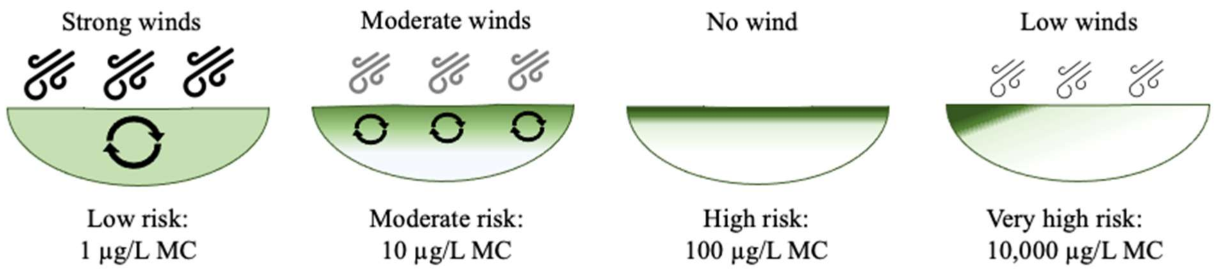

Figure 10. Illustration depicting *potential* formation, distribution, concentration, and health risk of a self-buoyant cyanobacterium (e.g., *Microcystis* spp., MC) in a pond. Concentrations are for reference only and represent the potential for cyanobacterium mixing and distribution within a water body (Adapted from Chorus & Welker, 2021; illustration, SA White).

2.2 Livestock Exposure to Cyanotoxins

The harmful effects of cyanotoxins can impact humans, pets, wildlife, and livestock. Animals can suffer after exposure to cyanotoxin-contaminated water (Wood, 2016). According to a nationwide HAB survey conducted in 2019 (CDC, 2021b), 14 states voluntarily reported a HAB that resulted in human (63 cases) and animal (domestic pets 27 cases, livestock 11 cases, and wildlife 329 cases) illness or death. Readers of this manual are encouraged to watch a YouTube video by Dr. Cory Heaton (https://www.youtube.com/watch?v=sHnsiS22CB4&t=231s).

The effects of cyanotoxins vary with exposure route, exposure concentration, and weight of the organism exposed. Exposure routes include ingestion of algal material, drinking from or wading in contaminated water, ingestion of contaminated nutritional supplements, and licking of contaminated furs (Rankin et al., 2013; Wood, 2016).

To determine exposure levels that would be protective to humans, dogs, and livestock, we started by identifying average organism weight and daily water consumption (Table 3). This information was compiled from various sources: livestock information included literature-based estimates using average cattle weights with maximum water consumed; dog information was from a recent study in Oregon (Farrer et al., 2015) that anticipated water consumption and body weight; and human water intake was based on the authors' calculations following methods used by Farrer et al. (2015) and normalized to beef and dairy cow weight and daily consumption of water.

Table 4 provides estimated cyanotoxin levels that would be protective of organisms and are lower than those reported by other cattle drinking water guides because they represent conservative estimates of no observable adverse effect concentrations. For example, Olkowski (2009) reported permitted microcystin LR values in drinking water at 4.2 µg/L for cattle with an average weight of 800 kg and peak water consumption of 85 L/day. The microcystin LR concentration was a 10x higher concentration than that calculated for beef and dairy cows using the method detailed by Farrer et al. (2015), which was a more protective estimate that used lower body weight (550 to 567 kg cattle mass) and higher water consumption (136 to 227 L/day of water consumption) as shown in Table 3.

Table 3. Average body mass and water consumed per day for humans, dogs, and beef and dairy cattle.

Organism	**Average weight (kg)**	**Average weight (lbs)**	**Water consumed (L/day)**	**Water consumed (gal/day)**
Human	60 [a]	132	2.0	0.40
Dog	variable		0.255	0.05
Beef cow	550	1210	14 - 136	3-30
Dairy cow [b]	567	1250	136 - 227	30-50

[a] 60 kg based on WHO recommendation rather than 70 kg (EPA recommendation) to be more protective)

[b] Breed specific average weights [Ayrshire – 1,150 lbs (522 kg), Brown Swiss – 1,350 lbs (612 kg), Dairy Shorthorn – 1,450 lbs (658 kg), Guernsey – 1,050 lbs (476 kg), Holstein-Friesian – 1,600 lbs (725 kg), and Jersey – 900 lbs (408 kg)]

Table 4. Calculated drinking and recreational water guidelines for concentration limits for cyanotoxins to mitigate risk of cyanotoxin toxicity for humans and dogs – adapted for livestock using calculations from Farrer et al. (2015). Values are equivalent to no-observable adverse effect concentrations (NOEC) for species listed.

Cyanotoxin	**Water Source**	**Human (µg/L)**	**Dog (µg/L)**	**Beef Cow (µg/L)**	**Dairy Cow (µg/L)**
Anatoxin-a	Drinking [a]	3.0	0.4 [b]	0.40	0.25
	Recreational	20.0		2.70	1.64
Cylindrospermopsin	Drinking	1.0	0.1	0.12	0.07
	Recreational	6.0		0.81	0.50
Microcystins	Drinking	1.0	0.2	0.20	0.12
	Recreational	10.0		1.35	0.82
Saxitoxins	Drinking	1.0	0.02	0.20	0.12
	Recreational	10.0		1.35	0.82

[a] Drinking and recreational guidelines for humans were developed by the Oregon Health Authority (Farrer et al., 2015)

[b] Separate drinking and recreational values for dogs were not calculated

2.3 Livestock Reactions to Cyanotoxins and Treatment

Acute exposure of animals to cyanotoxins can cause vomiting, skin rash, diarrhea, and visual disturbances (e.g., blurred vision, halos). Sublethal effects include tremors, loss of body control, and labored breathing. Chronic effects include paralysis, loss of motor function, and, ultimately, death (Christensen & Khan, 2020). Symptoms and treatments can vary by cyanotoxin, as briefly noted below. Livestock owners should seek guidance from a veterinarian as soon as possible following a known or suspected cyanotoxin exposure.

Within minutes or days of ingestion, microcystins may cause symptoms such as vomiting, diarrhea, lethargy, depression, anorexia, jaundice, abdominal tenderness, dark urine, and tarry stools. Treatment options for this exposure include emesis induction and oral activated charcoal slurry to achieve gastric decontamination. Oral cholestyramine can also be effective up to 7 days post-exposure (Rankin et al., 2013). Livestock symptoms expressed within minutes to days after cylindrospermopsin exposure are similar to those of microcystin and are compounded by excessive thirst and increased urination. Timely intervention also entails gastric decontamination with emesis induction and oral activated charcoal slurry.

Exposing livestock to neurotoxins like anatoxin-a and saxitoxin can cause sporadic reactions within minutes. Symptoms such as irregular breathing, seizures, paralysis, respiratory arrest, and sudden death can occur within minutes to hours of exposure. Medical interventions include gastric decontamination, artificial ventilation, and supportive therapy (California Department of Public Health, 2017).

2.4 Cyanotoxin Sampling and Testing

Many cyanobacteria species can produce toxins, but we do not yet understand the conditions that trigger the production or release of toxins by cyanobacteria. While algae cells are alive, the toxins may be intracellular, but when the cells are lysed (or killed), the toxins - if present - will be released so that cyanotoxin levels will likely spike following treatment of a cyanobacteria bloom (Figure 11).

