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California Water Boards' Framework and Strategy for Freshwater Harmful Algal Bloom Monitoring: Full Report with Appendices

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California State Water Boards' Framework and Strategy for Freshwater Harmful Algal Bloom Monitoring: Full Report with Appendices

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LIST OF ACRONYMS

AB	Assembly Bill
AFDM	Ash free dry mass
ASCI	Algal stream condition index
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BSMP	Beach Safety Monitoring Program - AB 411
BMAA	Beta-N-methylamino-L-alanine
BMP	Best management practices
BOG	Bioaccumulation Oversight Group
CalFire	California Department of Forestry and Fire Protection
Cal-HABMAP	California Harmful Algal Bloom Monitoring and Alert Program
CC	Climate change
CCHAB	California Cyanobacteria Harmful Algal Bloom Network
CDC	Center for Disease Control
CDFW	California Department of Fish and Wildlife
CDPH	California Department of Public Health
CEDEN	California Environmental Data Exchange Network
CeNCOOS	Central and Northern California Ocean Observing System
Chl-a	Chlorophyll *a*
CIcyano	Modified Cyanobacteria index
CSCI	California Stream Condition Index
CyAN	Cyanobacteria Assessment Network
DOC	Dissolved organic carbon
ELAP	Environmental Lab Accreditation Program
EPA	Environmental Protection Agency
ESA	European Space Agency
FHAB	Freshwater harmful algal bloom
FIB	Fecal Indicator Bacteria
HAB	Harmful Algal Bloom
HTB	Heal the Bay
MC	Microcystins
MERHAB	Monitoring and Event Response for Harmful Algal Blooms
MERIS	MEdium Resolution Imaging Spectrometer
MIB	2-methylisoborneol
MLLW	Mean low water
MODIS	Moderate Resolution Imaging Spectroradiometer
MS4	Municipal Separate Storm Sewer System
NARS	National Aquatic Resource Surveys
NASA	National Aeronautics and Space Administration
NGO	Non-governmental organization
NHD	National Hydrography Dataset
NLA	National Lakes Assessment

NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	Non-point source
OC	Organic carbon
OEHHA	Office of Environmental Health Hazard Assessment
OHHABS	One Health Harmful Algal Bloom System
OIMA	Office of Information Management and Analysis
OLCI	Ocean and Land Colour Instrument
OM	Organic Matter
PSA	Perennial Stream Assessment
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
qPCR	Quantitative polymerase chain reaction
R	R statistical program
RCMP	Reference Condition Monitoring Program
RGB	Red Green Blue
RMP	Regional Monitoring Program
RWQCB	Regional Water Quality Control Board
SAGs	Stakeholder advisory groups
SCCOOS	Southern California Coastal Ocean Observing System
SCCWRP	Southern California Coastal Water Research Project Authority
SFEI	San Francisco Estuary Institute
SLSTR	Sea and Land Surface Temperature Radiometer
SMC	Southern California Stormwater Monitoring Coalition
SOP	Standard Operating Protocol
SPATT	Solid Phase Adsorption Toxin Tracking
SS	Special study
SWAMP	Surface Water Ambient Monitoring Program
SWQCB	State Water Quality Control Board
TAC	Technical Advisory Committee
TIRS	Thermal Infrared Sensor
TMDL	Total maximum daily load
TN	Total nitrogen
TP	Total phosphorus
USFS	U.S. Forest Service
USDFW	United States Department of Fish and Wildlife
USGS	United States Geological Survey
UV	Ultraviolet
WHO	World Health Organization
WQ	Water quality
WQMC	Water Quality Monitoring Council
WQX	Water Quality Exchange Database

EXECUTIVE SUMMARY

Freshwater harmful algal blooms (FHABs), defined as an overgrowth of cyanobacteria or eukaryotic algae, are found in California inland waters. FHABs can produce toxins that can harm humans, dogs and domestic livestock, and wildlife. High biomass of both toxic and non-toxic blooms causes odor, poor aesthetics, and a cascade of ecological effects including proliferation of pathogenic bacteria, clogging of benthic habitats, low dissolved oxygen, and fish kills. FHABs are impairing multiple beneficial uses including imperiling drinking water sources, recreation, tribal and cultural uses, agriculture, and aquatic life. Nutrient pollution, hydromodification, and physical habitat alteration resulting from human activities are the principal drivers, but climate change is already exacerbating FHABs through warming, higher CO_2 levels, and changing precipitation regimes. However, little is understood about the extent of FHAB risks to core beneficial uses because inland surface waters are not routinely monitored for these impacts. Severe impacts have been documented in communities with chronic FHAB problems in the Klamath River, Clear Lake, Central Coast, Central Valley, and Inland Empire among others. FHAB impacts compound other adverse conditions in economically disadvantaged communities such as limited access to recreational opportunities, clean water, health care and affordable and safe housing. The State Water Board responded to the emerging FHAB problem by establishing a long-term vision and strategic plan called *the FHAB Assessment and Support Strategy*. This 2016 document called for an FHAB monitoring program, comprised of 1) incident response, 2) ambient monitoring, and 3) decision support. Since then, the Water Boards developed an incident response program and made investments in remote sensing, but ambient monitoring has yet to be fully implemented.

This document articulates the framework and strategy to develop and implement an FHAB Monitoring Program. Program elements are organized around addressing key management questions related to five core beneficial uses: **swimmable (contact and non-contact recreation), fishable**, **aquatic life**, **raw water sources,** and **tribal tradition and culture**. These core uses serve as overarching themes that cover multiple individual beneficial use designations. Management questions are focused on immediate information needs about FHABs: 1) understanding the **status and trends** of FHABs and 2) the **environmental drivers** influencing FHAB magnitude, frequency, and duration. Specific consideration is given to three waterbody types: 1) lakes and reservoirs, 2) streams and rivers, and 3) coastal confluences. An executive synthesis of this document is available at: https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1141_FHABStrategy_Synthesis.pdf. A fact sheet summarizing the main elements of the report was also produced and is available at: https://ftp.sccwrp.org/pub/download/DOCUMENTS/FactSheets/1141_FHABStrategy_FactSheet.pdf.

The Monitoring Framework and Strategy documents how data from ambient monitoring and incident response can be used to inform management decisions to protect public health and the environment. Three major ambient monitoring approaches were considered: 1) a **partner program** that provides infrastructure to encourage FHAB monitoring by other federal, state and local agencies, tribal governments, community science groups, etc., 2) **remote sensing approaches** that build upon the current partnership that California has formed with federal agencies and 3) **field surveys** developed and managed by the Surface Water Ambient Monitoring Program (SWAMP) or its partners. **Incident response** will need to continue and will strengthen through synergies with ambient monitoring approaches. **Data management, visualization, and decision support** systems that are a core part of monitoring infrastructure were identified to support and optimize the utility of FHAB data for management decisions and ensure timely and open accessibility of data to the public. Recommendations are intended to inform management decisions to protect public health and the environment and improve water quality. The document is meant to provide a comprehensive vision and roadmap for the tools and guidance needed to support agencies and organizations as they are informed of and seek to address FHABs in a coordinated way.

Approach to Developing FHAB Monitoring Program Framework and Strategy

We developed the vision and programmatic elements of a comprehensive FHAB monitoring program with the help of Technical Advisory Committee (TAC) of national harmful algal bloom (HABs) experts, Regional Board HABs staff, Tribes' Natural Resources programs, and community scientist monitoring leads, among others. The TAC produced a comprehensive framework that could form the foundation of an FHAB monitoring program that protects the core beneficial uses. The Water Board staff considered TAC recommendations, then formulated a strategy that represents the incremental implementation of a subset of these options.

Recommended Actions to Build an FHAB Monitoring Program

The Strategy recommends six actions to implement an FHAB monitoring program, implemented with appropriate data systems and decision support tools in accordance with open data policies:

1. **Develop and implement an FHAB partner monitoring program.** Water Boards are envisioned as the primary coordinating agency with multiple partner agencies that are all assessing specific waterbodies following a suite of standardized methods. Partner agencies could include tribes, local environmental health and park departments, drinking water agencies, private waterbody managers, or scientific non-governmental organizations (NGOs).
2. **Strengthen the incorporation of remote sensing into the program:** Remote sensing is a cost-effective and complementary approach to field-based assessments of FHAB status, trends, and drivers. The Water Boards have made strategic investments to capitalize on federally curated FHAB remote sensing products for large lakes and reservoirs, provided through a Californian FHAB satellite portal. These investments, while among the first of their kind in the U.S., have not yet resulted in extensive use to address FHAB management questions or actions. The strategy recommends making strategic investments to capitalize on cost-effective and complementary information that it provides to field-based assessments of FHAB status, trends, and drivers.
3. **Implement field surveys focused on human health:** Human health impacts from FHABs include ingestion of toxins from contact recreation, aerosols and odors affecting non-contact recreation, and consumption of toxin-contaminated fish or shellfish. Field surveys based on one-time field assessment do not assure that public health in sampled waterbodies is actually being routinely protected, while remaining cost effective. This is a fundamental challenge of FHAB monitoring. The strategy recommends implementation of state-coordinated field surveys focused on protecting human health—a TAC priority recommendation.
4. **Conduct focused assessments of FHAB drivers:** Waterbody, watershed, or regional-scale integrated assessments of FHAB drivers and responses are time and resource intensive but produce data that are the most likely to result in a corrective management action. To address the management information needs from the statewide to waterbody scale, the strategy recommends use of existing field survey data and remote sensing to conduct a statewide status and drivers assessment and to screen watersheds for FHAB risk, then fund intensive FHAB assessments at these high priority and higher risk watersheds or waterbodies. Existing remote sensing, SWAMP Stream Bioassessment Program, and EPA aquatic resources surveys capture the

majority of recommended FHAB responses and drivers. They represent an important leveraging opportunity to assess the status and trends of FHABs statewide and to support decisions on prioritizing these more intensive assessments. Understanding of FHAB risk environmental drivers will improve over time as data gaps are addressed.

