Satellite Remote Sensing Tools to Assist with Monitoring and Management of Harmful Algal Blooms

Lead: ERDC Envrionmental Laboratory

USACE Harmful Algal Bloom Research & Development Initiative

Delivering scalable freshwater HAB prevention, detection and management technologies through collaboration, partnership and cutting-edge science.

Problem

There are hundreds of thousands of waterbodies in the United States, many of which require various degrees of monitoring for water intakes, recreation, fisheries, etc. Partly due to the extensive geographic coverage of these waterbodies across the U.S., management of Harmful Algal Blooms (HABs) tends to be reactionary. Innovations in remote sensing technology, such as readily available high resolution satellite imagery and web-based tools, can help shift towards more proactive HAB response and management.

Objective

Satellite-dervied products can provide a synoptic view of water quality conditions (e.g., chlorophyll-a) for more effective, near-real time monitoring of spatial and temporal variation across an entire waterbody or multiple waterbodies over a large region at one time. The overarching goal is to integrate satellite imagery into management to help reduce costs and labor by minimizing and prioritizing the location and timing of field samples (for collection and analytical detection) and serve as part of early monitoring for potential toxin-producing HABs.

Approach

The United States Army Corps of Engineers (USACE) has been conducting research and development to better understand and help advance the role of remote sensing in inland water quality monitoring for over a decade. These advancements include foundational research on evaluating satellite derived algorithms for chlorophyll-a and phycocyanin estimation, participating in numerous lab and field demonstrations, and developing a suite of remote sensing-based software tools (Reif 2011, Beck et al., 2016, Beck et al., 2017, Johansen et al., 2019, Saltus et al., 2022). Water resource managers are looking to integrate such remote sensing approaches into management plans for proactive decision making to mitigate the adverse impacts