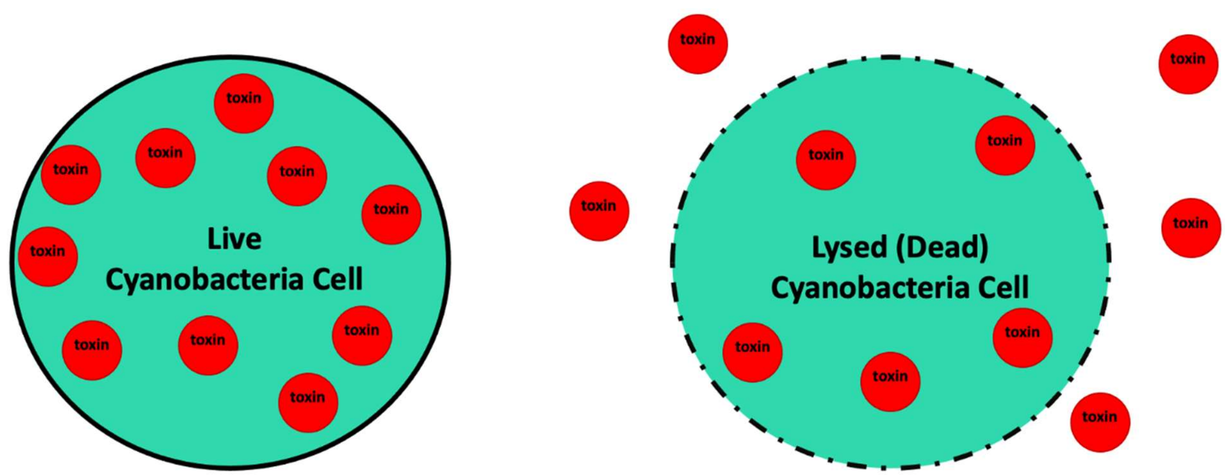

Figure 11. If produced, toxins may be held within the live cyanobacteria cells but will be released when the cell dies, and the membrane breaks down (Graphic: H Nix).

2.4.1 Do It Yourself: On-Site Tests for Cyanotoxins

DIY sampling kits are helpful and can provide rapid results for the presence/absence of specific cyanotoxins. Results from these sampling kits will not be as accurate as professional analysis. Kits available for purchase vary in cost, accuracy, and range of toxins tested. While no endorsement should be inferred, an example is the 5Strands BlueGreenTest® (approximately

$35, as of July 2022), a single test screens for 11 commonly occurring cyanotoxins and provides results in about 15 minutes.

Note: Agents may want to keep some test kits on hand to help with rapid response, especially when a pond is the only water source for livestock.

2.4.2 Professional Testing: Commercial Laboratories

Commercial laboratories throughout the country provide cyanobacteria identification and cyanotoxin testing; however, these services may be cost-prohibitive. Many facilities are geared toward sampling by environmental professionals that follow strict sampling protocols and have business accounts with the labs. Of note, cyanotoxin levels can change rapidly, and we do not yet understand the factors that trigger cyanotoxin production and release.

The following labs were identified as options for individuals/non-business customers for cyanotoxin sampling. It is likely incomplete and should not be considered an endorsement of these companies.

GreenWater Laboratories, Florida (https://www.greenwaterlab.com): turn-around time from receipt of sample is typically 1-2 business days for the PTOX Cyanobacteria Screen and 2-3 business days for toxin analysis. Contact: Shirley Rodman (shirleyrodman@greenwaterlab.com; 386.328.0882). Additional information: Description of Services, Sampling & Shipping Instructions, Chain-of-Custody form (should be included with samples), and Example PTOX Report.

Midwest Laboratories, Nebraska (https://midwestlabs.com/): usually need 7 business days to process a sample, which must be received at the lab within 48 hours of sample collection. As of summer 2020, microcystin testing was $45 for standard turn-around time. Contact them to coordinate expedited services (approximately $150) if needed. They do not offer recommendations, consulting, or guidance on how to interpret the results. Customers should open an account to get started.

Eurofins Eaton Analytical, Inc., California (https://www.eurofinsus.com/environment-testing/testing-services/drinking-waterpotable-water-testing/algal-toxins/): $550 (in 2020) per sample for testing of multiple algal toxins (no option for partial testing). The fee must be pre-paid and includes shipping a sample kit to the landowner and back to the lab. Tests performed include anatoxin-a, cylindrospermopsin, microcystin (LA, LF, LR, LY, RR, YR), and nodularin. Contact: Joe Mattheis (JosephMattheis@EurofinsUS.com; 919.376.7978).

3.0 HAB Response

Organisms, whether humans, domestic animals, livestock, or wildlife, can encounter algal toxins produced by HABs by swimming, drinking, eating, and aerosol-based (airborne) exposure routes (Jewett et al., 2008). Exposures and potential harm of the exposure depend upon the specific toxin, concentration, and sensitivity of the individual organism. Some algal species produce harmful toxins. Other species may not produce toxins but can cause the water to taste bad and reduce the animal's water intake. Additionally, the excess density of some blooms can damage ecosystems via shading, oxygen depletion, and low food quality.

Death may occur if livestock drink water from stagnant ponds while a cyanoHAB is ongoing (Figure 12). If a HAB is suspected and the water body experiencing a bloom is used as drinking or cooling for livestock, protect your livestock using the actions detailed below.

3.1 Immediate Response to Suspected HAB

Err on the side of caution. Assume a harmful algal bloom is toxic.

- Provide access to clean, non-contaminated water (the best choice, if possible)
- Restrict access to natural water bodies with suspected HABs to prevent exposure from drinking or wading access
- If livestock must access the pond, move access points for livestock to the upwind side (Figure 12), or limit access to a location with less/no visible algae (not foolproof, but may be helpful if no other options are available)
- If livestock exhibit any symptoms of illness, call a veterinarian to evaluate treatment options.

If livestock health was impacted (sickness/death), collect a water sample (see details above) wearing gloves or other appropriate PPE, and submit it to a lab. Ask your veterinarian to contact the state veterinarian to report the HAB and suspected reason for livestock sickness or death.

Figure 12. Moving livestock to the upwind side of the pond may reduce risk of exposure to cyanotoxins (Image credit: Katie Callahan, Clemson University).

3.2 Algaecide Applications

Any mitigation strategy (physical or chemical) could potentially expose the operator/manager to toxins released by the HAB, so appropriate personal protective equipment (PPE) should be worn (Wolfe, 2021).

Algaecide application will kill the cells, likely releasing toxins (Figure 11). Thus, cyanotoxin levels may spike after herbicide application. Typically, for copper-based products, only treat one-quarter to one-third of the pond at a time to permit areas in the pond where dissolved oxygen levels may not decline to the point that fish die (MDC, 2017). However, if the HAB-impacted pond is the only drinking water source for livestock, one may want to treat the entire pond at one time to flush the toxin through the system more quickly. If treating the entire pond with a copper sulfate-based product (most common) or another algaecide, livestock access to the pond should be restricted for at least 7 days to permit degradation of the toxin released from the HAB (Arnold, 2014).

Algaecides are chemical compounds that kill algae once applied to an algal bloom (US EPA, 2022). **Before any chemical application, read the current product label. The label is the law**. The label provides mixing and application directions, PPE requirements, and warnings related to product activity, reentry intervals, and impacts on aquatic organisms. The factsheet Chemical Control of Aquatic Weeds (https://bit.ly/36IU8I2) provides a list of products registered for use in ponds by the US EPA. Additionally, the application of pesticides to waterbodies in SC is regulated by SCDHEC and must comply with the National Pollutant Discharge Elimination System (NPDES) Permit for discharges from the Application of Pesticides (https://bit.ly/SCpesticideNPDES).

Table 5 provides information on how long to wait before watering livestock after applying algaecides for algae control. This wait-time before livestock watering will typically be a shorter period than one should wait to permit any toxins to dissipate as cyanobacterial communities die off and decay.

Table 5. Effectiveness and waiting periods for select algaecides. Table adapted from Heaton and Whetstone (2015).

Common Herbicide Name	Effectiveness[1]			Example Trade Name(s)	Waiting Period (Days) After Application[2]			
	Filamentous	Planktonic	Branched (Chara)		Irrigation	Fish Consumption	Watering Livestock	Swimming
Copper complexes, copper sulfate	E	E	E	Crystalline copper sulfate and various liquid organic copper complexes	NR	NR	NR	NR
Diquat	P	G	G	Reward	3 to 5	NR	1	NR
				Weedtrine D	5	NR	5	NR
Endothol	G	G	G	Hydrothol 191 Hydrothol 191 granular	7 to 25	NR	7 to 25	NR
Sodium Carbonate Peroxyhydrate	E	E	U	GreenClean PAK 27	NR	NR	NR	NR

[1] E = Excellent (90-100%); G = Good (80-89%); P = Poor (<70%); U = Unknown
[2] NR = No Restrictions

Adequate algae control may require more than one chemical treatment; it is best to plan 10 – 14 days between algaecide applications. MDC (2012) provides calculations for estimating how many acre-feet of water need to be treated to determine how much active ingredient is required to control the HAB. Copper-based products are the most commonly applied to control HABs (MDC, 2012). They also tend to be the most effective across a range of algal species (Heaton and

Whetstone, 2015). Algaecides commonly used to control algae include copper sulfate, copper chelates, sodium peroxyhydrate, and endothall.