5. **Synergize incident response with ambient monitoring.** Incident response is a core component of the FHAB Monitoring Program. Even as ambient monitoring increases, the Water Boards will need to respond to the public reports of blooms. Public observations of conditions at waterbodies statewide are more frequent than that of Water Board staff and partner agencies. The member of the public who provides these incident response reports should be considered a partner to the Water Board who can ultimately provide more surveillance than ambient monitoring can feasibly provide. The strategy recommends that incident response efforts should continue, and procedures be improved to harmonize with ambient monitoring and efficiently respond to FHAB reports from the public.
6. **Work to integrate HAB monitoring elements into all relevant Water Board programs and policies.** FHABs are interconnected with other fundamental water quality issues, in particular, eutrophication, climate change, hydromodification, and land use change that can alter physical habitat, temperature, and light regimes. Thus, FHAB issues crosscut a number of Water Board policies and programs. The strategy recommends that a specific and concerted effort should be made by FHAB and other Water Board staff to link FHAB elements to all applicable programs for a more holistic approach to assessing, managing, and preventing FHAB issues.

Summary: An Integrated View of Outputs and Anticipated Outcomes

Taken together, multiple monitoring approaches provide complementary, cost-effective, and actionable information to protect public health and mitigate FHABs. Investments must be made across all approaches in order to achieve our goal of public health and beneficial use protection. Our proposed strategy is scalable to available resources and can be used to incrementally fill these data gaps on FHABs over time. The anticipated outcomes of this proposed FHAB Monitoring Program include 1) Strong collaborative partnerships that adopt a shared set of standard practices and information through open data systems, 2) Data visualization tools that enhance decision support, 3) Science tools such as predictive models and improved thresholds to diagnose impairments of beneficial uses, and 4) Partner and Water Board science tools, actions (waterbody-specific mitigation projects, 303(d) listings, adoption of total maximum daily loads), and policies (e.g., biostimulatory objectives, climate change, recycled water).

The report provides a comprehensive and visionary list of FHAB monitoring options for the Water Boards to consider and is not designed to consider financial constraints or potential program budgets. Water Boards staff can now evaluate what can be implemented given potential FHAB Monitoring Program financial and personnel resources. The strategy can be implemented in stages through the development of subsequent multi-year FHAB Monitoring Program Workplans.

Developing an FHAB monitoring program would benefit State and Regional Board programs, and other State and local agencies. We can only manage what we measure, and without data, water quality and public health cannot be protected, and waterbodies cannot be restored. With FHABs impacting many beneficial uses, FHAB monitoring data will be used across multiple scales of government, citizenry, and stakeholder groups. We stress that funding monitoring alone doesn’t protect us from or mitigate FHABs, but provides data to inform it, and allows us to track the progress resulting from implementation actions.

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1. INTRODUCTION

1.1 Purpose of the Report

This document describes California's Freshwater Harmful Algal Bloom (FHAB) Monitoring Framework and Strategy. The document articulates the vision and programmatic elements and recommends the priority options for how FHAB monitoring and assessment can be used to inform management decisions to protect public health and the environment and improve water quality. It provides a roadmap for the tools and guidance needed to support agencies and organizations as they are informed of and seek to address FHABs in a coordinated way. The report is not designed to consider financial constraints or potential program budgets but provides a comprehensive and visionary list of FHAB monitoring options for the Water Boards to consider. Water Boards staff will then take the recommendations and evaluate what can be implemented given potential FHAB Monitoring Program financial and personnel resources. Ultimately, components of the strategy will be implemented in stages through the development of subsequent multi-year FHAB Monitoring Program Workplans.

An overview of the Monitoring Strategy is summarized in the "Executive Synthesis" – a separate document. This report constitutes the main document, which is comprised of one introductory and seven technical chapters and is intended to provide deeper background and rationale for strategic priorities recommended by Water Board staff for implementation in the Executive Synthesis.

1.2 What are freshwater harmful algal blooms and why are they a problem in California?

What is a Harmful Algal Bloom?
Cyanobacteria and **eukaryotic algae** naturally occur in all aquatic systems and are the foundation of food webs that support aquatic life in our lakes, rivers, estuaries, and oceans (see inset box: What Organisms Make Up Algal Blooms). In an "undisturbed state," there is a high diversity and abundance of species that shifts in responses to natural environmental factors. When conditions are favorable for certain species, they can reproduce very quickly and rapidly accumulate biomass, in what are commonly referred to as **"blooms." Harmful algal blooms (HABs)** are defined as blooms with any negative consequence (to society or ecosystem[1]) that occurs as a consequence of cyanobacteria, macroalgae and/or eukaryotic algae. While HAB species are naturally occurring, human activities can alter the environment in ways that promote HABs to increase their

> **What Organisms Make Up Algal Blooms?**
>
> **Photosynthetic cyanobacteria** and **eukaryotic algae** are naturally occurring aquatic microbes that form the foundation of many aquatic food webs by generating organic carbon via photosynthesis. Cyanobacteria are a diverse group of bacteria that evolved more than two billion years ago. Although cyanobacteria are prokaryotes, they are also known as **"blue-green algae"** due to historical taxonomic associations with eukaryotic algae. **Eukaryotic algae** are a diverse group of organisms with different life history strategies. Common microalgae in freshwaters are diatoms, dinoflagellates, chlorophytes (green algae), chrysophytes, and cryptomonads. Common macroalgae include many species of *Cladophora*. Cyanobacteria and algae co-occur in aquatic ecosystems and can have both benthic (bottom dwelling) and planktonic (surface water) forms. Their abundances can change rapidly in response to shifting environmental conditions.

[1] "Ecosystem" hereafter refers to a system of interconnected elements formed by the interaction of a community of organisms (plants, animals, including humans and their domestic animals, etc.) with their environment.

magnitude, frequency/duration, and/or extent. HABs occur across the continuum from freshwater[2] streams, and lakes to estuarine and marine[3] habitats (Paerl and Otten 2013; Paerl et al. 2018). This document is focused on FHABs found in California's freshwater resources.

FHABs are a global environmental threat (Brooks et al. 2017; Glibert et al. 2005; O'Neil et al. 2012) and challenging to monitoring and mitigate (see inset box: Challenges of FHAB monitoring, page 4). The negative impacts of FHAB events can be caused in two main ways: 1) production of toxins that can harm ecosystems including wildlife, humans, dogs and domestic animals and 2) high biomass that accumulates in aquatic habitats and causes a cascade of problems (Figure 1.1). Both toxic and non-toxic blooms can cause negative environmental effects such as the clogging or impairment of gill function in aquatic organisms, benthic habitat alteration, impairment of navigation and/or recreation, light attenuation, or the drawdown of oxygen at the time of bloom senescence and decline. FHABs impact multiple beneficial uses[4] including recreation, aquatic life, and drinking water by reducing aesthetics, lowering dissolved oxygen concentration, causing taste and odor problems, and producing potent toxins (Backer et al. 2013; Carmichael and Boyer 2016; Chorus and Bartram 1999; Graham et al. 2010; Griffith and Gobler 2020; Heisler et al. 2008; Hilborn and Beasley 2015; Jüttner and Watson 2007).

Most documented FHAB impacts are from cyanobacterial HABs and their associated toxins. In California, toxic cyanobacterial blooms have been a recurring and escalating issue throughout the state that have garnered considerable concern and public attention, particularly in the Klamath River watershed, Clear Lake, Pinto Lake, Sacramento and San Joaquin River Delta, Lake Elsinore, East San Francisco Bay Area lakes, and reservoirs in the State Water Project. Public health advisories at recreational waterbodies have roughly doubled since 2016. Toxigenic cyanobacteria often dominate phytoplankton assemblages (Magrann et al. 2015) and toxins are now regularly detected in southern California lakes and reservoirs, depressional wetlands, and coastal lagoons (Howard et al. 2017). Toxigenic cyanobacteria genera have been shown to be prominent in the microbial communities of more than 1,200 wadable streams sites sampled throughout the state and 33% were positive for cyanotoxins (Fetscher et al. 2015). Multiple studies have documented that cyanobacterial blooms can also have impacts on aquatic life in downstream estuarine and marine systems, including in Monterey Bay (Miller et al. 2010; Kudela 2011; Gibble and Kudela 2014), San Francisco Bay (Peacock et al. 2018), and in southern California (Tatters et al. 2019). Cyanotoxins were ubiquitous and persistent in Monterey Bay National Marine Sanctuary coastal watersheds over a 3-year time-series survey (Gibble and Kudela 2014). The deaths of more than 30 endangered sea otters in Elkhorn Slough and Monterey Bay were linked to ingestion of a freshwater toxin, microcystin, that bioaccumulated in marine bivalves (Miller et al. 2010; Kudela 2011).

Other toxic algae may not threaten human health; however, they can threaten aquatic life in ways that impact fishing and recreation. Golden algae (*Prymnesium parvum)* are a common FHAB species that has caused massive fish kills in California lakes and reservoirs (D. Caron, Personal Communication, 2019). *P. parvum* can both photosynthesize and consume other organisms, making it very resilient; its microscopic prey is immobilized via toxic compounds called prymnesins that are toxic to fish but have not been linked to human health impacts (Manning and

[2] Freshwater refers to aquatic habitats with ocean derived salinities less than 0.5 practical salinity units (psu).
[3] Marine refers to aquatic habitats with ocean derived salinities greater than 35 psu.
[4] Beneficial uses, sometimes called "designated uses," describe uses specified in our water quality standards for each waterbody or waterbody segment; categories of uses include aquatic life, recreational, water resources, tribal and cultural, and fishable uses.

La Claire 2010; Svenssen et al. 2019). Blooms of *P. parvum* can cause mass mortalities of fish and other aquatic animals. This organism is considered invasive and has been expanding its range throughout the southwestern U.S. since the 1980s. Blooms caused by euglenid algae that can produce the toxin euglenophycin, which has ichthyotoxic and herbicidal properties, are also of concern. This toxin was initially linked to the euglenid species *Euglena sanguinea* but has since been linked to several additional species. To date, significant blooms of these taxa have not been reported in California but have been reported in several states in the southeastern United States (Kulczycka et al. 2018). The diatom *Didymosphenia geminate* (commonly called "rock snot") is also of concern as an invasive species that can form large benthic mats that negatively impact the populations of many freshwater invertebrate species. Accumulations of this species have been reported in the South Fork of the American River (M. Hoddle, Personal Communication, 2020).