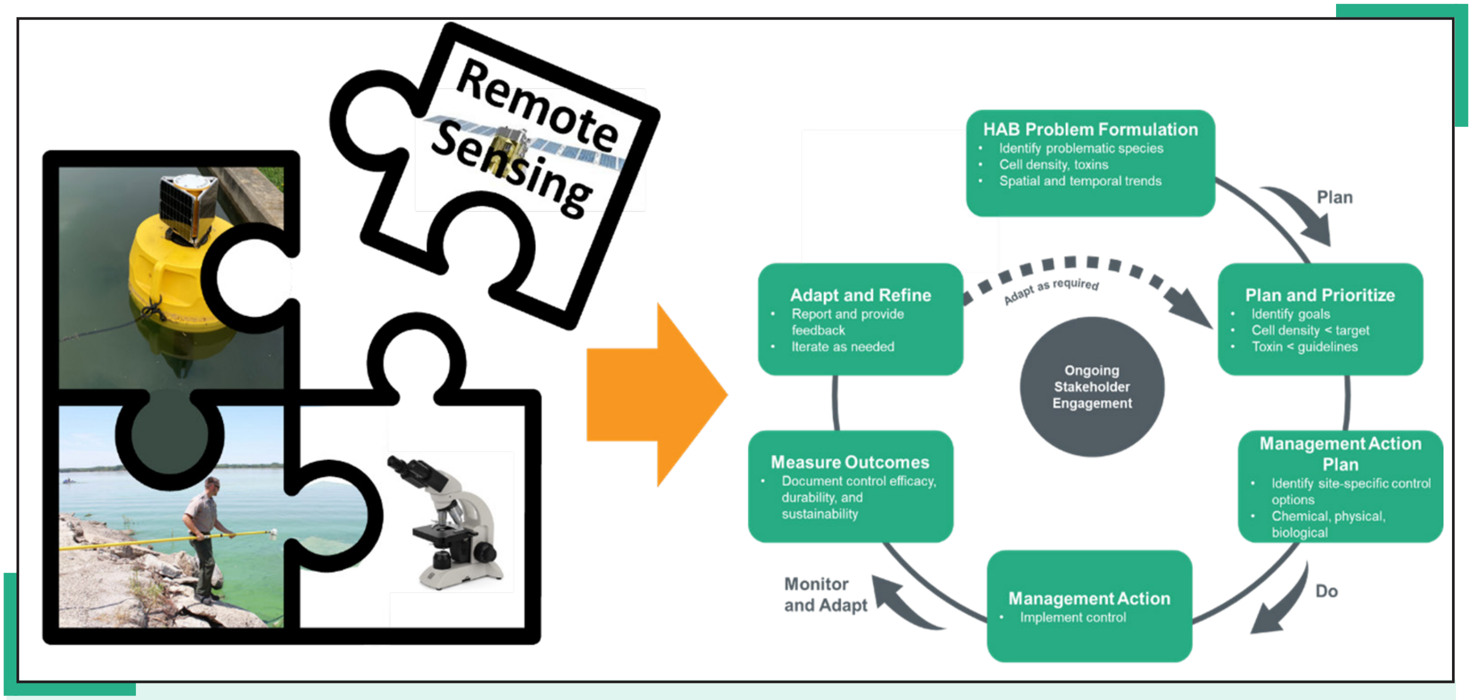

Figure 1. *Conceptual approach for integrating remote sensing data to inform HAB management*

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of HABs, especially since they often have limited spatial and temporal data to inform when and where to treat. For example, actionable data used to determine bloom location and cell density and to inform response planning are often confined to a limited number of field samples or shoreline observations(Calomeni et al. 2017). Furthermore, these challenges likewise impact the evaluation of HAB treatment, in which field samples likewise lack sufficient spatial and temporal coverage to thoroughly evaluate and understand treatment efficacy. Thus, limited data often leads to uncertainty surrounding HAB treatment and can impact intended mitigation plans. Therefore, there is an opportunity to pair additional lines of evidence using remote sensing technology to better inform HAB adaptive management and mitigation strategies (Figure 1).

Operational Satellites

Currently there are a handful of satellite platforms in orbit which provide imagery useful for the detection and monitoring of potential HABs at spatial, spectral, and temporal resolutions suitable for management. Table 1 details a short list of commonly used satellite platforms color-coded to demonstrate their utility for HAB monitoring by different types of resolution (e.g., spatial, spectral, and temporal), in which green, yellow, and red coded cells represent relatively good, moderate, and poor utility, respectively. For example, sensors with relatively coarse spatial resolution (e.g., >250 meters[m]) are coded yellow or red and are more appropriate for large waterbodies (e.g., Lake Erie or the Gulf of Mexico), while those with relatively high spatial resolution (e.g., <30 m) are coded green and are more appropriate for lakes, reservoirs, or large ponds. Regarding spectral resolution, it is important to note that the majority of remote sensing-based algorithms applied to imagery are designed to utilize optically-active pigments (chlorophyll-a and phycocyanin) as proxies for algal biomass. Sensors offering spectral configurations with numerous, narrow bands (~5-20 bands) allow for the detection of HAB-associated pigments, such as the green band (~550 nanometers [nm]), phycocyanin absorption (~620 nm), chlorophyll-a reflectance peak (665 nm–680 nm), and cell backscattering (~709 nm). The Medium Resolution Imaging Spectrometer (MERIS) and Sentinel-3 Ocean and Land Colour Instrument (OLCI) are the only satellite imagers that have spectral bands specific to phycocyanin absorption, making them the most appropriate for the detection of cyanobacteria (coded green), while other sensors coded yellow (e.g., Landsat 8) or red (e.g., Moderate Resolution Imaging Spectroradiometer [MODIS]), either have relatively fewer or coarser spectral bands or bands that are not as well placed for detecting HAB-associated pigments. Likewise, the same color-coded schema is applied to temporal resolution which describes the number of days between satellite overpasses at the same location (e.g., revisit frequency). For example, sensors with 1-2-day revisit frequences are coded green (e.g., Planet and OLCI), while others with relatively longer revisit frequencies are coded yellow (e.g., Sentinel-2 Multispectral Instrument) or red (i.e., Landsat 8). Lastly, costs associated with image acquisition are listed as ‘yes’, in which additional costs must be considered for routine HAB monitoring, or ‘no’, in which imagery is publicly available.

