LONG POND
MARSTONS MILLS

2025
End-Season Report

Monitoring period:
Aug 6 – Nov 16, 2025

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Monitoring Approach, Data Used, Summary of Initial Findings, and Next Steps

Subtidal deployed a continuous monitoring buoy in Long Pond (Marstons Mills) from August 6th, 2025 until November 16th 2025, spanning late summer through fall. This period captured stratified conditions, episodic weather-driven mixing, and fall turnover—processes that often influence HAB dynamics in kettle ponds.

The system measured key water quality parameters at two depths to characterize whole-pond behavior. One sensor package was positioned near the surface, while a second was initially deployed at approximately two-thirds depth. On September 26, this deeper sensor was repositioned to 18 inches above the sediment to better resolve near-bottom oxygen conditions that may promote sediment phosphorus release and subsequent harmful algal blooms (HABs)[1]. Multi-depth measurements of temperature, dissolved oxygen, chlorophyll-a (a measure of phytoplankton abundance), phycocyanin (a proxy for cyanobacteria levels), and conductivity were used to evaluate stratification, mixing, HAB abundance, biological productivity, and potential internal nutrient cycling. Surface and atmospheric context was provided by measurements of sunlight intensity, wave activity, and local hydrodynamics, alongside continuous meteorological data on precipitation, wind speed and direction, and air temperature.

Additional Data Used for Context

To place in-lake observations in a watershed context, we integrated data from the Cape Cod Commission Freshwater Data Portal and the Association to Preserve Cape Cod (APCC), including pond bathymetry, watershed and buffer delineations, land use, pond stress indicators, estimated phosphorus loading pathways, and cyanobacteria and nutrient sampling records.

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[1] Harmful algal blooms, or HABs, occur when colonies of cyanobacteria grow out of control and produce toxic or harmful effects on people, fish, shellfish, mammals and birds. The human illnesses caused by HABs, particularly from cyanobacteria blooms, can be debilitating or even fatal to pets and humans.

Assessment Objective, Initial Findings, and Next Steps for the 2026 Monitoring Season

The objective of this assessment is to synthesize continuous in-pond monitoring, meteorological forcing, water sample results, and watershed-scale data to understand conditions in Long Pond, identify emerging patterns in harmful algal bloom activity, and develop testable hypotheses about potential bloom drivers.

Based on this initial deployment, we developed preliminary driving hypotheses suggesting that harmful algal blooms in Long Pond are influenced primarily by internal nutrient recycling in a shallow, weakly stratified system. Septic system groundwater phosphorus loading and rainfall driven episodic nutrient inputs may play an amplifying role contributing to overall nutrient accumulation and bloom susceptibility. These are still working hypotheses that require further testing due to the partial-season monitoring in 2025.

In addition to the drivers listed above, regional climate warming is likely increasing Long Pond's susceptibility to harmful algal blooms. Massachusetts and New England are warming significantly faster than the global average, with Cape Cod coastal surface waters warming at nearly three times the global rate. Elevated water temperatures can extend bloom seasons and amplify harmful algal growth when nutrients are available.

Further evaluation of these hypotheses will require full-season monitoring in 2026, beginning in early spring and continuing through fall, with an emphasis on capturing pre-bloom conditions, episodic low-oxygen events near the sediment, and the full progression of bloom development, peak, and resolution. These priorities are outlined in Section 4.

What We Observed This Season

Sustained harmful algal bloom activity across late summer and early fall

During the monitoring period, Long Pond exhibited **significant harmful algal bloom activity**, including sustained blooms with notable duration and magnitude. A major bloom developed in late August and persisted through mid-September, followed by a series of smaller HAB events extending into November. The persistence of HAB activity well beyond peak summer conditions indicates that conditions favorable to blooms extend into fall.