Figure 1.1. High biomass of rafting macroalgae in Loma Alta Slough, Oceanside (photo from RWQCB Phosphorus TMDL), sampled high density bloom in Pinto Lake, Watsonville (photo from CA water boards), benthic algae and cyanobacterial mat in Eel River (photo by Keith Bouma-Gregson), and cyanobacterial bloom behind the Klamath Dam (photo source unknown).

Challenges of FHAB Monitoring

A multitude of factors make the detection and assessment of FHABs challenging, including:

Multiple Morphologies and Toxins. HABs in freshwater and estuarine environments are diverse and can be formed by many different species of cyanobacteria and eukaryotic algae. As a group, cyanobacteria encompass over 150 genera that span a diverse range of cell shapes, sizes, and structures. Eukaryotic algae are equally diverse with both micro- and macroalgae, requiring a high level of taxonomic expertise.

Temporal and Spatial Heterogeneity of Bloom Biomass. Predicting the timing of FHAB events is extremely challenging because, the timing of peak blooms exhibits large annual and interannual variability. Some waterbodies experience multiple bloom events within a year and the magnitude of the event can vary drastically. Community composition (which species are dominant) can also vary among locations, and temporally within a given ecosystem. These dynamics make intermittent sampling or extrapolation of observations across years ineffective.

Plasticity of Habitat. It is often challenging to estimate the spatial extent of a bloom, particularly in large waterbodies, that can thrive in multiple habitats within a waterbody. Some planktonic cyanobacteria have the unique ability to regulate their buoyancy, moving up and down in the water column throughout the day. Other species preferentially proliferate subsurface or on the benthos, making visual and remote identification of a bloom difficult or impossible. Surface blooms can be shifted by the wind, resulting in shifting accumulations of biomass and toxin concentrations in a single location throughout a given day.

Multiple Toxins and Variability in Toxin Concentrations. The overall biomass of toxigenic species alone can be a poor predictor of cyanotoxins in a waterbody. Many toxigenic genera can produce multiple toxins. Monitoring only a single cyanotoxin can underestimate health risks as multiple cyanotoxins could be present depending on which taxa are present. Cyanobacteria regulate their toxin production based on environmental conditions and therefore toxin concentrations can be dangerously high for variable periods of time within a waterbody, on timescales ranging from hours to days. Additionally, there is known species and strain variability in the amount of toxin produced by toxigenic organisms. High biomass of a toxigenic species does not always translate to high toxin concentrations. Under sampling can result in an underestimation or overestimation of these factors.

Impacts Can Occur Far Downstream from FHAB Bloom Origin. A bloom can occur upstream and the toxins can be transported downstream (as described above), resulting in a waterbody looking like it has low algal biomass but contains dangerous concentrations of biotoxins that were produced elsewhere. Similarly, mats can dislodge from the benthic environments in which they developed and be transported downstream, resulting in downstream impacts from upstream sources. Monitoring in higher order systems requires consideration of FHAB dynamics within the system as well as impacts from upstream.

HABs are not exclusive to microalgae, as high macroalgal biomass (e.g., the green algal taxa *Cladophora* spp. or *Spirogyra* spp.) can cause oxygen depletion following bloom termination and decomposition, benthic habitat alteration, clogging of water intakes for industrial or municipal uses, impairment of navigation, and/or recreation or light attenuation. Roughly 20-30% of southern California stream miles are impacted by macroalgal blooms (Mazor et al. 2018); 50% of Southern California Bight estuaries had macroalgal biomass exceeding thresholds that impact benthic macroinvertebrates (Sutula et al. 2014; Green et al. 2014) and seagrass (Bittick et al. 2018), and 30% had chronic blooms periods longer than 2 months (McLaughlin et al. 2014). Similar high biomass, chronic macroalgal blooms have been reported in the estuaries of other regions of California including Elkhorn Slough (Hughes et al. 2011), Humboldt and Bodega Bays (Sutula et al. 2014), and Morro Bay and Tomales Bay (Bittick et al. 2018).

FHABs are already having important impacts on California's economy and communities, the value and extent of which has not been systematically quantified and represent a critical knowledge gap. Taken across these beneficial uses, the societal impacts of FHABs are likely to be severe, including: impacts to public health (Backer and Moore 2010), commercial fisheries and aquaculture, recreation and tourism, home values and commercial real estate

(Bingham et al. 2016), and disruption to social and cultural practices, with economic losses and social impacts to both individual and community (Dodds et al. 2009; Dyson and Huppert 2010; Sanseverino et al. 2016; Willis et al. 2018). FHAB impacts compound other adverse conditions common in economically disadvantaged communities such as limited access to recreational opportunities, clean water, health care, and affordable and safe housing. These impacts will accelerate with climate change.

What is more, the lack of routine monitoring on both FHAB status and trends and the socioeconomic and social impact creates a vicious circle, in which the understanding of the extent and magnitude of impact is limited and therefore funding allocated by the legislature for FHAB monitoring and management actions falls short of what is actually required. At minimum, several special studies are needed to quantify the socio-economic and cultural impacts of FHABs in California.

1.3 What is California Doing about FHABs: Context for Monitoring

California responded to the emerging FHAB threat by developing an Assessment and Support Strategy (SWAMP 2016); the goal was to articulate a coordinated and widely supported long-term program to assess, communicate, and manage cyanobacterial and other nuisance FHABs. Monitoring[5] is an important component of this strategy (Figure 1.2). Most freshwater systems in California are not regularly monitored for FHABs and associated toxins, unlike in California's marine waters, which have several routine monitoring efforts in place (see inset box: Status of Marine Monitoring).

The Assessment and Support Strategy had two components (Figure 1.2, see inset box below for definitions and intent of each component): **1) FHAB event response**, and **2) ambient monitoring**. FHAB predictive models can be combined with ambient and incident response data to provide broad **decision support** to protect public health and manage water quality.

Types of FHAB Monitoring and Assessment

Event Response. Responding to FHAB events within individual waterbodies is of key importance for the protection of human and animal health, particularly in the context of recreational uses. Once a toxic bloom is confirmed, appropriate public health advisories can be issued and communicated to the public to help keep people and animals safe. This approach focused on providing an immediate response to waterbodies experiencing a suspicious accumulation of cyanobacterial surface scum reports of illness and/or mortality events. Responding to potential events is most effectively addressed through field assessments, but early warning of events can be determined from satellite observations which can prompt the deployment of a field crew. Ultimately, event response approaches can address immediate human and animal health threats but does not result in a dataset that is effective at determining status, trends, or drivers of FHABs.

Ambient Monitoring. The "ambient" in ambient monitoring refers to the consistent data collection regardless of current bloom conditions. Ambient monitoring provides valuable data on physical, chemical, and biological indicators to better understand status, trends, and environmental drivers of FHAB events and can be designed to address these information needs on multiple spatial scales spanning from individual waterbodies or watershed, to larger spatial scales such as regional and statewide assessments. Ambient monitoring can be accomplished using multiple approaches, including **field monitoring** and **satellite remote sensing**.

[5] Monitoring is defined as the periodic or continuous collection of data (measured parameters) using consistent methods.

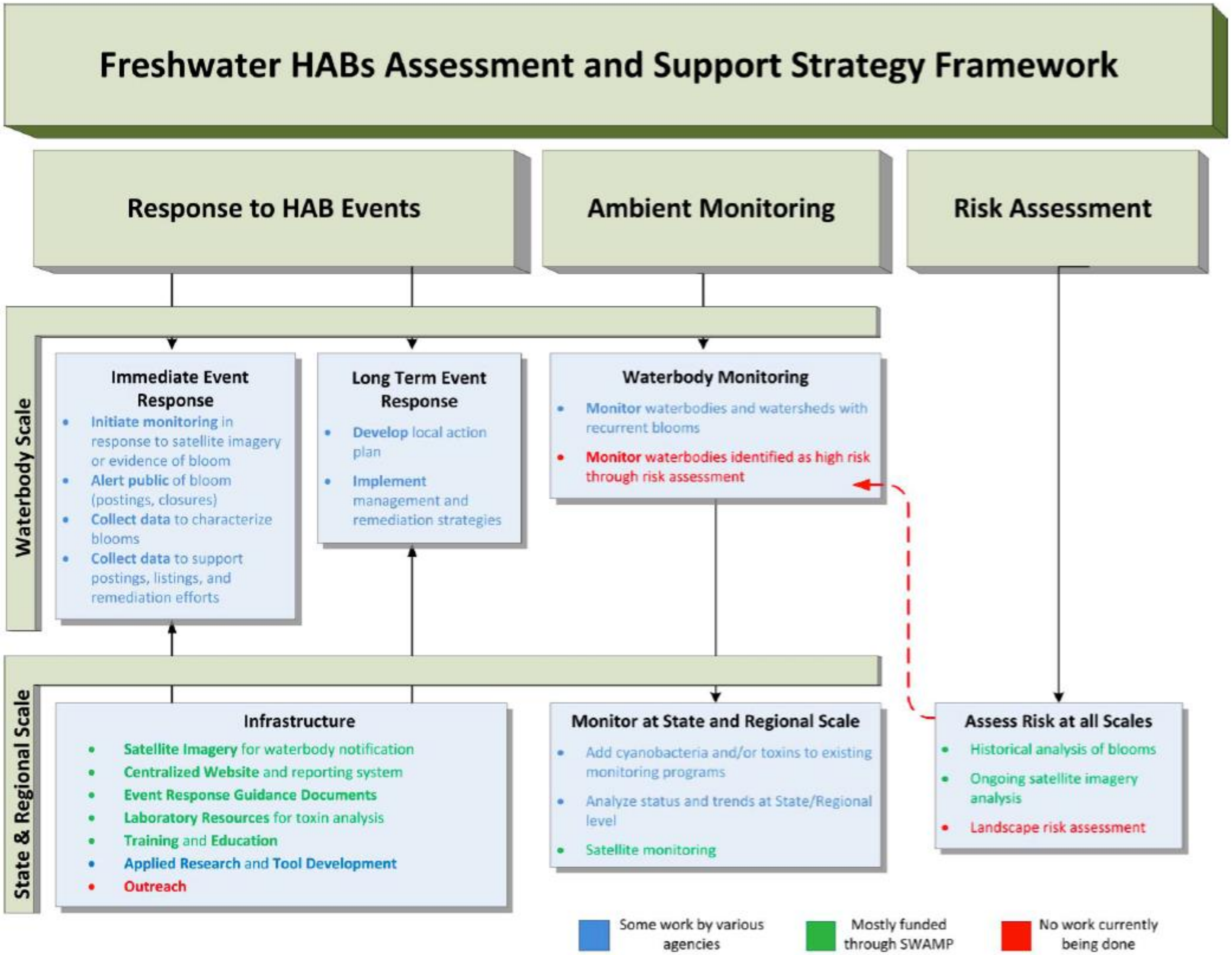

Figure 1.2. From California Freshwater HAB Assessment and Support Strategy (SWAMP 2016), which was the starting point for development of the FHAB monitoring strategy.