In SC, application of pesticides may not be allowed to waterbodies with a Tier 3 (e.g., high quality) designation or if there is a downstream impairment for the pesticide or its degradation byproducts. Before any algaecide application, it is important to determine the SCDHEC water body classification (SCDHEC, 2020) and to identify any related water quality impairments nearby (Figure 13). Algaecide applications are restricted in waters classified as Outstanding Resource Waters and Trout Natural. Use the water body classification tool provided at https://gis.dhec.sc.gov/watersheds/ to ensure your algaecide application complies with SC regulations. Instructions for using the portal can be downloaded from https://bit.ly/3gNw9vK. If a downstream impairment is suspected, consult with SCDHEC prior to any pesticide applications (https://bit.ly/SCpesticideNPDES).

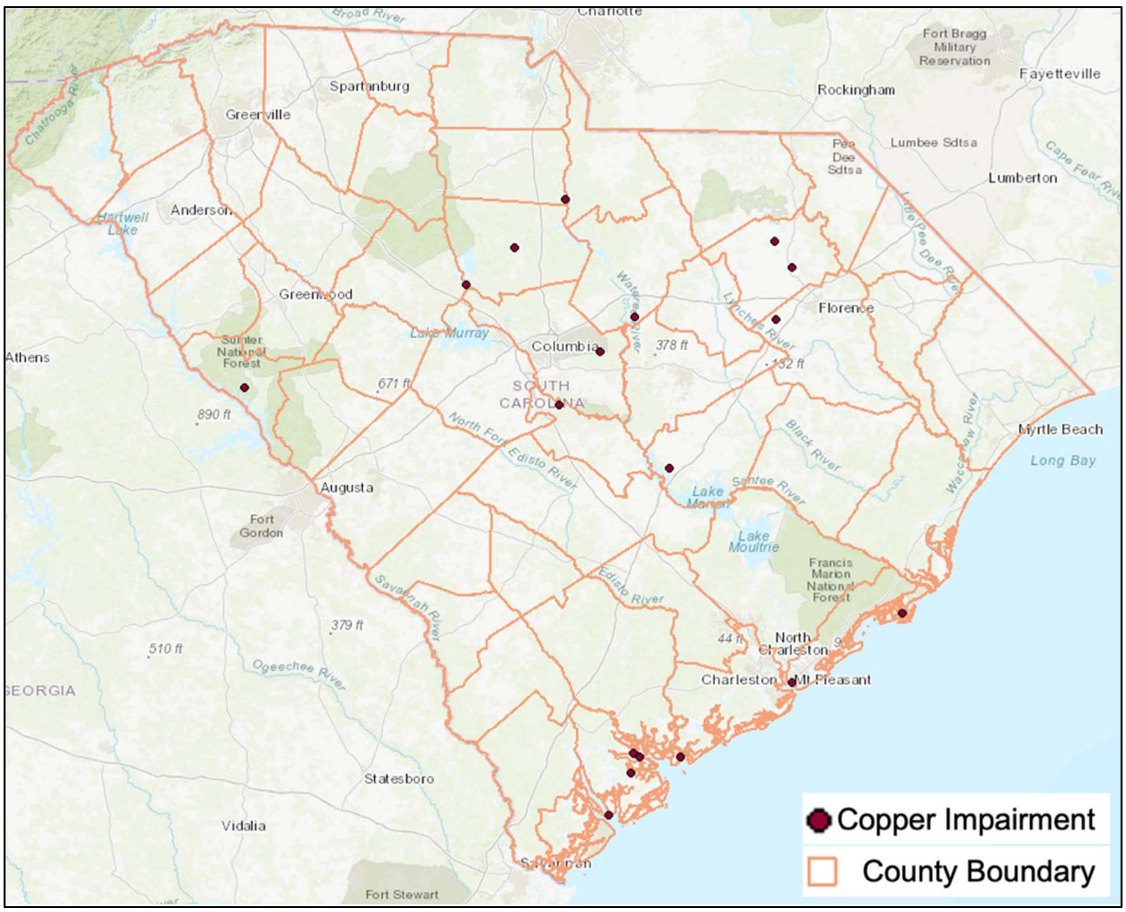

Figure 13. Map showing locations of copper impairments (burgundy circles) throughout SC counties as identified the 2018 303(d) impaired waters list (Source: SC Watershed Atlas).

3.2.1 Copper sulfate

Copper sulfate products (multiple trade names) are available in dry (powder and crystal nugget) forms. When applying copper sulfate products, application should be focused on areas where the algal bloom is growing. While toxic to algae, copper is also harmful to other aquatic organisms (e.g., beneficial invertebrates and fish – think the food chain), so be careful to apply the label rate to the right location in the pond. Copper readily binds to sediment and organic matter, so any application should be targeted where the major bloom is ongoing to avoid loss of active ingredient to binding to non-target organisms, sediment, or floating particles (Lembi, 2009). Ideally, the powdered product (not the crystal nugget form) should be mixed/dissolved in water and then sprayed over the water surface where the HAB is dominant to ensure contact with the algae (Lembi, 2009). Mixing the powder with water will help it remain suspended in solution a little longer and increase the potential for the product to bind to algae.

3.2.2 Copper chelates

Chelated copper products are available in liquid (e.g., Algimycin ®, Captain®, Cutrine Plus®, Cutrine Ultra®, K-Tea®, etc.) or granular (e.g., Cutrine Plus®) formulations. Chelated copper products are applied when the water hardness is high (typically > 121 mg/L calcium carbonate) (USGS, 2018). Water hardness is a measure of the buffering capacity of water, which is regulated by the concentration of calcium and magnesium in the water. Calcium and magnesium are typically associated with carbonate.

If water is too hard (>121 mg/L calcium carbonate), copper sulfate may precipitate from the water column, becoming less active or able to control algae. In instances where water hardness is high, chelated copper products often provide better algae control. Mix the chelated copper with water and then spray over the surface of the water where algae are evident (Lembi, 2009).

3.2.3 Sodium carbonate peroxyhydrate

Sodium carbonate peroxyhydrate (SCP) products are granular in form and kill algae rapidly via oxidation (Lembi, 2009). SCPs are sold under the trade names EcoBlast™, GreenClean®, PAK™ 27, and Phycomycin®. SCPs are created from a mixture of sodium carbonate and hydrogen peroxide. When applied to water, the particle splits and becomes sodium carbonate and hydrogen peroxide (Wisconsin DNR, 2012a). The hydrogen peroxide oxidizes (breaks) the algae cell walls, and dead algal cells precipitate from the water column. When using SCP to manage a water body, treat no more than half the water body surface to prevent unsafe drops in dissolved oxygen. No waiting period is required for the use of water after SCP treatment; however, if SCP was applied to a HAB, as those algal cells break, any toxin in the cells will be released (Figure 11), so it is wise to wait until the cyanotoxins dissipate before allowing livestock to drink from the pond.

3.2.4 Endothall

Endothall is available in liquid and granular formulations. Formulations are also either a dipotassium or monoamine salt. Endothall cannot be applied within 600 feet of a potable water intake (Wisconsin DNR, 2012). Both liquid and granular formulations can be used as spot treatments or broadcast widely to control an extensive bloom. Waiting periods for watering livestock after endothall application vary from 7 to 25 days, depending upon which endothall formulation was applied (Heaton and Whetstone, 2015). Trade names of endothall products available for pond applications to control algae include Aquathol K, Aquastrike, Aquathol granular, Aquathol Super K, Cascade, Hydrothol 191, Hydrothol 191 granular, and Teton. Read the label and apply the product at the label recommended rates. Hydrothol products should only be applied by a Category 5 (aquatic) certified applicator as it has the potential to burn skin or kill fish (Wisconsin DNR, 2012b).