Advancements in cloud-computing and storage have led to a dramatic improvement in the development of user-focused software and web-based applications. Notably, open-source programming and web apps have helped reduce technical barriers and the need for multiple programs to integrate remotely sensed imagery as a complementary tool for monitoring HABs to aid decision-making and management goals. Seven common, nationally focused tools include: (1) Sentinel Hub’s EO Browser: https://apps.sentinel-hub.com/eo-browser/;

Satellite Sensor	Spatial Resolution (centimeters [cm] and meters [m])	Spectral Resolution (number of bands, range, and bandwidth in nano-meters [nm])	Temporal Resolution (number of days, revisit frequency)	Imagery Acquisition Cost?
Planet PlanetScope and SkySat constellations (2014 - Present)	🟩 50cm-3m	🟨 Bands: 4-8 Range: 443–865 Bandwidths: 15-50	🟩 1	Yes
WorldView-2 and -3 multi-spectral sensors (2009 – Present)	🟩 1.8	🟨 Bands: 6 Range: 400-725 Bandwidths: 40-70	🟩 1-2	Yes
Sentinel-2 Multispectral Instrument (MSI) (2016 – Present)	🟩 20	🟨 Bands: 8 Range: 443–865 Bandwidths: 15-65	🟨 5	No
N Landsat 8 Operational Land Imager (OLI) (2013 – Present)	🟩 30	🟨 Bands: 5 Range: 443–865 Bandwidths: 20-60	🟧 16	No
Moderate Resolution Imaging Spectroradiometer (MODIS) (High Spatial) (1999 – Present)	🟨 250-500	🟧 Bands: 4 Range: 469-858 Bandwidths: 20-50	🟩 1-2	No
MODIS (Low Spatial) (1999 – Present)	🟧 1000	🟨 Bands: 12 Range: 412-940 Bandwidths: 10-50	🟩 1-2	No
Medium Resolution Imaging Spectrometer (MERIS) (2002 – 2012) Sentinel-3 Ocean and Land Colour Instrument (OLCI) (2016 – Present)	🟨 300	🟩 Bands: 21 Range: 400-1020 Bandwidths: 3-40	🟩 1-2	No

Table 1. *List of satellite sensors for HAB monitoring. Note that the number of bands reported in the spectral resolution column has been adjusted to only those useable in the majority of remote sensing-based algorithms for estimating optically-active pigments (chlorophyll-a and phycocyanin), which are used as proxies for algal biomass. Green is good, yellow is moderate, and orange is poor.*

(2) EPA's CyAN WebApp: https://qed.epa.gov/cyanweb/account; (3) USACE's waterquality R tool: https://github.com/RAJohansen/waterquality; (4) USACE's HAB ArcPro Toolbox: https://erdc-library.erdc.dren.mil/jspui/handle/11681/42240; (5) USACE's HAB Explorer WebApp: https://jecop-public.usace.army.mil/hab/; (6) NALMS: https://cyanos.org/bloomwatch/ ; (7) BloomOptix AI https://bloomoptix.com/.

Figures 2-4 illustrate examples of some of the widely available tools that can aid managers, applicators, and the public with monitoring near-real time water conditions.

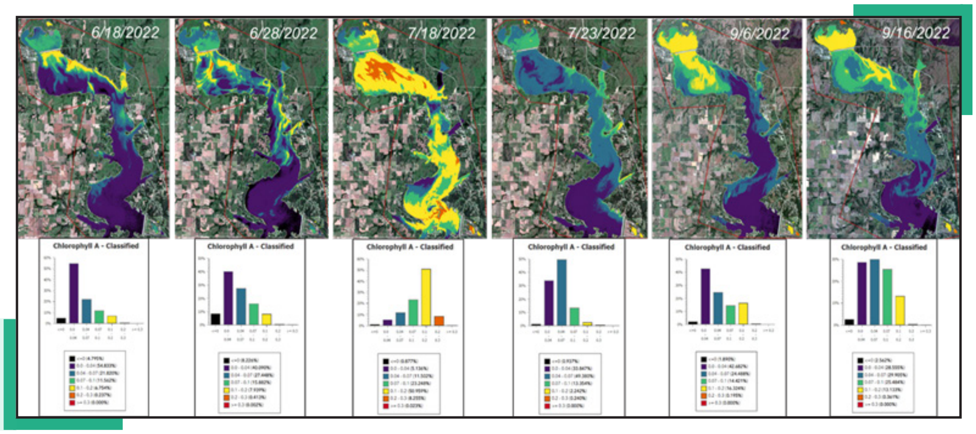

Figure 2. *Time series results from the USACE HAB Explorer WebApp showing the spatial extent of a HAB in Milford KS between 06/18/2022 through 09/16/2022.*