Since the publication of the Assessment and Support Strategy, Water Board staff has made significant progress on the development of infrastructure to support and implement the incident response and remote sensing components. This includes routine acquisition of satellite imagery products from NOAA to identify and track cyanobacteria blooms and the incident response program that includes a centralized website and reporting system to provide data management, visualization, and reporting capabilities. Other advances include the development of guidance documents on incident response and management strategies, limited laboratory resources to support local incident response, and outreach aimed at providing educational materials to policymakers, water managers, health care professionals, veterinarians, and the public. Use of these resources is in evidence with HAB monitoring that is currently being conducted by partners such as the tribes in the Klamath River and Clear Lake and other local and state agencies, such as East Bay Regional Park District and Department of Water Resources.

Status of Marine HAB Monitoring in California

Monitoring for marine algal toxins in shellfish has occurred since the 1920's. Following the discovery of domoic acid in Californian waters in 1991, California Department of Public Health initiated the first statewide algal toxin monitoring program. This program has provided valuable data on the phytoplankton present in coastal waters along with marine shellfish tissue toxins. Additional monitoring began in 2008 with the formation of California Harmful Algal Bloom Monitoring and Alert Program (CalHABMAP). This program coordinates weekly HAB observations at seven pier locations and shares observations with relevant stakeholder groups on a weekly basis. This program has been continuously funded by SCCOOS and CeNCOOS for over ten years. These observations have allowed for the development of product like the California-Harmful Algae Risk Mapping model (Anderson et al. 2016) and the California HAB bulletin.

1.4 Linkage of FHABs to Water Board Mission, Policies and Programs

The mission of the Water Boards is to *"To preserve, enhance, and restore the quality of California's water resources and drinking water for the protection of the environment, public health, and all beneficial uses, and to ensure proper water resource allocation and efficient use, for the benefit of present and future generations."* Monitoring to assess the status, trends and drivers of FHABs in order to protect water quality and beneficial uses is consistent with this mission. Furthermore, FHABs as an environmental problem have a strong linkage to various Water Boards policies and programs. Discussions with State and Regional Water Boards staff are needed to specifically link FHAB monitoring to these Water Boards programs. For example, FHABs are fundamentally a eutrophication problem

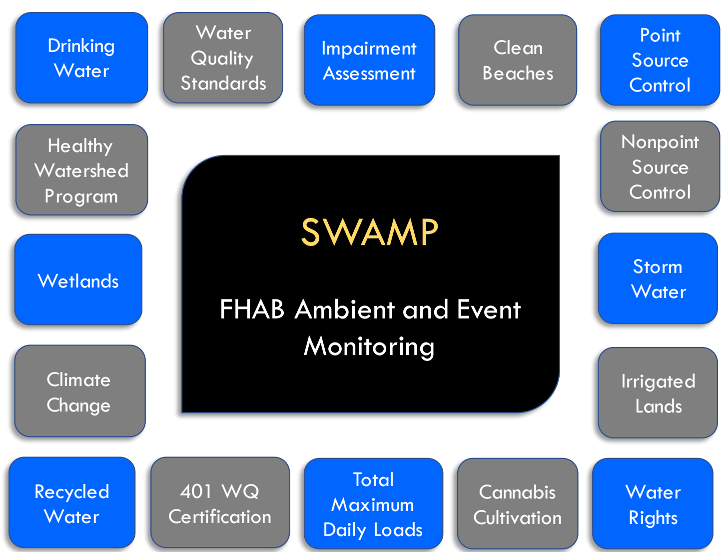

Figure 1.3. Conceptual view of relationship of FHAB monitoring to Water Boards policies and programs.

that has a strong linkage to biostimulatory[6] objectives through a shared set of indicators. Ultimately, biostimulatory numeric targets or objectives can serve as evaluation criteria for FHAB monitoring program data. Biostimulatory objectives implementation strategies, including TMDL implementation plans, non-point and point source control, storm water, forestry, irrigated lands, and cannabis cultivation, can use FHAB monitoring approaches, standardized protocols, and data management systems to evaluate the programs' effects on status and trends of FHABs. Municipal storm water programs play a major role in policy and plan implementation. This is where TMDL requirements live and are carried out through watershed scale best management practices and monitoring. 401 water quality certifications under the Federal Energy Regulatory Commission include adaptive management plans to address water quality issues, including FHABs. Water Rights programs could consider how hydromodification is impacting FHABs in establishing flow criteria. Stakeholders involved in these programs are a potential source of FHAB monitoring program partners; for example, the Beach Safety Monitoring Program-AB 411 (BSMP (AB 411)) is a unique leveraging opportunity to extend beach monitoring to FHABs.

1.5 Goal of Monitoring Strategy and Core FHAB Program Components

The goal of this FHAB Monitoring Framework and Strategy is to articulate the vision and programmatic elements to inform management decisions for protecting public health and the environment through an FHAB ambient monitoring and assessment program. It provides a roadmap for the tools and guidance needed for monitoring FHABs in freshwater and estuarine systems. It also provides a strategic set of priority actions to develop and implement this program near term. The bulk of the report focuses on the ***core monitoring*** that can be used by Water Boards and partners to develop and design a statewide comprehensive FHAB monitoring program, including assessment of 1) status and trends of FHABs that characterize risk to humans and ecosystem health and 2) to the extent practicable, the environmental drivers influencing FHAB magnitude, frequency, and duration. As core monitoring is developed, *special studies* were identified and prioritized, which included scientific studies intended to develop or inform specific components of the implementation program (e.g., standardized operating procedures) and extend or provide more insight into core monitoring results. For purposes of this document, "special studies" are designed to answer or inform specific questions that contribute to the design of the program or improve the scientific basis for management-oriented monitoring. The intended audience is Water Boards managers to help inform funding decisions in support of program implementation.

The first phase of this strategy focused on developing the monitoring elements and identifying special studies that create a strong linkage and leverage between the three high priorities called out in the FHAB Assessment and Support Strategy: 1) ambient monitoring and assessment, 2) incident response, and 3) decision support, including predictive FHAB models. Information on environmental drivers and efficacy of Water Boards programs and policies is important to the extent practicable in a statewide FHAB monitoring program. Mitigation of FHABs is not a focus but can be incorporated into the strategy in a subsequent phase, primarily through consensus on a core suite of standardized indicators and protocols.

[6] Biostimulatory refers to the substances and conditions that cause an accelerated accumulation of organic matter (eutrophication), with a cascade of ecosystem effects, including HABs.

The Water Boards staff did not specify an amount of funding for this FHAB monitoring program, such that it would constrain its scope. Therefore, the strategy identified high priority components based on: 1) scientific quality and value of information provided to managers and 2) extent of existing effort or leveraging available to accomplish it. Water Boards staff will implement recommendations in the strategy in different stages over time as financial and personnel resources are identified.

1.6 Approach to Develop FHAB Monitoring Strategy

The approach to developing the FHAB Monitoring Strategy was formulated with monitoring program design principles (see inset box: Monitoring Program Design Principles and Key Terms).

Monitoring Program Design Principles and Key Terms

- Monitoring should be question driven.
- Monitoring should generate high quality data that is used for decision-making and planning efforts. Therefore, management questions and information needs are stated and explicitly considered.
- The level of monitoring effort should reflect the value of the resource and/or the potential for impact, with more monitoring allocated to situations where the resource value and/or the potential impact is higher (in terms of both the probability of an impact's occurrence and its extent and magnitude) and less monitoring to situations where such value or potential is lower or where monitoring is not likely to provide useful information.
- Results of the monitoring must be timely to inform decision-making, reflecting the principle that different decisions have different time scales (e.g., immediate recreational advisories and listing a waterbody as impaired) and the results must be clearly communicated to key audiences.
- Monitoring should be adaptive in terms of its ability to both trigger follow-on studies as needed and make necessary midcourse corrections based on monitoring findings to keep monitoring approaches up to date.

In designing the FHAB monitoring strategy, participants benefited greatly from considering the monitoring design components and definitions (Olsen et al. in prep).

The ***spatial design*** identifies the geographic region of interest and the waterbody type(s) and components to be monitored. The ***temporal design*** includes the collection of time periods that are specified by the monitoring program objectives. Together, these spatial and temporal design decisions specify the ***target population*** to be sampled.

Indicators and ***metrics*** describe what information the monitoring program will collect to address management questions (described in detail in Section 2.5). An ***indicator*** is the type of measurements, while ***metric*** is the precise measurement and value resulting from multiple locations and temporal measurements. ***Estimates*** provide the summary information that the program will report to satisfy the objectives, expressed through ***key graphics***. These can, and should, be determined prior to considering what the specific monitoring design will be. The choice of how to collect the measurements depends on several factors including cost, number of spatial-temporal units to be measured, length of time available for field collection, and expertise of field crews available.

The overarching approach to developing the monitoring strategy consisted of formation and use of a Technical Advisory Committee (TAC). The TAC, consisting of national experts in FHAB ecology and monitoring program design, key technical staff from State and Regional Water Boards and other state agencies and tribes, and community scientist groups, provided broad perspectives in what monitoring constituted an effective monitoring strategy. The TAC was used to work through each monitoring element, discuss optional approaches and their inherent advantages and disadvantages, and provide consensus recommendations, where possible.

Water Boards staff proposed a set of key management questions (described in detail in Section 2.1) that reflect agency priority information needs and are consistent with information needs of other potential partners from the federal to local level. These management questions were initially vetted by the TAC, then were broken into subgroups to discuss explicit recommendations for FHAB ambient monitoring approaches that can answer those questions.