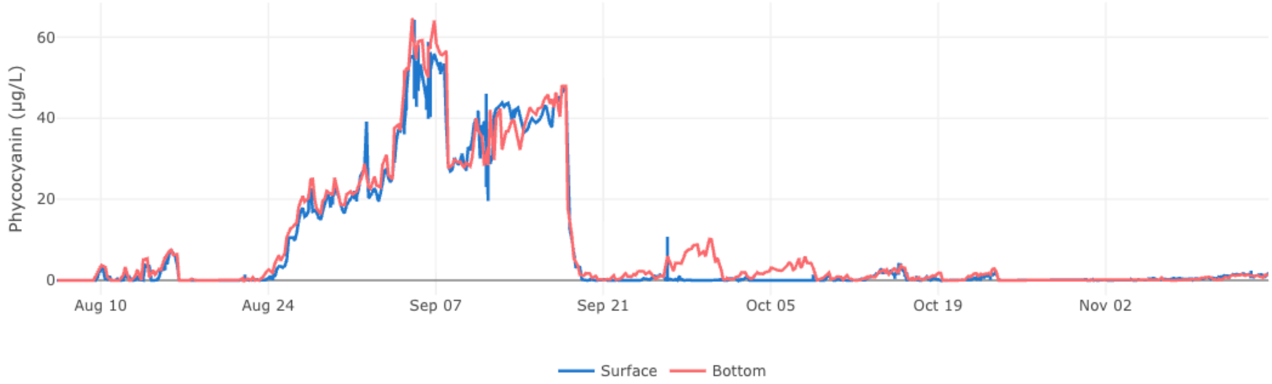

Figure 1. HAB activity over the monitoring period

The chart shows surface and near-bottom phycocyanin concentrations (a proxy for HAB/cyanobacteria levels) in Long Pond from August 3 through November 16. Elevated phycocyanin concentrations were observed during late summer and early fall, indicating sustained cyanobacteria activity over an extended period. Phycocyanin was detected throughout the deployment, with pronounced peaks beginning in late August and intermittent activity continuing into November.

Bloom timing, vertical structure, and evolution

Phycocyanin concentrations were generally similar or higher at depth than at the surface prior to the major bloom, suggesting that HAB activity was not confined to surface waters. A rapid escalation in phycocyanin occurred beginning around **August 23**, with concentrations increasing by approximately fourfold over two days, followed by an additional multi-fold increase over the subsequent week. The bloom declined sharply between **September 17–19**, after which phycocyanin levels remained intermittently elevated at depth through October.

Conditions preceding the late-August harmful algal bloom

The major harmful algal bloom that began around **August 23** was preceded by a distinct sequence of physical and biological changes observed over the prior week.

Between **August 16 and 21**, Long Pond experienced a period of elevated wind speeds, coincident with a rapid surface cooling and partial mixing event in which surface water temperatures declined from approximately **78°F to 73°F**. A discrete rainfall event also occurred on **August 19**.

In the weeks leading up to this period, **chlorophyll-a concentrations increased rapidly**, approximately doubling between the second and fourth weeks of August. This increase in chlorophyll-a measured phytoplankton biomass preceded the sharp rise in phycocyanin associated with the HAB event that initiated on ~ Aug 23rd.

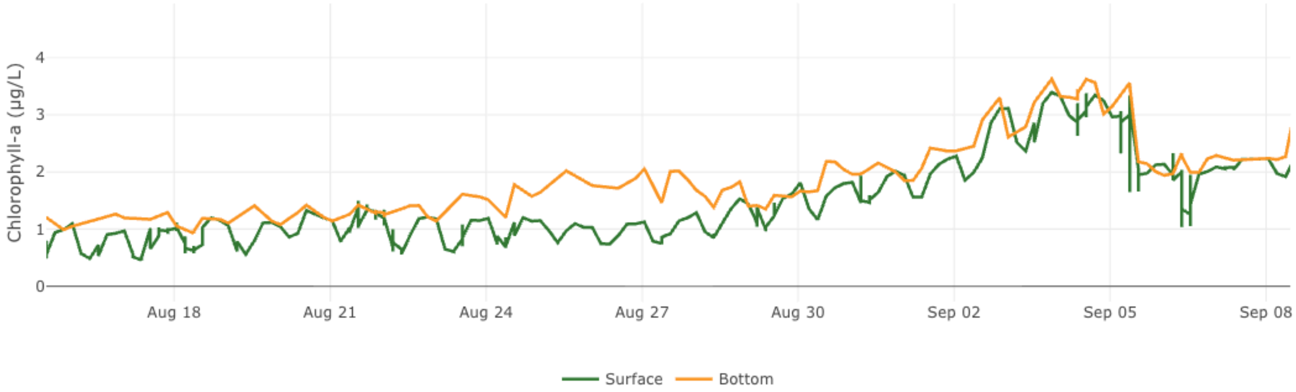

Figure 2. Chlorophyll-a surge preceding bloom onset

Surface and near-bottom chlorophyll-a concentrations (a measure of phytoplankton abundance) from August through early September. Chlorophyll-a levels increased rapidly in mid-to-late August, approximately doubling prior to the onset of the major HAB event shown in Figure 1. This increase indicates rising overall phytoplankton biomass preceding HAB dominance and may be useful as a predictive mechanism for harmful algal bloom occurrences.