3.3 Retesting Water Post-Algaecide Application

Wait, at minimum, seven days after algaecide application to collect a water sample to determine if any toxins remain in solution. Upon receiving analysis results indicating that toxin concentrations are below threshold levels (as detailed in Table 4), livestock can safely begin using the water source again. If water testing is not desired, wait, at minimum, the label recommended waiting period or 14 days to start reuse of the water source, whichever is longer. In either case, after algaecide application the algal cells will decay, releasing nutrients and potentially driving another bloom.

Additional BMPs should be implemented for long-term control, and additional chemical treatments may be necessary for short-term control of the algal bloom. Thus, if this pond is the primary drinking water source, visually and physically monitor the water every seven days, using the methods detailed above (stick test, jar test) during hot, dry weather to determine if an algal bloom is beginning and spot-treat the pond with the appropriate chemical to control the algal bloom. Ideally, to break the cycle of blooms, nutrient concentrations within the pond should be reduced; this can be accomplished using the practices detailed in the Causation and Prevention section.

4.0 Causation and Prevention

4.1 Conditions

Different conditions in the watershed or area that drains to the livestock pond could contribute to algal blooms occurrence and severity. Generally, the availability of nutrients such as N and P, more so P than N in the freshwater ponds, coupled with suitable environmental conditions such as light, high temperature, slow-moving water, and stable water column pH could influence the algal population and potential for high-density blooms in the pond. These problems could also be aggravated by a high-intensity storm followed by drought. As excess nutrients are flushed into the pond after a storm, and water begins to evaporate during a drought, nutrients remaining in the solution become more concentrated.

4.2 Practices and HAB Prevention

Since nutrients are the critical drivers for algal growth, various on-farm practices can be adapted to control N and P loadings to the ponds. Strategic practices could be implemented throughout the watershed to control nutrients at the source and limit their movement to water bodies. Understanding the sources of nutrients, transport mechanisms, best management practices, and cycling processes within the pond itself could help prevent, mitigate, and manage the transport of N and P and minimize water quality impacts.

In the following sub-sections, multiple management practices are grouped under broader categories to assist in operation-wide management of nutrients and other factors that could reduce occurrence of HABs. The solutions suggested below are not an exhaustive list of practices and implementation of numerous solutions may be necessary to successfully prevent HABs. Appropriate solutions will likely vary between sites and individuals.

4.2.1 Livestock Management Practices

Controlling nutrients at the source is much more economically feasible than the costs associated with HAB response and management. Effective livestock management on-farm helps mitigate nutrient runoff and reduce the risk of HABs occurrence in surface waters. Livestock often stay better hydrated when provided clean water, resulting in improved herd health. Some strategies and measures to help limit nutrient movement on-farm are described below.

Figure 14. Managed, or rotational, grazing on a livestock farm encourages healthy forage growth (Image credit: NRCS).

Managed Grazing: Managed or rotational grazing involves moving livestock from one pasture to another to concentrate grazing in a select pasture for a limited time (Figure 14). This encourages healthy forage growth that prevents erosion and improves assimilation of nutrients into the land.

Restricted animal movement: Limiting livestock movement into areas with high erosive potential can minimize nutrient movement from pasture to the pond. Restricting livestock movement also helps manage animal excreta and manure in the field, farm, and watershed.

Manure Management (e.g., testing, application, treatment): Set up the livestock operation to efficiently manage livestock manure to minimize the export of nutrients from the land to waterways (Sharpley et al., 2006). Manure can be stored in an earthen pit, concrete pit, large tank, or roofed building (Figure 15) to avoid runoff carrying it to a nearby waterway. Prior to a manure application, test both the manure and soil in the application area to avoid over-application of nutrients (USDA-NRCS 2002). Before applying manure, consider the land use and previous soil amendments to avoid over-application of nutrients. Avoid manure applications before a storm event and consider tillage-assisted manure application to decrease the potential for nutrient loss with runoff.

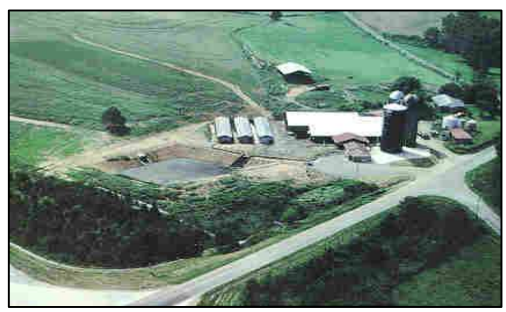

Figure 15. Animal waste management (e.g., storage) on a livestock farm (Image credit: NRCS).

If manure production exceeds the local crop needs, livestock owners should consider developing additional infrastructure to store, compost, and/or transport manure to land where nutrient additions and organic carbon will enhance crop production with minimal impacts on water quality.

Nutrients in Livestock Feed: Managing dietary P intake in the livestock will help reduce the amount of P excreted by animals. Research indicates that reducing dietary P from 0.48 percent to 0.38 percent can result in 30-35 percent less P in the manure (Wu et al., 2000, 2001). Milk production goals and livestock health should also be considered when shifts in P feeding percentages are considered to manage P in the watershed.

4.2.2 Land Management Practices

Effective management of the soil and land area draining to the pond are the key strategies to mitigate HABs. Strategic land management helps minimize the export of nutrients and sediment to waterways. Examples of these strategies are listed below.

Vegetate Bare Soils: Even small patches of bare soil can generate a significant volume of sediment over time. Take steps to prevent erosion from these areas using plants or mulch. Native grasses can be established from seed and provide excellent erosion prevention. Native plants are adapted to the local climate so, once established, are typically drought-tolerant and require little maintenance. Vegetating bare soil improves soil health and minimizes nutrient transport to the streams and ponds.

Soil Testing for N and P: The USDA-NRCS recommends soil sampling and testing at least once every three years (USDA-NRCS, 2002). Samples must be collected from multiple locations across the pasture, field, or watershed (depending upon practice intended for the sampled area). Soil samples should be collected at 5 to 10 cm depth for fields under conservation tillage and pastures. For nutrients, particularly P, sampling depths may be < 5 cm.

Fertilizer Application: Apply the correct amount of fertilizer at the right time using calibrated equipment to minimize nutrient leaching from the soil (Sharpley et al., 1998). Avoid applying fertilizer before a storm. Consider local weather conditions and crop needs to improve effectiveness of fertilizer applications and to reduce potential runoff.

Irrigation: Efficient irrigation practices in the pasture or the farm should be used to reduce the risk of nutrient losses from the soil. Over-irrigation leads to supersaturated soil conditions that will more readily leach nutrients during a rain event. Erosion from irrigation results in higher nutrient loss than during rain events (Lentz et al., 1998, Sharpley et al., 1998).

Crop Rotation and Cover Crops: Crop rotation is the practice of growing multiple crops on the same land during different seasons. This practice helps utilize nutrients at different root depths and reduces nutrient runoff. Cover crops provide soil cover, protect the soil surface from erosion, aid in regulating soil moisture, and improve soil infiltration, thus preventing nutrient losses (NRCS, 1998).

Conservation Tillage: Leaving at least 30% of the soil surface covered with crop residue will reduce soil erosion, minimize nutrient losses, and increase soil infiltration (Mostaghimi et al., 2001). Conservation tillage is considered one of the most cost-effective best management practices to minimize nutrient losses (Sharpley et al., 2006) and improve soil health. Conservation tillage should be employed along with other farm management practices to reduce the loss of nutrients from the land to the waterbodies.

Contour Farming and Strip Cropping: Farming sloping land so that cultivation follows land contours and growing strips of crops along the counter of the field help minimize erosion, reduce runoff, and increase soil infiltration. This management strategy should be adopted in fields with low to moderate slopes (NRCS, 1998).

Grass Swales: Grass swales are structural linear vegetated depressions that act as water conveyance structures while treating water as it moves through the landscape (Figure 16). Swales are relatively inexpensive to implement. Baffles or swales help reduce the water flow volumes and improve water quality by trapping sediment and nutrients.

Figure 16. Grassed swales minimize soil erosion and nutrient losses (Photo from NRCS photo library).