Three major monitoring approaches were considered in developing the FHAB ambient monitoring strategy. First, Water Boards **field surveys** developed and managed by the Surface Water Ambient Monitoring Program (SWAMP) have been the backbone of California water quality monitoring. Second, a **partner program component** that provides infrastructure to encourage FHAB monitoring by other federal, state and local agencies, tribes, and community science groups was a priority. Third, **remote sensing** has emerged an important collaboration with NOAA through the Cyanobacteria Assessment Network (CyAN) (Schaeffer et al. 2015).

Each of these three ambient monitoring components were discussed by TAC subcommittees. Within each, a general approach was used to structure discussions and recommendations that formed the basis for the programmatic components described in this report, developed through the following generic steps.

- Vet key management questions, information needs, and plausible management decisions or actions.
- Develop conceptual models of pathways of FHAB impacts on beneficial uses and key indicators that represent measures of those impacts as well as potential drivers or environmental context for FHABs.
- Describe key indicators, target population, spatial and temporal design elements/options, and monitoring approaches that map onto each of the identified management information needs.
- Identify opportunities to leverage existing surveys or programs. Because monitoring of FHABs is an inherently expensive proposition, leveraging provides an opportunity to conserve resources by 1) aligning or adding methods to optimize information collected, or 2) adding resources to expand sampling effort to increase sampling frequency or spatial coverage. Leveraging at times can make monitoring implementation more complicated for all parties involved, due to the require additional coordination among entities. For that reason, in this report, we attempt to identify opportunities for leveraging, but leave the detailed consideration and weighing of cost/benefits to a subsequent stage, understanding that these existing programs may have significant constraints to such a collaboration.
- Identify the types of infrastructure and support needed to implement, particularly in the case of the partner monitoring program.
- Identify and briefly describe the special studies and technical needs required to address key information/infrastructure gaps for implementing the monitoring strategy.

The TAC subcommittees met in person or over the phone to develop content and work through key questions and issues. Based on the fleshed out set of options for each program committee, the State Water Board staff identified priority components to formulate a strategy for ambient monitoring, with further refinements expected pending availability of dedicated resources. The opportunities to invigorate and synergize with FHAB incident response were documented. Though the TAC has not endorsed all content or recommendations made in the report, we have highlighted strong consensus or endorsement of concepts in bold font or inset boxes.

Incident response was discussed in terms of how it could be synergized with ambient monitoring approaches. **Data management, visualization,** and **decision support systems** that are a core part of monitoring infrastructure were identified to support and optimize the utility of FHAB data to support management decisions.

Together, these options can synergistically address the multiple management questions and objectives identified at the onset of strategy development (see Section 2.1). However, the resources and staff required to implement all the recommendations promoted through TAC and subsequent discussions have not been identified. A ***strategy*** is needed to incrementally build and implement an FHAB monitoring program. Therefore, Water Boards staff identified priority building blocks in a manner that is flexible to scale with future available resources and has incremental timelines for development. Water Boards staff considered TAC recommendations for prioritized elements and program components for each of the elements and actions examined in the previous chapters, then formulated recommended actions that represent the strategic implementation of a subset of these approaches, recommendations, and options discussed. Components were considered for implementation over three timescales of "immediate" (< 2 years), "near-term" (2-5 years), and "long-term" (> 5 years) based on the information or outcomes related to a specific element, as well as the linkages of specific actions to other core recommendations and approaches. Many recommendations build off each other (i.e., special studies needed before a component could be implemented). Elements were also considered roughly according to the level of funding that would be required to implement the action or element. The cost associated with each element was determined as "low" (< $200,000), "medium" ($200,000 – $999,999), and high (> $1,000,000). Other programmatic elements were considered within this report, but ultimately were not determined to be a strategic priority at this time and are assigned as "lower priority" in the following sections.

With the completion of the strategy, the TAC and stakeholder advisory groups (SAGs) represented an opportunity to vet the emerging monitoring strategy throughout its development process and identify significant points of resource leveraging and coordination. One key audience for the strategy is the California Cyanobacteria Harmful Algal Bloom (CCHAB) Network, which provides a forum for bringing together agencies, tribes, and organizations to coordinate management strategies to FHAB control and prevention. The CCHAB Network has representatives from federal, state, and local agencies, tribes, and the regulated, academic, and nonprofit communities. The CCHAB Network is an established Workgroup of the California Water Quality Monitoring Council (WQMC) that was given roughly quarterly updates on the project and invited to comment on the draft strategy.

1.7 How to Use This Report?

The **FHAB Monitoring Strategy** is organized into the executive synthesis, one introductory and six technical chapters, followed by a chapter summarizing the strategic (priority) components for implementation identified from discussions with the TAC and deliberations of Water Boards staff.

The **Executive Synthesis** is intended to serve as a stand-alone document summarizing the approach to develop recommendations, findings, and strategic priorities for implementation for an FHAB monitoring program. This is intended to be a high-level overview for executive managers and non-technical audiences. This executive synthesis can be access at this link: https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1141_FHABStrategy_Synthesis.pdf.

In this main report you will find:

An **Executive Summary** which gives a quick overview of the purpose of the document and its key findings.

Chapter 1 gives an **Introduction**, including purpose of the report, approach to developing the monitoring strategy, and report organization.

Chapter 2 provides **important background information**, including FHAB management questions and information needs, priority waterbody types and their definitions, targeted beneficial uses, conceptual pathways of FHAB impacts, and their causal drivers. The conceptual models provide the rational for the core indicators used throughout Chapter 3-7.

Chapter 3 provides an **overview of existing and/or proposed ambient monitoring components (remote sensing, partner program, field surveys)** and, if relevant, specific recommendations for their refinements.

Chapter 4 and 5 describe options for how each of those ambient monitoring program components can be specifically used to answer the FHAB management questions and information needs identified for **status and trends (Chapter 4)** and **environmental drivers (Chapter 5)**.

Chapter 6 describes and reflects on **existing FHAB incident response** and specific refinements to improve its utility, particularly through synergies with ambient monitoring.

Chapter 7 describes the **decision support tools** that could be created to maximize the utility of the FHAB ambient and incident response monitoring data to protect public health and manage water quality. It includes discussion of the use of the monitoring data to develop **FHAB predictive models**.

Chapter 8 provides a set of Water Boards staff **recommendations** that represent the "Monitoring Strategy" and highlights monitoring approaches and components that should be specifically prioritized for implementation.

Appendices provide supporting documentation, including **definitions of indicators** and **descriptions of special studies**.

2. OVERVIEW OF KEY MANAGEMENT QUESTIONS AND CONCEPTUAL MODELS OF FHAB IMPACTS ON BENEFICIAL USES

2.1 FHAB Management Questions

The California legislature, tribal governments, land and water resource managers, and the public have a common set of information needs about how FHABs are impacting the beneficial uses of California waterbodies: Are our waterbodies drinkable, fishable, and swimmable? Are our ecosystems healthy? How are tribal and cultural uses impacted? What's causing FHABs? Are our strategies to manage them effective? The State Water Board identified six overarching management questions to address these needs, adapted from the SWAMP strategy (SWAMP 2010), that serve as the foundation of state-led FHAB monitoring at a statewide-, regional-, or watershed-scale (Table 2.1) and that speak to swimmable, fishable, aquatic life and tribal/cultural uses. Four of these questions related to status, trends, environmental drivers, and FHAB incident response are addressed in the first phase of Monitoring Strategy development.

These questions are similar to those that drive the types of monitoring conducted by partner programs, whether by water resource and drinking water managers, landowners, or public health monitoring, etc. (Table 2.1). The similarity of these management questions at the statewide or regional scales versus waterbody-specific scales is intentional; ultimately, the FHAB monitoring program will be strengthened by the degree to which: 1) it leverages and uses high quality FHAB data collected by partner monitoring programs that contribute data to answer key State Water Boards management questions and needs; and 2) FHAB partner monitoring programs are supported by and find value in state-led monitoring, because it provides a shared set of monitoring protocols as well as important context for waterbody-specific FHAB status, trends, and drivers.

2.2 FHAB Toxins of Interest

While cyanobacteria and algae produce an array of bioactive compounds, ranging from anti-microbial to UV protectant properties, a subset of these compounds are highly toxic to humans and wildlife. A majority of documented FHAB impacts in California are attributed to these cyanobacterial HABs and their associated toxins (cyanotoxins; see Appendix 1 Table A1). Cyanotoxins include several classes of neurotoxins, hepatotoxins, dermatoxins, and cytotoxins which represent a significant threat to human and ecosystem health. The Water Boards has chosen to initially focus on three of seven major classes of cyanotoxins, shown in bold: 1) **microcystins**, 2) **anatoxins**, 3) **cylindrospermopsin**, 4) nodularin, 5) saxitoxins, 6) lyngbyatoxin (and other dermatoxins), and 7) beta-N-methylamino-L-alanine (BMAA). Recreational guidance thresholds in California have been developed for microcystins, anatoxin-a, and cylindrospermopsin, which is why these toxins were chosen as an initial focus. Microcystins are a group of hepatotoxic cyclic peptides with more than 200 distinct structural congeners with varying toxicity potencies (Spoof and Catherine 2016). Nodularin, although not an initial focus of the framework, shares chemical similarities to microcystins and are measured in tandem by some of the most common quantification techniques. Anatoxin-a is a neurotoxic alkaloid inhibits the function of cellular ion channels in mammals (Van Apeldoorn et al. 2007; Botana and Alfonso 2015). Cylindrospermopsin is an alkaloid hepatotoxin but has also been shown to have other modes of toxicity including dermatoxic, cytotoxic, and genotoxic activities (de la Cruz et al. 2013). The other toxins noted (non-bolded) are of interest for the future (expanded) program.

Table 2.1. A summary of six overarching management questions that serve as the foundation of FHAB monitoring at varying scales. The first four are addressed in this first phase of the Monitoring Framework. Management questions and associated example decisions are included at statewide, regional, or watershed scale (in blue) and at the waterbody(ies) scale (in green). The monitoring design for statewide, regional, or watershed scale assessment may differ from that of an individual waterbody, but through coordination and appropriate monitoring design, these programs can often be nested so information from the larger scale assessment can inform the individual assessment and vice versa. FHAB prediction, mitigation, and prevention (in gray) will be addressed in a subsequent phase.