Together, these observations indicate that the August 23rd HAB emerged following a short interval marked by changes in physical conditions (wind driven mixing and surface temperature declines) and increasing biological productivity. These co-occurring patterns provide important context for evaluating potential bloom drivers in subsequent sections of this report, as well as monitoring in subsequent years.

Evaluation of Potential Bloom Drivers, Preliminary Hypotheses, and Key Uncertainties

This section presents an initial evaluation of potential HAB drivers in Long Pond, based on data collected during the monitoring window from August through November 2025. Because this deployment did not capture spring or early summer conditions, and because many bloom-driving processes can vary seasonally, the interpretations below should be considered preliminary hypotheses rather than confirmed conclusions.

A full-season deployment in 2026, spanning spring through fall, will be required to validate, refine, or revise these hypotheses.

Initial Hypotheses Based on 2025 Observations

Primary Hypothesis: Internal Loading Pattern B — Shallow, Polymictic Recycling System

Based on 2025 observations, Long Pond shows patterns most consistent with a shallow, internally enriched system in which phosphorus stored in bottom sediments may play an important role in fueling HABs.

Historical sampling data show that total phosphorus concentrations are consistently higher in bottom waters than at the surface, indicating that phosphorus has accumulated within the lake over time rather than being supplied primarily through ongoing surface inputs (see Table 1 below). While surface phosphorus concentrations remain near the mesotrophic range, bottom-water concentrations are substantially higher, pointing to a persistent internal nutrient reservoir.

***Table 1*. Summary of historical total phosphorus concentrations in Long Pond (source: Cape Cod Commission Freshwater Data Portal)**

Period	Surface Total Phosphorus (μg/L)	Bottom Total Phosphorus (μg/L)
2001–present	16.2 (n=17)	34.7 (n=17)
Last 5 years	19.9 (n=12)	28.4 (n=12)

Long Pond is relatively shallow (~21 ft) and exhibits weak, transient stratification with frequent mixing (polymictic). In systems with these characteristics, internal phosphorus does not need to be released continuously under prolonged low-oxygen conditions to influence blooms. Instead, short-lived low-oxygen conditions near the sediment or physical mixing events (often wind-driven) can intermittently mobilize phosphorus from sediments and transport it into surface waters, where it becomes available to cyanobacteria.

Because monitoring began in August, this deployment may have missed earlier-season conditions when short-lived bottom-water oxygen depletion or redox-driven sediment phosphorus release may have intermittently occurred and potentially contributed nutrients to subsequent blooms. Confirming whether and when these episodic release events occur — and how they relate to bloom initiation — is a primary objective for a full-season 2026 deployment.

At present, this internal recycling framework represents the leading working hypothesis, supported by persistent bottom–surface phosphorus gradients, shallow depth, and observed bloom behavior, while recognizing that additional data are needed to confirm the dominant mechanisms driving HABs in Long Pond.

Secondary Contributor Hypotheses That May Amplify Blooms

The following system types are not currently considered primary nutrient sources, but may help explain why and when blooms intensify in an internally enriched system.

Background Contributor: External Nutrient Dominant Pattern C — Groundwater-Dominant Seepage Systems

Long Pond is surrounded by residential development served primarily by septic systems, including approximately 69 homes with an average system age of more than 50 years (source: Cape Cod Commission Freshwater Data Portal). In sandy, permeable soils typical of Cape Cod, nutrients from septic systems can enter ponds through slow, diffuse groundwater seepage.

Groundwater-driven nutrient inputs can raise a pond’s baseline nutrient levels, increasing overall productivity even in the absence of major storm events or surface inflows. For this reason, groundwater inputs were evaluated as a potential contributor to bloom susceptibility in Long Pond.

However, historical total phosphorus sampling *does not show* a clear (i.e., statistically significant) long-term increase in either surface or bottom phosphorus concentrations since monitoring began in 2001. This pattern suggests that while groundwater nutrient inputs may help explain why Long Pond is nutrient-enriched overall, they are unlikely to be the primary factor controlling the timing, intensity, or recent changes in HABs. Over time, this sustained phosphorus loading can be stored in bottom sediments, creating a legacy nutrient pool that can be mobilized during hypoxic and/or mixing conditions and subsequently fuel HABs. At this stage, groundwater seepage is best understood as a background condition that sets the stage for blooms, rather than a direct trigger of individual bloom events.

Potential Amplifier: External Nutrient Dominant Pattern B — Externally Pulsed / Event-Responsive Systems

The major HAB event starting in late August followed a short interval of strong winds, surface cooling, partial mixing, and rainfall. In externally pulsed or event-responsive systems, episodic inputs such as rain events and watershed runoff can deliver additional nutrients to the system on short timescales, potentially triggering or intensifying blooms. These nutrient pulses are often transient but can be highly effective when they coincide with favorable light and temperature conditions.