Filter Strips: Filter strips are a structural practice in which an area of vegetation is used to reduce the velocity of water flow and decrease the movement of sediment, nutrients, and other contaminants through settling and infiltration (Figure 17). Filter strips slow the velocity of water, allowing the settling of the pollutants and uptake of the nutrients by plants. Filter strips are installed along the edge of fields or along waterways. Generally, they are used on slopes less than 10% (USDA, 1997). With proper maintenance, the buffer can function for up to 10 years (Lant et al., 1995).

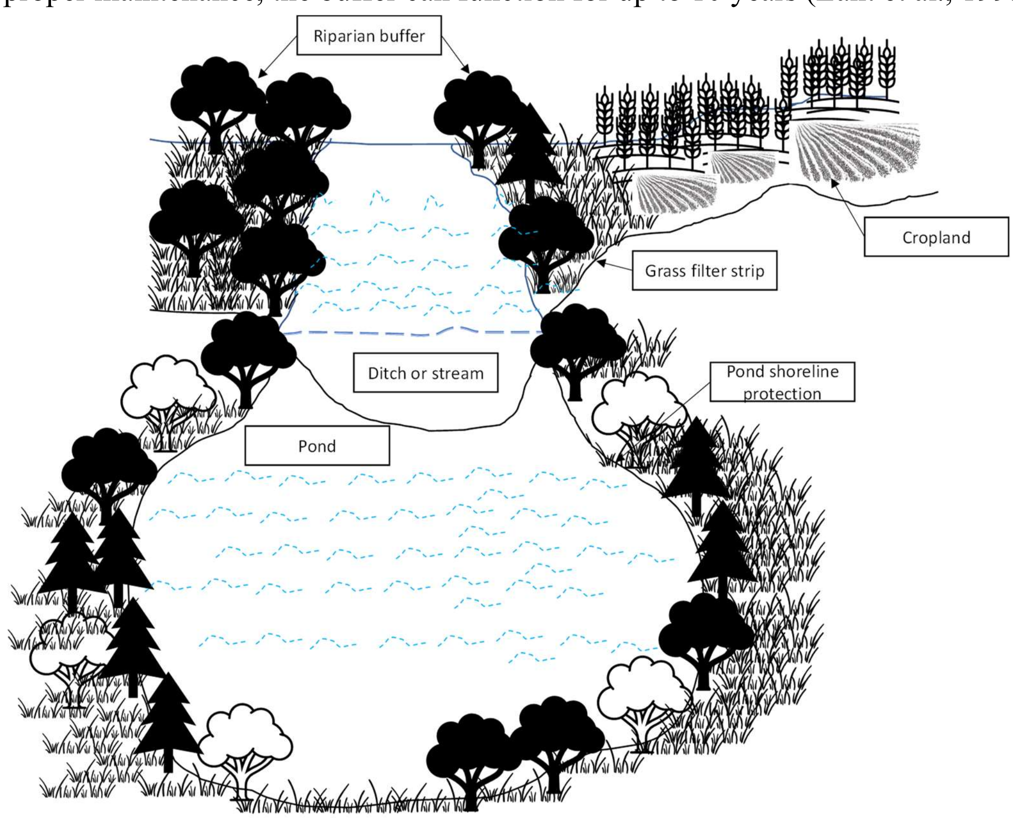

Figure 17. Combination of land management techniques to reduce nutrient loading from the land into streams and ponds. (Graphic: D. Sahoo)

Fencing Livestock Out of Waterways: Regular movement of livestock in a concentrated area can kill vegetation, leaving bare soil that is prone to erosion. Erosion leads to accelerated sedimentation and increase of nutrients in streams and ponds. Fencing livestock out of sensitive areas, such as streams and ponds (Figure 18) is intended to protect the banks and reduce the impacts of livestock travel into and out of ponds (White et al., 2021). Fencing minimizes damage to the banks and shorelines. Livestock water access points can be constructed as a part of the pond fence, restricting access less than 5% of the water body (i.e., protecting 95–100% of the water body). Funding assistance may be available to assist with fencing livestock out of waterways from USDA NRCS (http://bit.ly/3TukvUg) or SCDHEC Section 319 grants (http://bit.ly/3twB9YV), which may be available within qualifying watersheds.

Riparian Buffer: Riparian buffers are a vegetated area of trees and shrubs adjacent to a stream draining into a pond or located along the shoreline of the pond (Figure 17). Riparian buffers protect the stream banks from erosion and scouring and help to prevent streambank failure (sloughing). Riparian buffers remove excess nutrients and prevent them from flowing into the pond. They also offer multiple ecological services in the watershed. Riparian buffers may also serve to reduce presence of non-migratory waterfowl, further reducing nutrient loading.

Constructed Wetlands: Constructed wetlands efficiently treat nutrients on-farm (House et al., 1994). In addition to nutrient benefits, constructed wetlands may provide wildlife habitat and various ecosystem services.

Healthy Forest: Integrating trees into livestock operations on the same land could help the operation in multiple ways. Forest cover in the pasture can help reduce erosion and nutrient losses to the pond. It can also help the livestock reduce heat stress, thus improving livestock performance. The location of the forest on the farm is critical to maximizing the benefits.

4.2.3 In-Pond (and Stream) Management Practices

Over time as sediment and nutrients are captured by the pond, changes in environmental conditions cause the nutrients to release back into the water column, further assisting in likely

Figure 18. Fencing along a stream to reduce erosion from livestock movement and reduce sediment and nutrient runoff to waterways (left). Pond fencing and the graveled path as a livestock barrier to minimize shoreline degradation that affects nutrient cycling in the ponds (Right) (Image credit: left-Department for Environment Food and Rural Affairs; right-NRCS).

HABs. Implement some of the following measures in and around a livestock pond to reduce the impact of nutrients and sediment in the pond.

Excessive Sediment Removal: Sediment accumulation reduces the storage capacity and decreases the depth of the pond. Excess sediment also contributes to increased unpleasant odors (reduced-state sediment chemistry), enhanced potential for excess aquatic plant growth as nutrients cycle, and reduced diversity of aquatic wildlife. Over time excessive sediment can become a source of nutrients. Pond dredging may be performed periodically depending on the extent of sedimentation in the pond (Swistock et al., 2013). Please see Clemson Extension's LGP article: Pond Maintenance: Dredging for additional information. (https://lgpress.clemson.edu/publication/pond-maintenance-dredging/)

Protect Heavy Use Areas around the Pond: High-traffic access points around the pond will usually have noticeable signs of livestock activity. The livestock may use these access points to enter the pond either to cool off or to drink water. Heavy use areas weaken over time and become susceptible to erosion and nutrient losses, further contributing to sedimentation of the pond. Heavy use areas should be protected and stabilized (Figures 18-19).

Gravel Path or Rock Pad: As an alternative to protected high access areas, a limited access ramp for pond watering cattle could help direct livestock to desired pond entry locations (Figure 19). A cattle access path could be graveled down to the pond edge to allow cattle to drink from the pond. A drinking rock pad will also help in this situation and should extend at least 12 feet from the edge of the pond. Graveled paths and rock pads should avoid excessive slopes that could impact cattle's movement or increase sediment movement into the pond (Briggs and Lemenager, 2020). Adding gravel below a pond's full pool elevation would be considered "fill material" and may need to comply with federal (e.g., Clean Water Act) and state regulations. Please see SCDHEC Water Quality Certification Program website for additional information. (https://bit.ly/WatersofSC).

Figure 19. Graveled and protected heavy use area (Image credit: John Jennings, The Kerr Center for Sustainable Agriculture).

Manage Aquatic Vegetation: Excessive nutrients drive growth of aquatic vegetation. Too much vegetation could affect the nutrient cycling and water quality conditions in the pond. While aquatic vegetation relies on nutrients for its growth, the death and decay of these plants could release nutrients back into the water column, accelerating new growth. Timely management (harvest) of aquatic vegetation could reduce the frequency of HABs and aid in a healthy pond. Various control mechanisms such as prevention of nutrient entry, mechanical control, biological control, and habitat alteration can be used to manage vegetation (Lembi, 2009). Chemical control can reduce the growth of aquatic vegetation, but nutrients not absorbed by aquatic vegetation remain available to algal communities; thus, managing nutrient entry is the most critical step in aquatic vegetation and HAB management.