<table>
<tr><th rowspan="2">Category</th><th colspan="2">Statewide, Regional, or Watershed Scale (state-led)</th><th colspan="2">Individual Waterbody (Partner Monitoring)</th></tr>
<tr><th>Management Questions</th><th>Examples of Decisions That Are Supported by Monitoring</th><th>Management Questions</th><th>Examples of Decisions That Are Supported by Monitoring</th></tr>
<tr><td>Status</td><td>What is the overall magnitude[7] and extent of FHABs within the state, its regions, or a watershed scale?</td><td rowspan="2">Prioritize watersheds or waterbodies
305(b) report
Briefings for Legislature and State Water Board
Status and trends report to public on MyWaterQuality portal</td><td>Are FHABs degrading water quality in the waterbody and what is the timing of when FHABs occur</td><td rowspan="2">303(d) listing
TMDL compliance
Catchment conservation/ protection
Recreational advisory signage posting</td></tr>
<tr><td>Trends</td><td>How are magnitude, extent, and frequency changing over time?</td><td>Are FHABs in the waterbody getting better or worse over time?</td></tr>
<tr><td>Environmental Driver (Natural and Human)</td><td>What are the major drivers of FHABs across waterbodies or within a watershed?</td><td>Biostimulatory objectives and implementation policy
Environmental flow policy
State/regional NPS control strategies
Irrigated lands program/Ag waiver requirements
NPDES permit requirements</td><td>What are the drivers of FHABs in the waterbody?</td><td>TMDL development and implementation through
MS4, NPDES, and industrial permits, Irrigated Lands Program/Ag Waiver Requirements, etc.</td></tr>
<tr><td>Incident Response</td><td>What percentage of the waterbodies in my region or watersheds have recently had FHAB events?</td><td>Prioritization of funding for monitoring</td><td>Should human use or domestic animal use be restricted in the waterbody? When is it safe to resume active use?</td><td>Incident response/public health posting and de-posting
Public decisions to use/avoid use (fishing, recreation)
Drinking water advisories</td></tr>
<tr><td>FHAB Prediction</td><td>Which waterbodies are at risk of experience FHABs?</td><td>Prioritization of funding for monitoring</td><td>What are the time periods that my waterbody most likely has an FHAB problem?</td><td>Timing to go out to sample a waterbody for a bloom
Prioritization of management actions, including monitoring requirements</td></tr>
<tr><td>Mitigation and Prevention</td><td>How effective are water quality maintenance and improvement projects or programs for preventing, maintaining or restoring beneficial uses impacted from FHABs?</td><td>Briefings for Legislature and State Water Board
Status and trends report to public on MyWaterQuality portal</td><td>How effective are management actions in mitigating an FHAB problem?</td><td>Adaptive management of watershed or waterbody-specific restoration actions (BMPs, floodplain restoration, water-column mixing)</td></tr>
</table>

[7] *Magnitude* refers to the intensity of the FHAB; *extent* refers to the spatial coverage.

We also note that other cyanobacterial metabolites and degradation products can also be problematic, because they can cause dermal issues or taste and odor problems. Many species of cyanobacteria can produce odor and taste compounds including geosmin, 2-methylisoborneol (MIB) and sulfur compounds (Graham et al. 2010; Jüttner and Watson 2007), which are not linked to negative health impacts at environmentally relevant concentrations (Burgos et al. 2014) but can reduce the quality of drinking water and aesthetic experience during recreation and also impact the quality of meat in fishery species. Rotting algae can also cause unpleasant odors from the formation of sulfur compounds which can become inhalation hazards at high concentrations.

2.3 Targeted Core and Tribal Beneficial Uses

Why Are Beneficial Uses Important?

Beneficial uses, sometimes called "designated uses," describe uses specified in our water quality standards for each waterbody or waterbody segment; categories of uses include aquatic life, recreational, water resources, tribal and cultural, and fishable uses. These beneficial uses help set goals for waterbodies and provide the framework by which water quality objectives protect waterbodies from pollutants and contaminants.

The FHAB monitoring strategy and, ultimately, the implementation guidance, specifies what monitoring approaches are useful to answer the management questions for each of the core beneficial uses that are supported in the diversity of waterbody types in California (Table 2.2). The 2010 SWAMP strategy uses the term "core beneficial uses" as an organizational strategy to consolidate the many beneficial uses identified in California (see inset box: Why Are Beneficial Uses Important). Managing these core beneficial uses simplifies the management context and should also account for most other beneficial uses as well. The FHAB monitoring strategy also considered Tribal Tradition and Culture beneficial uses to address the various ways tribal communities use water resources that may not be covered by the four core beneficial uses.

Table 2.2. Important risk pathways associated with impairment by FHABs and associated eutrophication. Aquatic uses including: EST, MAR, COLD, WARM, MIGR, RARE, and SPWN are grouped with terrestrial wildlife (birds, amphibians, mammals, etc.) including WILD, MIGR, and RARE. Poor water quality is linked to both human and aquatic/wildlife uses.

Use Category	Increased Biomass/ Organic Matter	Altered Trophic Structure	Lower Yield Fisheries and/or Contaminated with Toxin	Poor Taste and Odor	Poor Aesthetics	Poor Sediment/ Water Quality	Toxins and harmful metabolites
Aquatic/Terrestrial (Wild) Life	X	X				X	X
Swimmable	X			X	X	X	X
Fishable	X	X	X	X	X	X	X
Drinkable/Raw Water	X			X		X	X
Tribal and Cultural Uses	X	X	X	X	X	X	X

Note: This table attempts to highlight the *major* stressor-response factors associated with a specific beneficial use. Additional stressor-response relationships may also affect use support but are judged to be less likely as a primary cause of impairment of that use.

Freshwater lakes and reservoirs

Irongate Reservoir, Source: Jeff Barnard, Associated Press

Silverwood Lake, Source: James Quigg, Associated Press

Rivers and Streams

South Fork Eel River, Source: Unknown

Mokelumne River, Source: MediaNews Group

Coastal Confluences

Ormand Beach, Source: Sean Anderson

Elkhorn Slough Estuary, Source: Brent Hughes

Figure 2.1. Examples of FHAB blooms in different waterbody types.

California surface waters can be divided into three major aquatic habitat types that were identified as priorities for ambient monitoring (Figure 2.1): 1) freshwater lakes and reservoirs, rivers and streams, and 3) coastal confluences[8]. Monitoring recommendations for many larger waterbodies including the San Francisco Bay/Delta are considered a special case that calls for watershed specific FHAB monitoring program development, which is beyond the scope of this effort. However, it is possible that the monitoring questions, indicators, and approaches to sampling are applicable and transferable. The monitoring strategy is intended to cover all inland waterbody types, but implementation guidance will be prioritized in the near-term for streams, rivers, lakes, and reservoirs.

2.4 Conceptual Model of Pathways of Impacts and Linkage to FHAB Indicators

FHABs can impair waterbodies in several ways that can ultimately result in failure to adequately support human and aquatic life beneficial uses. Conceptual models of these pathways are useful in showing how FHABs, their drivers, and beneficial uses are linked, and they point to informative and representative indicators[9] and metrics[10] that can be used to address management information needs (USEPA 1998; Suter 1999). Four conceptual models representing aquatic life, swimmable, fishable, and drinkable were developed to characterize the pathways by which FHABs impact each beneficial use (Figure 2.2, Table 2.2). A fifth conceptual model of impacts to tribal uses was developed by the Karuk and Clear Lake tribal representatives (Figure 2.3). Finally, a conceptual model of environmental drivers of FHABs was adapted from Paerl (2018; Figure 2.4). Collectively, these conceptual models were vetted by the TAC and used as the basis to identify indicators and metrics of FHAB "response" associated with specific pathways of effect (Table 2.3) and environmental drivers (Table 2.4). Detailed explanations of the conceptual models are provided in Appendix 2. The indicators are defined in Appendix 3.

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[8] **Coastal Confluences** are the estuarine and marine habitats that are directly influenced by riverine freshwater inputs to the coast. They include the subtidal and intertidal habitats of enclosed bays, coastal lakes and lagoons, river mouth estuaries, and marine open embayments. The landward limit is 0.5 psu and where water level is not influenced by the tides, though the seaward limit depends on pathway of impact and cannot be strictly geographically defined. For example, marine life in open embayments (e.g., sea otters) may be impacted by cyanotoxins through bioaccumulation of toxins, while recreational uses are at greater risk of impact inshore and proximal to the freshwater source.

[9] An *indicator* is a characteristic of an ecosystem that is related to, or derived from, a measure of biotic or abiotic variable, that can provide quantitative information on ecological condition, structure and/or function or a physical, chemical or biological stressor. Relative to the term "metric," an indicator may be used to define a category of specific measures (e.g., algal biomass)

[10] A *metric* refers to very specific type of measurement (chlorophyll-a fluorescence, ash-free dry mass, etc.) for which a protocol could be cited for its use in a monitoring program.