These externally driven nutrient inputs are difficult to isolate from physical mixing processes, because rainfall events frequently co-occur with increased wind stress and surface cooling (such as those observed between August 16 and 21, prior to the August 23 HAB onset). As a result, if present, this pattern is best interpreted as an amplifying mechanism in which externally pulsed nutrient inputs intensify blooms when nutrients are already available, rather than as a standalone indicator of sustained nutrient enrichment.

Additional Amplifier: Regional Climate Warming and Elevated Water Temperatures

Regional climate warming likely acts as a system-level amplifier of HABs in Long Pond by increasing water temperatures and extending periods favorable for bloom development. Cyanobacteria often exhibit competitive advantages at elevated temperatures, particularly in phosphorus-enriched systems. In this context, warming is best understood as an amplifying factor that interacts with nutrient availability and physical mixing, rather than a primary driver of bloom initiation.

System Types Considered but Less Consistent With Observations

These HAB system lake archetypes were evaluated and appear less consistent with observed conditions, given current data.

Internal Loading Pattern A — Stratified Lakes with Seasonal Oxygen Depletion and Nutrient Cycling

In deeper lakes that remain strongly stratified, bottom waters often become persistently low in oxygen, leading to continuous phosphorus release from sediments and predictable bloom responses following seasonal turnover.

Long Pond does not exhibit strong, long-lasting stratification nor clear evidence of sustained bottom-water oxygen depletion during the monitoring period. While brief low-oxygen events cannot be ruled out, this classic pattern appears less consistent with observed thermal structure. However, bottom-water oxygen conditions have not been evaluated in the spring to summer period and are a major objective for 2026 sampling.

External Nutrient Dominant Pattern A — Watershed-Controlled Eutrophication (Chronic External Loading)

In watershed-dominated systems, blooms typically recur at similar times each year and respond slowly to changes in land use or nutrient management. Long Pond lacks significant tributary inflows, and much of 2025 monitoring occurred during drought conditions, both of which limited sustained watershed nutrient delivery and reduced the likelihood that watershed processes exerted strong control over bloom development. Long Pond also does not show evidence of steadily increasing surface phosphorus through time, making this pattern unlikely to be the dominant driver. Future monitoring through periods with more consistent rains (i.e., spring) can further confirm these observations.

Summary Hypotheses and Key Takeaways

Our preliminary driving hypotheses suggest that HABs in Long Pond may be influenced primarily by internal nutrient recycling in a shallow, weakly stratified system. Septic system groundwater phosphorus loading contributes to overall nutrient accumulation and bloom susceptibility and rainfall driven episodic nutrient inputs may potentially play an amplifying role.

Recommended 2026 Monitoring Priorities

This section builds directly on the hypotheses outlined above, requiring further validation, and describes how 2026 monitoring is designed to refine them. The purpose of the 2026 monitoring season is to test these leading hypotheses of a shallow system, where nutrients stored within the pond serve as the primary driver and groundwater nutrient inputs and rain-driven nutrient inflows as secondary amplifiers. This is best achieved through monitoring across the full seasonal cycle to assess whether they remain consistent when early-season conditions, bloom initiation, and seasonal transitions are considered.

What 2026 monitoring is designed to resolve

Full-season monitoring will help clarify:

- Whether internal nutrient availability increases prior to bloom development, particularly in relation to short-lived low-oxygen conditions near the sediment
- How physical mixing events interact with nutrient availability to influence bloom timing and intensity
- Whether early-season conditions set bloom trajectories that only become visible later in the summer
- The relative impacts of rainfall events on HAB activity

These mechanisms can produce similar summer bloom patterns but imply very different management and remediation approaches.

Recommended 2026 approach

- Continue buoy-based monitoring from early spring through fall, including bottom measurements positioned just above the sediment to monitor for brief low-oxygen events.
- Continuous monitoring and comparison of bloom development to temperature, stratification, wind, and weather.
- Where buoy data suggest potential nutrient mobilization or mixing events, use targeted surface and bottom-water phosphorus sampling to evaluate whether nutrients increase first near the bottom and later appear at the surface.

What this enables

By the end of the 2026 season, this approach is expected to provide stronger, decision-relevant confidence around which processes are most important for HABs in Long Pond and which are less likely to be effective targets for remediation. This reduces the risk of pursuing costly or ineffective interventions and helps focus future efforts on the mechanisms that matter most to supporting and maintaining healthy pond conditions.

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