Pond Aeration: Pumping and releasing air along the bottom of a pond increases dissolved oxygen levels, encourages circulation of the water, and may prevent release of nutrients from accumulated sediment (Figure 20). These improvements may help prevent HABs, encourage beneficial aerobic bacteria, and improve water quality conditions. Factors such as pond size, depth, shape, and availability of power should be considered when selecting a pond aeration system. While aeration is encouraged, caution may be warrented during and following a cyanoHAB in case of increased cyanotoxin aeresolization; future research may help us better understand if this is a concern.

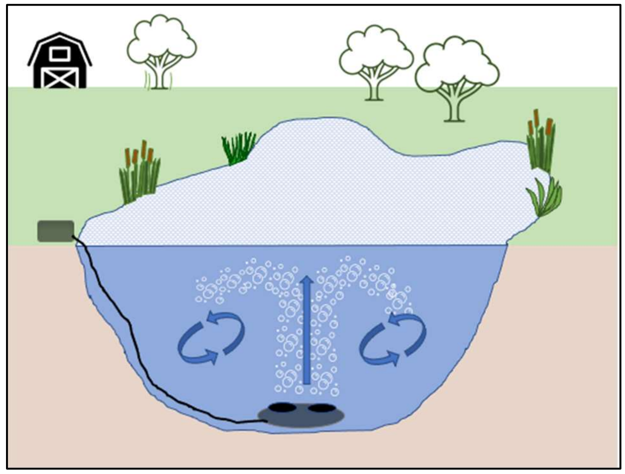

Figure 20. An aerator pumps and releases air along the bottom of a pond (Graphic: B. Davis).

Streambank Stabilization: Degradation of streambanks due to cattle movements causes bank failures and associated nutrient loading to the downstream water bodies (Sharpley, 2006). Protecting streambanks using bank stabilization techniques (Figure 21) helps improve water quality. Banks can be stabilized using vegetative plantings, bioengineering, and by utilizing structural systems.

Stabilize Pond Shoreline: Livestock movement at the edge of the pond can create turbid water, erode the shoreline, and release nutrients that can end up accelerating harmful algal blooms. Efforts should be made to exclude livestock from pond banks and edges to protect the shoreline and prevent the bank from failing.

Fish: Tilapia (*Oreochromis* spp.) feed on algae and some aquatic vegetation. They can be very effective in longer-term control of algae in ponds, are often less expensive than repeated pesticide application, and provide ecological benefits. Triploid grass carp (*Ctenopharyngodon*

Figure 21. Streambank stabilization to minimize bank erosion and nutrient losses (Image credit: Clemson Extension, *Stream Bank Repair Manual for South Carolina*).

idella var Triploid) may help control cyanobacteria (except *Lyngbya*). See Greene County S&WCD (http://bit.ly/3ExjPcG) for a brief overview and USEPA NEPIS report (https://bit.ly/NEPIS_BGA) for more in-depth information.

Algaecides: In addition to various nutrient management strategies in livestock ponds, chemical pesticides can also be used to manage HABs. See section 2.2 for detailed information on specific choices, application methods, and waiting periods before livestock can consume water.

4.3 Climate and HABs

In the last few decades, industrial and human activities have accelerated changes in the climate, including an annual incremental increase in the average surface temperature (Santos & Bakhshoodeh, 2021). The fourth assessment report of the Intergovernmental Panel on Climate Change predicted a higher frequency of HABs due to increased average temperature (IPCC, 2007). The spatial and temporal changes in precipitation patterns can change the hydrology of inland waters and influence water quality. From 1901 to 2015, annual precipitation in the United States increased by approximately 4%, although seasonal and regional differences existed. Most increases were noted in the Northwest, Midwest, and Great Plains, while parts of the Southeast and Southwest had decreases in precipitation in the first part of the 21st century. Drought drove much of the precipitation decrease experiences in the Western and Southwestern parts of the country (Easterling et al., 2017). However, future precipitation trends (end of the century) in the Southeastern US are difficult to predict because of uncertainty in simulating precipitation processes like thunderstorms and hurricanes (NCA, 2013), although interannual decreases and increases exist across the states in the region.

Climate change is expected to impact water quality through temperature increase, drought, precipitation, and increased runoff that transports contaminants and sediments into water bodies. Current BMPs are targeted at reducing non-point source pollution under the historic climate and could become less effective if the magnitude of threats from climate change projections are accurate (Hounnou, 2022). Climate change is expected to result in increased intensity and frequency of heavy storms, potentially affecting urban BMPs such as stormwater infrastructure (Johnson et al., 2022). Soil erosion can also be directly impacted by climate change through increased rainfall amount, intensity, and extreme rainfall invents. Indirectly, climate change also impacts soil erosion through high air temperature, increasing evapotranspiration rates, reduced canopy density, and changes in plant biomass. Soil erosion is expected to be more intense under future climate variation. These impacts can be reduced or prevented by implementing BMPs that protect the soil, such as afforestation, conservation tillage, and cultivating drought-resistant cultivars (Li & Fang, 2016).

Nutrient dynamics in a watershed are also affected by climate change through their impacts on nutrients released from catchment soils, transport to water bodies, and biogeochemical processes in water bodies. Changes in seasonal patterns of rainfall and increased soil temperature affect the process of nitrification. Nitrate availability in streams is expected to increase due to increased mineralization because of changes in soil moisture. Nutrient and sediment loads from agricultural landscapes may also increase due to high storm events associated with climate change (Arnell et al., 2015).

Increased water temperatures could also trigger HAB growth by increasing biogeochemical in-stream processes. The high frequency and intensity of rainfall with periodic drought periods enable stratification in water bodies and provide favorable conditions for algal blooms. Over the short-term, intense rainfall could reduce HAB intensity due to frequent dilution and flushing activities. In the long-term, nutrient and sediment loads may also increase because of intense runoff caused by these rainfall events and provide enabling conditions for HABs. Droughts followed by a series of rainfall events also trigger enabling conditions for rapid algal proliferation. Small rainfall events occurring for long periods also favor algal proliferation due to the rapid use of nutrients introduced by the rainfall events and stratified water columns (Reichwaldt & Ghadouani, 2012).

While we cannot definitively state that climate change will impact HABs in one specific way, it is likely that HAB frequency and intensity will increase in the coming years if better land, livestock, and nutrient management practices are not employed. This manual provides current best practices that can be employed to prevent and mitigate HABs. Use of no single practice will likely prevent a HAB; but integrating use of multiple management strategies that address water, soil, plant, and animal movement holistically can help protect water quality and preserve water resources for livestock, wildlife, and recreational purposes.

5.0 References

Anderson, D, P Glibert, J Burkholder. 2002. Harmful Algal Blooms and Eutrophication Nutrient Sources, Composition and Consequences. *Estuarine Research Foundation*: 25(4b):704–726. https://doi.org/10.1039/b709565c

Arnell, NW, SJ Halliday, RW Battarbee, RA Skeffington, AJ Wade. 2015. The implications of climate change for the water environment in England. *Progress in Physical Geography: Earth and Environment.* 39(1):93–120. https://doi.org/10.1177%2F0309133314560369.

Arnold, M. (2014). Harmful Algal Blooms – Are My Cattle in Danger? University of Kentucky Cooperative Extension Service. <accessed 17 March 2022. https://afs.ca.uky.edu/files/harmful_algal_blooms.pdf >.

Babica P, L Bláha, B Maršálek. 2006. Exploring the natural role of microcystins - A review of effects on photoautotrophic organisms. *Journal of Phycology*. 42(1):9–20. doi:10.1111/j.1529-8817.2006.00176.x.

Bellinger, EG, DC Sigee. 2015. *Freshwater Algae: Identification, Enumeration, and Use as Bioindicators*. John Wiley & Sons. https://doi.org/10.1002/9780470689554

Bhaskar, JT, BV Parli, SC Tripathy. 2020. Spatial and seasonal variations of dinoflagellates and ciliates in the Kongsfjorden, Svalbard. *Marine Ecology.* 41(3):1–12. https://doi.org/10.1111/maec.12588

Bláha, L, P Babica, B Maršálek. 2009. Toxins produced in cyanobacterial water blooms - toxicity and risks. *Interdisciplinary toxicology.* 2(2):36–41. https://doi.org/10.2478/v10102-009-0006-2

Boesch, DF, RB Brinsfield, RE Magnien. 2001. Chesapeake Bay eutrophication: scientific understanding, ecosystem restoration, and challenges for agriculture. *Journal of Environmental Quality.* 30:303–320.