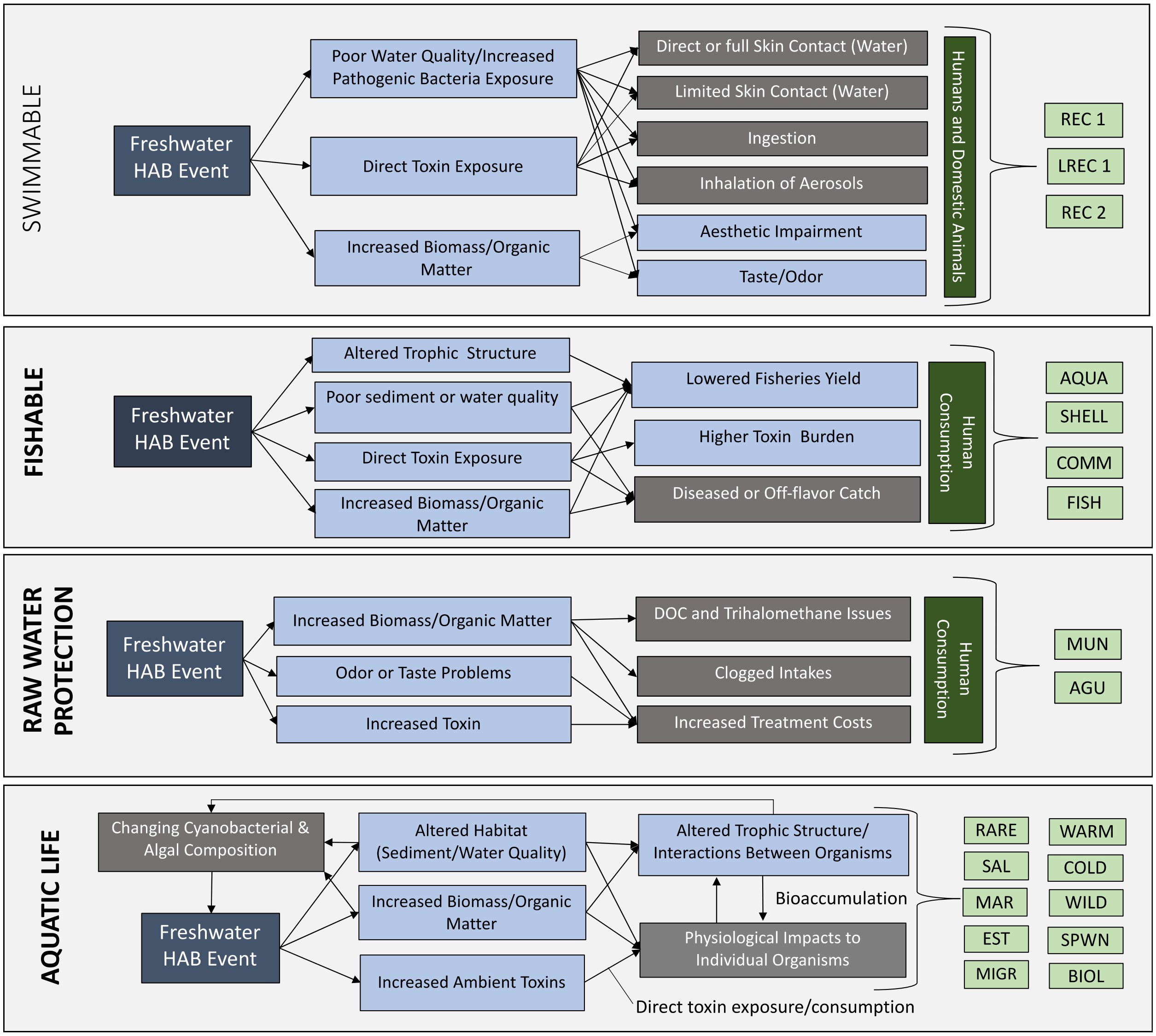


Figure 2.2. Conceptual models depicting impact of freshwater HAB events on core beneficial uses, via pathways of impairment. Light blue boxes represent pathways of impairment of beneficial uses (Table 2.2) for which groups of indicators and metrics can be use to measure the specific responses given in Table 2.3. Definitions for specific beneficial uses shown in the light green boxes can be found on the Water Boards website: www.waterboards.ca.gov/about_us/performance_report_1314/plan_assess/docs/bu_definitions_012114.pdf.

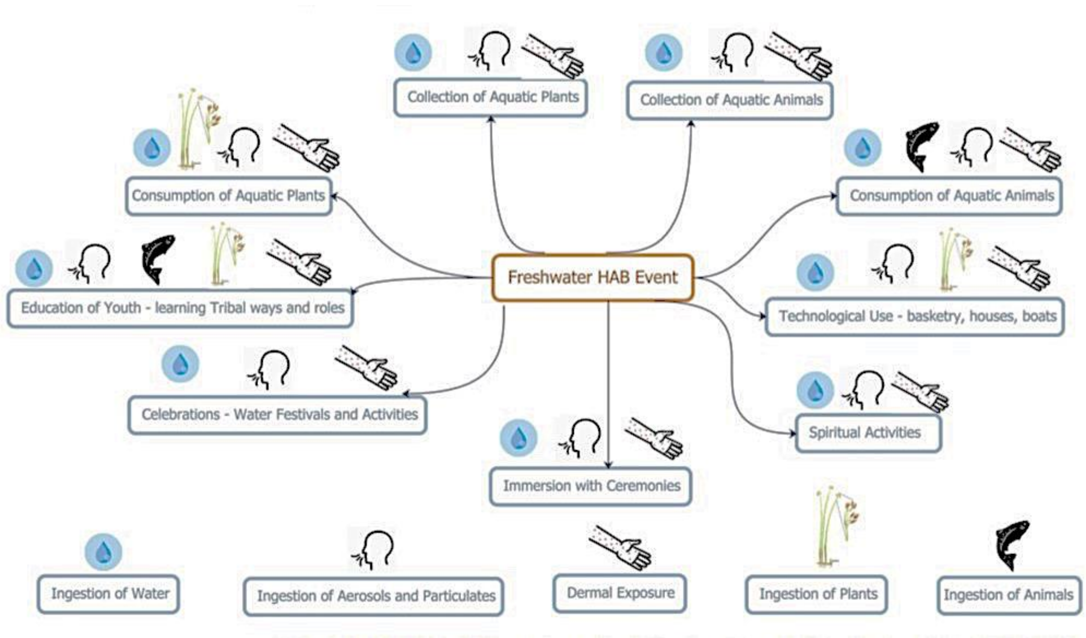


Figure 2.3. Conceptual model of pathways by which tribal cultural uses are impacted by FHABs. Uses can be repetitive, gender assigned, and long-term. Exposures can occur second hand through the use and trade of plants and animals that have been in contact with FHABs (Big Valley Band of Pomo Indians and the Karuk Tribe with assistance from Meyo Mamulo and Dr. Jeanine Pfeiffer).

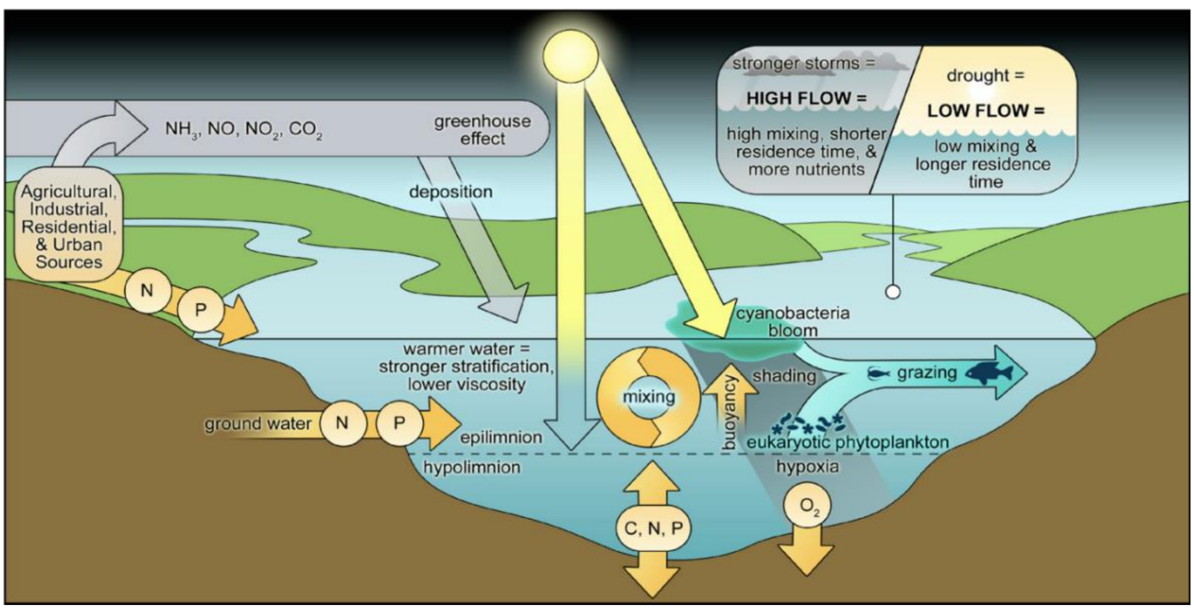


Figure 2.4. From Paerl (2018). Conceptual model of factors affecting cyanobacteria blooms including warmer water, drought and decreased flow, decreased mixing, increased residence time, and increased N and P inputs from agricultural, industrial, and urban sources.

Table 2.3. List of FHAB response indicator groups, metrics, risk pathways; the reference number links to a brief description of the indicator groups and metrics to given in Appendix 3. OM = organic matter, OC = organic carbon.

Indicator Group	Metric	Increased Biomass/ OM	Altered Trophic Structure	Lower Fisheries Yield and/or Toxin Burden	Poor Taste / Odor	Poor Aesthetics	Poor Sediment/ Water Quality	Direct Toxin Exposure	Metric Ref. No. (R#)
Water Clarity and/or Quality	Remotely sensed water clarity	X	X	X		X	X		R1
	Secchi depth or light penetration	X	X	X		X	X		R2
	Turbidity or total suspended solids	X	X	X		X	X		R3
	Dissolved oxygen		X	X			X		R4
	pH		X	X			X		R5
	DOC		X				X		R6
Sediment Quality	Sediment TN, TP and OC	X	X			X	X		R7
Photosynthetic (Algal and Cyanobacterial) Benthic or Planktonic abundance	Remotely Sensed Chlorophyll a	X				X	X		R8
	Water column/benthic particulate OC, nitrogen, phosphorus and nutrient ratios	X	X	X			X		R9
	Planktonic, benthic, or drift algal Chl-a (discrete samples)	X	X			X	X		R10
	In Situ Chl-a Fluorescence	X	X			X	X		R11
	Macrophyte or macroalgal % cover	X	X			X			R12
Cyanobacterial Abundance	Remotely sensed CIcyano	X	X			X	X		R13
	Visual scum	X				X			R14
	Discrete planktonic or benthic phycocyanin	X	X			X			R15
	In Situ phycocyanin fluorescence	X				X	X		R16
	Cyanobacterial cell density	X	X			X			R17
	Toxigenic species abundance (qPCR)	X			X	X			R18
Algal/cyanobacterial Community Composition	Species composition via microscopy			X	X	X			R19
	Species relative abundance via molecular barcoding			X	X	X			R20
Primary consumer	invertebrate composition	X	X	X					R21
Toxins/Taste& Odor Compounds	Total planktonic/benthic toxin samples		X	X				X	R22
	Via passive sampler		X	X				X	R23
	Toxin gene counts		X	X	X			X	R24
	Tissue toxins, MIB, geosimn		X	X	X			X	R25
	MIB, Geosimn, Sulfur				X				R26
	Sediment toxins			X				X	R27

Table 2.4. FHAB environmental driver indicator groups, metric reference number, and example metrics. Explanation of each indicator group given in Appendix 3. CC = climate change.