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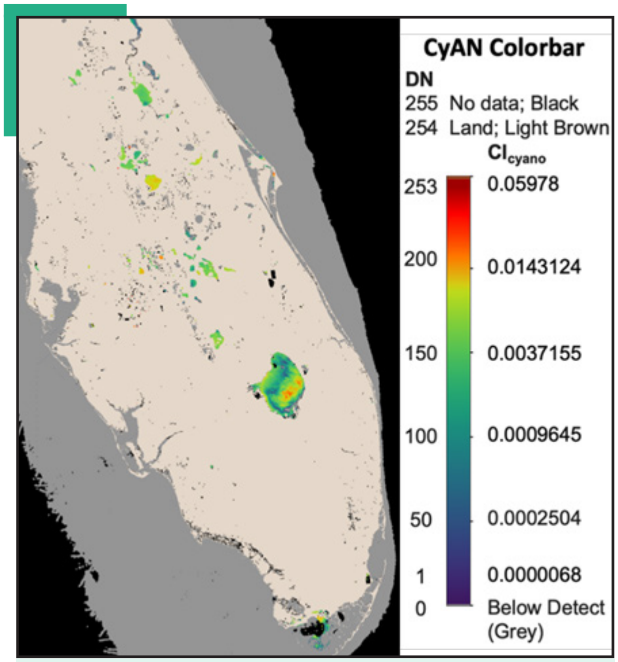

Figure 3. *(Above) Sample results from the EPA's CyAN WebApp for central and southern Florida in June 2024.*

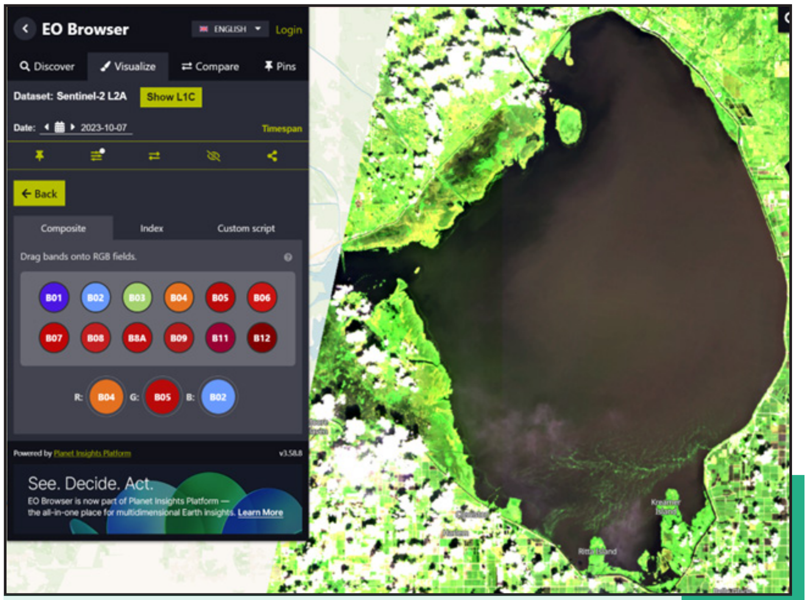

Figure 4. *(Below) Screenshot of Sentinel Hub's EO Browser results illustrating a minor bloom in Lake Okeechobee, Florida on 10/07/2023.*

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Partnership/Leveraging Opportunities

This work leverages synergy between researchers internal to the Environmental Laboratory in addtion to work performed by external partners such as the EPA.

Value to USACE Mission

These software tools provide improved capabilities for HAB monitoring and management. The tools can empower managers to take a proactive versus reactive management strategy, and facilitate the effcient allocation of limited resources. Addtionally, such tools have widespread applicability to USACE projects across the nation.

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