Briggs, NG, RP Lemenager. 2020. Heavy Use Area Pads for Cattle. PennState Extension. Available at: https://extension.psu.edu/heavy-use-area-pads-for-cattle. Accessed 2 May 2022.

Busari I, D Sahoo, HB Nix, CG Wallover, SA White, CB Sawyer. 2022. Introduction to Harmful Algal Blooms (HABs) in South Carolina Freshwater Systems. *Land Grant Press*. LGP 1146. Clemson University, South Carolina.

California Department of Public Health, C. 2017. Blue-Green Algae : A Veterinarian Reference Identifying Illness Due to Blue-Green Algae. *Blue-Green Algae Poisoning Veterinary Reference* (Issue 844).

CDC (Centers for Disease Control and Prevention). 2021a. *Harmful Algal Bloom-Associated Illnesses | CDC*. https://www.cdc.gov/habs/index.html

CDC (Centers for Disease Control and Prevention). 2021b. *Summary Report- One Health Harmful Algal Bloom System (OHHABS), United States, 2019*. Atlanta, Georgia: U.S. Department of Health and Human Services, CDC. https://www.cdc.gov/habs/data/2019-ohhabs-data-summary.html

Chen Y, D Shen, D Fang. 2013. Nodularins in poisoning. *Clinica Chimica Acta*. 425:18–29. doi:https://doi.org/10.1016/j.cca.2013.07.005. https://www.sciencedirect.com/science/article/pii/S0009898113002738.

Chorus, I, M Welker. 2021. Toxic cyanobacteria in water: a guide to their public health consequences, monitoring and management. Taylor & Francis. https://doi.org/10.1201/9781003081449.

Christensen, VG, E Khan. 2020. Freshwater neurotoxins and concerns for human, animal, and ecosystem health: A review of anatoxin-a and saxitoxin. *Science of the Total Environment*. 736:139515. https://doi.org/10.1016/j.scitotenv.2020.139515

Easterling, DR, KE Kunkel, JR Arnold. 2017. Precipitation Change in the United States. *Fourth National Climate Assessment*. Volume 1. https://science2017.globalchange.gov/chapter/7/

Farrer, D, M Counter, R Hillwig, C Cude. 2015. Health-based cyanotoxin guideline values allow for cyanotoxin-based monitoring and efficient public health response to cyanobacterial blooms. *Toxins.* 7(2):457–477. https://doi.org/10.3390/toxins7020457

Guzmán-Guillén R, AI Prieto, VM Vasconcelos, AM Cameán. 2013. Cyanobacterium producing cylindrospermopsin cause oxidative stress at environmentally relevant concentrations in sub-chronically exposed tilapia (*Oreochromis niloticus*). *Chemosphere*. 90(3):1184–1194. doi:10.1016/j.chemosphere.2012.09.027. https://linkinghub.elsevier.com/retrieve/pii/S0045653512011538.

Heaton, WC, JM Whetstone. 2015. Chemical Control of Aquatic Weeds. *HGIC Factsheet.* HGIC 1720. https://hgic.clemson.edu/factsheet/chemical-control-of-aquatic-weeds/

Hounnou, L. 2022. Economic Impact of Climate Change on the Implementation of Best Management Practices in the Fort Cobb Watershed. *Journal of American Water Resources Association.* https://doi.org/10.1111/1752-1688.12999.

House, CH, SW Broome, MT Hoover. 1994. Treatment of nitrogen and phosphorus by a constructed upland-wetland wastewater treatment system. *Water Science and Technology*. 29:177–184.

IPCC. 2007. Climate change 2007: The Physical Science Basis. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon S, Qin D, Manning M, Marquis M, Averyt K, Tignor M, Miller HL, editors. Cambridge and New York: Cambridge University Press.

Jewett, EB, CB Lopez, Q Dortch, SM Etheridge, LC Backer. 2008. Harmful Algal Bloom Management and Response: Assessment and Plan. Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science

and Technology. Washington, DC.
Johnson, T, J Butcher, S Santell, S Schwartz, S Julius, S LeDuc. 2022. A review of climate change effects on practices for mitigating water quality impacts. *Journal of Water Climate Change.* 13(4):1684–1705. https://doi.org/10.2166/wcc.2022.363.
Kannan, MS, N Lenca. 2013. *Field guide to algae and other "scums" in ponds, lakes, streams and rivers*. 1–19. Northern Kentucky University. Accessed 1 April 2022. https://dec.vermont.gov/sites/dec/files/wsm/lakes/Ponds/lp_kentucky-algae-guide.pdf
Lembi, CA. 2009. Identifying and Managing Aquatic Vegetation. *Aquatic Plant Management. Purdue Extension*. APM-3-W. Accessed 1 April 2022. DNR PUB-WT-970. https://www.extension.purdue.edu/extmedia/apm/apm_3_w.pdf
Lentz, RD, RE Sojka, CW Robbins. 1998. Reducing phosphorus losses from surface-irrigated fields: emerging polyacrylamide technology. *Journal of Environmental Quality*. 27:305–312.
Li, Z, H Fang. 2016. Impacts of climate change on water erosion: A review. Earth-Science Rev. 163:94–117. https://doi.org/10.1016/j.earscirev.2016.10.004.
MDC (Missouri Department of Conservation). (2012). Aquaguide – Algae Control in Lakes and Ponds. FIS090. Available at: https://mdc.mo.gov/sites/default/files/2020-04/algae_control_oct2012.pdf. Accessed 1 April 2022.
Mostaghimi, S, KM Brannan, TA Dillaha III, AC Bruggeman. 2001. Best management practices for nonpoint source pollution control: selection and assessment. *In* WF Ritter and A Shirmohammadi, eds, *Agricultural Nonpoint Source Pollution, Watershed Management and Hydrology*, pp 257-304, Lewis Publishers,
NCA. 2013. Climate of the Southeast United States: Variability, Change, Impacts and Vulnerability. Ingram K, Dow K, Carter L, Anderson J, editors. Island Press.
New York State Federation of Lake Association. (2020). *What are Algae? – NYSFOLA*. https://nysfola.org/what-are-algae/
Nix, HB, L Beecher, RH Davis. 2021. Recreational Ponds in South Carolina. *Land Grant Press*. LGP 1125. Clemson University, South Carolina.
NRCS. 1998. National handbook of conservation practices, NRCS-USDA: Washington D.C.
Olkowski, AA. 2009. Livestock water quality: A field guide for cattle, horse, poultry, and swine. Agriculture and Agri-Food Canada. https://www.ag.ndsu.edu/waterquality/livestock/Livestock_Water_QualityFINALweb.pdf.
Osswald J, S Rellán, A Gago, V Vasconcelos. 2007. Toxicology and detection methods of the alkaloid neurotoxin produced by cyanobacteria, anatoxin-a. *Environment International*. 33(8):1070–1089. doi:10.1016/j.envint.2007.06.003. https://www.sciencedirect.com/science/article/pii/S0160412007001237.
Paerl, HW, TG Otten. 2013. Harmful Cyanobacterial Blooms: Causes, Consequences, and Controls. *Microbial Ecology*. *65*(4):995–1010. https://doi.org/10.1007/s00248-012-0159-y
Rankin, KA, KA Alroy, RM Kudela, SC Oates, MJ Murray, MA Miller. 2013. Treatment of cyanobacterial (microcystin) toxicosis using oral cholestyramine: Case report of a dog from Montana. *Toxins*. *5*(6):1051–1063. https://doi.org/10.3390/toxins5061051
Reichwaldt, ES, A Ghadouani. 2012. Effects of rainfall patterns on toxic cyanobacterial blooms in a changing climate: Between simplistic scenarios and complex dynamics. *Water Research*. 46(5):1372–1393. https://doi.org/10.1016/j.watres.2011.11.052.
Richardson, DC, MA Holgerson, MJ Farragher, KK Hoffman, KBS King, MB Alfonso, MR Andersen, KS Cheruveil, KA Coleman, MJ Farruggia, RL Fernandez, KL Hondula, GA

Lopez Moreira Mazacotte, K Paul, BL Peierls, JS Rabaey, S Sadro, ML Sanchez, RL Smyth, JN Sweetman. 2022. A functional definition to distinguish ponds from lakes and wetlands. *Scientific Reports.* 12(1):10472. https://doi.org/10.1038/s41598-022-14569-0.

Santos, RM, R Bakhshoodeh. 2021. Climate change/global warming/climate emergency versus general climate research: comparative bibliometric trends of publications. *Heliyon.* 7(11):e08219. https://doi.org/10.1016/j.heliyon.2021.e08219.

SC-DHEC (South Carolina Department of Health and Environmental Control). 2020. Water Classifications and Standards (Regulation 61–68). S.C. Code Sections 48-1-10 et seq. Office of Environmental Quality Control, Columbia, SC. https://live-sc-dhec.pantheonsite.io/sites/default/files/media/document/R.61-68.pdf

Sharpley, AN, JJ Meisinger, A Breeuwsma, JT Sims, TC Daniel, JS Schepers. 1998. Impacts of animal manure management on ground and surface water quality. *In* J.L. Hatfield and B.A. Stewart, eds., *Animal Waste Utilization: Effective Use of Manure as a Soil Resource*, pp. 173–242. Ann Arbor Press, Boca Raton, FL.

Sharpley, AN, T Daniel, G Gibson, L Bundy, M Cabrera, T Sims, R Stevens, J Lemunyon, P Kleinman, R Parry. 2006. Best management practices to minimize agricultural phosphorus impacts on water quality. United States Department of Agriculture, Agricultural Research Service, ARS-163.

Sheath, RG, JD Wehr. 2015. Introduction to the Freshwater Algae. *Freshwater Algae of North America: Ecology and Classification.* June 2015, 1–11. https://doi.org/10.1016/B978-0-12-385876-4.00001-3

Smith FMJ, SA Wood, T Wilks, D Kelly, PA Broady, W Williamson, S Gaw. 2012. Survey of *Scytonema* (cyanobacteria) and associated saxitoxins in the littoral zone of recreational lakes in Canterbury, New Zealand. Phycologia. 51(5):542–551. doi:10.2216/11-84.1.

Swistock, BR, WE Sharpe, T McCarty. 2013. Pond assessment and inspection. PennState Extension. (https://extension.psu.edu/pond-assessment-and-inspection, accessed on 03/29/2022)

US Department of Agriculture-Natural Resources Conservation Service. 1997. Filter Strips-Conservation Practice Job Sheet.

US Department of Agriculture–Natural Resources Conservation Service. 2002. A conservation catalog: practices for the conservation of Pennsylvania's natural resources. U.S. Government Printing Office, Harrisburg, PA.

USGS. 2019. NWQP Research on Harmful Algal Blooms (HABs) | *U.S. Geological Survey*. https://www.usgs.gov/mission-areas/water-resources/science/nwqp-research-harmful-algal-blooms-habs

US EPA (United States Environmental Protection Agency). 2022. Control Measures for cyanobacterial HABs in surface water. Available at: https://www.epa.gov/cyanohabs/control-measures-cyanobacterial-habs-surface-water. Accessed 1 April 2022.

US EPA (United States Environmental Protection Agency). 2021. Learn about Cyanobacteria and Cyanotoxins. https://www.epa.gov/cyanohabs/learn-about-cyanobacteria-and-cyanotoxins. Available at: Accessed 17 Jun 2022.

US EPA (United States Environmental Protection Agency). 2019. 2015 Drinking Water Health Advisories for Two Cyanobacterial Toxins. Office of Water. EPA 820-F-15-003. Available at: https://www.epa.gov/sites/default/files/2017-06/documents/cyanotoxins-fact_sheet-2015.pdf.

US EPA (United States Environmental Protection Agency). 2015. Health Effects Support Document for the Cyanobacterial Toxin Anatoxin-a. EPA 820R15104, Washington, DC; June, 2015. Available from: http://water.epa.gov/drink/standards/hascience.cfm

USGS. (2018). Hardness of Water. *Water Science School*. United States Geological Service. https://www.usgs.gov/special-topics/water-science-school/science/hardness-water. Accessed 1 April 2022.

van der Merwe, D. 2015. Chapter 31 - Cyanobacterial (Blue-Green Algae) Toxins. In: Gupta RCBT-H of T of CWA (Second E, editor. Boston: Academic Press. p. 421–429. https://www.sciencedirect.com/science/article/pii/B9780128001592000312.

Varjo, E, A Liikanen, VP Salonen, PJ Martikainen, 2003. A new gypsum-based technique to reduce methane and phosphorus release from sediments of eutrophied lakes: Gypsum treatment to reduce internal loading. Water Research. 37:1-10.

Wehr, JD, RG Sheath, JP Kociolek, eds. 2015. *Freshwater algae of North America: ecology and classification*. Elsevier.

White, SA, L Beecher, RH Davis, HB Nix, D Sahoo, AE Scaroni, G Wallover. 2021. Ponds in South Carolina. Land Grant Press, Clemson University, South Carolina.

WHO. 2003. Chapter 8 Algae and cyanobacteria in fresh water. *Guidelines for Safe Recreational Water Environments: Volume 1*. World Health Organization. https://apps.who.int/iris/bitstream/handle/10665/42591/9241545801.pdf?sequence=1&isAllowed=y. Accessed 1 April 2022.

Wisconsin DNR. (2012b). Endothall Chemical Factsheet. Wisconsin Department of Natural Resources. https://dnr.wi.gov/lakes/plants/factsheets/EndothallFactsheet.pdf. Accessed 1 April 2022.

Wisconsin DNR. (2012a). Sodium Carbonate Peroxyhydrate Chemical Fact Sheet. Wisconsin Department of Natural Resources. https://dnr.wi.gov/lakes/plants/factsheets/SodiumCarbonatePeroxyhdrateFactsheet.pdf. Accessed 1 April 2022.

Wood, R. (2016). Acute animal and human poisonings from cyanotoxin exposure - A review of the literature. *Environment International*. 91:276–282. https://doi.org/10.1016/j.envint.2016.02.026

Wolfe, EM. 2021. Harmful algal bloom resources for livestock veterinarians. *Journal of the American Veterinary Medical Association*. 259(2):151-161.

Wu, Z, LD Satter, R Soja. 2000. Milk production, reproductive performance, and fecal excretion of phosphorus by dairy cows fed three amounts of phosphorus. *Journal of Dairy Science.* 83:1028–1041.

Wu, Z, LD Satter, AJ Blohowiak, RH Staufacher, JH Wilson. 2001. Milk production, phosphorus excretion, and bone characteristics of dairy cows fed different amounts of phosphorus for two or three years. *Journal of Dairy Science.* 84:1738–1748.

APPENDICES

Appendix A – Online Resources

- Land Grant Press Article Introduction to Harmful Algal Blooms (HABs) In South Carolina Freshwater Systems https://lgpress.clemson.edu/publication/introduction-to-harmful-algal-blooms-habs-in-south-carolina-freshwater-systems/

- Land Grant Press Article – Pond Weeds: Causes, Prevention, and Treatment Options. https://lgpress.clemson.edu/publication/pond-weeds-causes-prevention-and-treatment-options/

- Clemson Extension Fact Sheet – Cyanobacteria: Understanding Blue-Green Algae's Impact on Our Shared Waterways https://hgic.clemson.edu/factsheet/cyanobacteria-understanding-blue-green-algaes-impact-on-our-shared-waterways/

- Clemson Extension Fact Sheet – Cyanobacteria – Is it Toxic? https://hgic.clemson.edu/cyanobacteria-is-it-toxic/

- SCDHEC Harmful Algal Blooms Program https://scdhec.gov/environment/your-water-coast/harmful-algal-blooms

- SC Task Group on Harmful Algae https://www.scseagrant.org/hab/index.htm