Type	Indicator Group	Metric No. (D#)	Impacted by CC?	Example Metrics
External - Climate	Air Temperature	D1	Yes	Mean Daily Air Temperature
	Precipitation	D2	Yes	Daily precipitation
	Wind	D3	Yes	Mean wind direction
	Insolation	D4	Yes	Irradiance
				Shading or Riparian Cover
External-Land use, Geology and Soils	Catchment Land Use	D5	No	% urban and agriculture of upstream catchment
				Shoreline buffer percent development
				Road density
	Catchment Slope	D6	No	Mean catchment slope
	Catchment Hydrology	D7	Yes	Degree of hydrologic flow alteration
	Catchment Geology	D8	No	% Igneous/metamorphic geology in catchment
	Catchment Soils	D9	No	
External-Nutrient Loading	Catchment Nutrient Loading	D10	Yes	
	Atmospheric Deposition	D11	Yes	Modeled monthly wet deposition of nitrogen
	Groundwater	D12	Yes	
External - Pesticides	Human Use	D13	Maybe	Rate of synthetic fertilizer application per year in catchment
				Pesticide application rate per year in catchment
External-Events	Events (e.g., Fires, floods)	D14	Yes	Date to antecedent fire event in catchment
Internal-Physical	Waterbody Hydrology/ Hydrodynamics	D15	Yes	Water surface elevation
				tratification/ mixing depth/ advection
				Residence Time
				Basin hydrology or hydrologic alteration
				Oxygen stable isotope (indicates water sources)
	Geomorphology	D16	Yes	Shoreline, lake or channel morphology
	Water Temperature	D17	Yes	Daily mean water temperature
	Ocean derived salinity	D18	Yes	Specific conductivity, salinity
	Physical habitat	D19	Yes	Sediment grain size
				Percent embeddedness
Internal - Biogeochemical	Light Attenuation	D20	Maybe	Secchi Depth/Turbidity/TSS
		D21		Water column photosynthetically active radiation
	Nutrients	D22	No	Nitrogen forms (NO3+NO2, NH4, DON, TN)
		D23		Phosphorus forms such as PO4, DOP, TP
		D24		Silica
	Water organic matter	D25	Yes	Water column Chl-a, POC, nitrogen, 24-hr diel Chl-a
	Sediment Organic Matter	D26	Yes	% TOC, total nitrogen, and total phosphorus
				Ash-free dry mass
	Carbonate Chemistry	D27	Yes	pH, DIC, PCO_2, alkalinity
	Ionic Composition	D28	No	Major Ions, conductivity, TDS, Hardness
	Dissolved Oxygen	D29	Yes	vertical profile (lakes); 24-hr diel
	Stable Isotopes	D30	Depends	
Internal - Biological	Algal Taxonomy	D31	Yes	Taxonomy via microscopy or DNA barcoding
	Algal Toxins	D32	Yes	
	Grazers/Zooplankton	D33	Yes	Benthic or pelagic invertebrate grazer abundance

3. Description of Ambient Monitoring Approaches

Ambient monitoring approaches involve consistent data collection over time with the purpose of better understanding status, trends, and drivers of FHAB events across multiple scales. A variety of ambient monitoring and assessment approaches exist, and each have inherent strengths and weaknesses in their ability to address specific management questions, the indicators that can be used in each approach, the spatial and temporal scales they can address, and their cost and feasibility. This chapter will provide an overview of three ambient approaches:

Section 3.1 CA FHAB Remote Sensing
Section 3.2 FHAB Partner Monitoring
Section 3.3 State-Coordinated Field Surveys

3.1 CA FHAB Remote Sensing

Remote sensing approaches for water quality monitoring, simply described, allow for the acquisition of data about waterbodies from a distance (see inset box: How Satellite Remote Sensing Acquires Data). Remote acquisition of data uses a combination of platforms and sensors to collect desired data types. The combination of platform and sensors used depends on the types of questions that are to be answered and the spatial and temporal scale at which the data are needed. Common remote sensing platforms used in freshwater systems include satellites, unmanned or manned aerial systems (e.g., drones, manned aerial surveys, etc.), or *in-situ* sampling platforms moored in a specific waterbody. These platforms can be equipped with a variety of sensors (e.g., hyperspectral radiometers, imaging radiometers, radiometers) that allow for the remote collection of data. Of these, satellite remote sensing approaches provide the most far-reaching tool for FHAB related data acquisition due to the broad spatial and temporal coverage afforded by this approach.

How Satellite Remote Sensing Acquires Data

Sensors on satellite platforms can detect light reflected from the earth at differing wavelengths that allow for the determination of a variety of waterbody properties. Depending on sensor packages deployed on a satellite, the data products can provide indicators of waterbody properties such as water transparency, biological properties, hydrology, temperature, and ice cover during the winter (Dörnhöfer and Oppelt 2016). These capabilities are best developed in lentic waterbodies such as lakes and reservoirs. The optically active water parameters that contribute to the total water-leaving signal are the water itself, phytoplankton, organic and inorganic suspended solids, and colored dissolved organic matter (CDOM); the sum of these three individual constituents, in combination, attribute to differences in overall water clarity, which is frequently used as a proxy for water quality (Topp et al. 2020). This fundamental principle applies regardless of satellite or airborne sensor. For example, water level and surface temperatures can be detected using either spectral or thermal sensors, both providing valuable contextual data to FHAB response indicators.

3.1.1 Overview

The 2016 FHAB strategy prioritized the implementation of satellite imagery for multiple uses both to monitor and respond to FHABs in the state. These uses were envisioned as 1) an incident response tool in which waterbody managers could be notified if satellite imagery suggested that a bloom was developing, 2) as a tool to help assess which waterbodies were at greatest risk for FHABs, and 3) use in ambient monitoring to assess the status and trends of FHABs in waterbodies that were visible via the satellite. Satellite imagery was highlighted as a promising tool for these uses and was envisioned to be able to support these goals at a fraction of the cost of field based ambient monitoring approaches.

In accordance with the vision articulated in the 2016 FHAB strategy, a satellite imagery tool has been developed specifically for use in California. The tool routinely acquires satellite-imagery products from NOAA and was developed as a partnership with SWAMP, NOAA, and SFEI. Currently, the data are sourced from geospatial satellite imagery from Sentinel-3's Ocean Land Color Imager (OLCI), and the data are post-processed by NOAA. These data are collated and stored by SFEI, who developed a platform to process and visualize the data sourced from NOAA, specifically for California. The outputs from this program are hosted via a web-based tool (https://fhab.sfei.org/) which provides statewide and waterbody-specific data in 255 large waterbodies throughout California. The tool is currently intended to address the following management questions:

- *What is the FHAB extent and magnitude in an individual waterbody and across larger spatial scales?*
- *To what extent are FHABs changing over time in individual waterbodies?*

Satellite imagery is used to estimate cyanobacterial abundance in individual pixels using spectral shape algorithms for specific satellite bands in the upper water column. The cyanobacteria index (CI, unitless, Wynne et al. 2008) was first used to estimate cyanobacterial density in a pixel. Based on additional research and refinement of the approach, the CIcyano value was adopted using a modified spectral shape algorithm to better eliminate false positives (Lunetta et al. 2015; Wynne et al. 2018). In short, the CIcyano value is a proxy of cyanobacteria specific Chl-a absorption and estimates the cyanobacterial biomass using a distinct wavelength signature that allows for the differentiation of cyanobacterial biomass from other algae and matter.

Data available with the Sentinel-3 sensor is comparable as a time series beginning in 2016[11]. The Sentinel-3 data have a 300-meter spatial resolution with satellite flyovers occurring every ~1-2 days for a given area of the state but is unavailable during periods of cloud cover during satellite overpass. 300 m x 300 m pixels (roughly 22 acres) are placed into a static grid of projected data bins for use by the tool. A minimum of 18 contiguous pixels must be present within a composite image for a waterbody to be effectively characterized. Shoreline pixels are masked to reduce the interference with land-based reflectance (e.g., from shoreline vegetation), which cannot be effectively differentiated from water reflectance within that pixel. Therefore, the lake's size and shape determine whether it is visible in the current tool (e.g., large but narrow lakes would not be included in the current tool). Based on these criteria, 255 Californian waterbodies are assessed (Figure 3.1) but during an evaluation of the 2002-2012 satellite data, 27 of these 255 waterbodies were too small or narrow to meet the 18-pixel threshold to generate useful statistics (SFEI 2017) but do still display any pixel data where available.

The data from the current satellite tool is provided through a map-based web tool and displays a suite of information derived from satellite imagery as well as comparisons to any existing field data present in the California Environmental Data Exchange Network (CEDEN). The tool provides the estimated cyanobacterial abundance for each pixel as a heatmap with the pixel color

[11] The OLCI instrument on board Sentinel-3 launched in 2016, but historical data are also available between 2002-2012 from the Envisat MERIS satellite sensor. Currently, the comparability of the data from these two satellite platforms is not well understood, and it is recommended that date from 2002-2012 be treated as distinct from date from 2016 and forward from the Sentinel-3 OLCI.

corresponding to a modified CIcyano value. For simplicity, the CIcyano value data provided by NOAA was rescaled so that the index appears on a scale of 1 to 1,000. Values below 1 or at 1,000 are considered below minimum detectable levels or at the maximum detectable levels, respectively. By default, the map-based tool provides a 10-day running composite of the maximum CIcyano values for each pixel for the statewide view. The web-based tool can also be used to visualize a specific lake from the inventory of the 255 lakes currently visible on the tool (Figure 3.1). Within this functionality, the modified CIcyano value for each pixel can be viewed within that waterbody. Additional data about the modified CIcyano value (90th percentile, mean, and median) are shown across a selected time period. Data are also provided about the total number of pixels visible for the same selected time period. Data can be downloaded in the form of geoTIFF and CSV files of 10-day pixel maximum values and single day pixel values. The current tool also has some integration of available data about a specific waterbody that is housed in CEDEN.

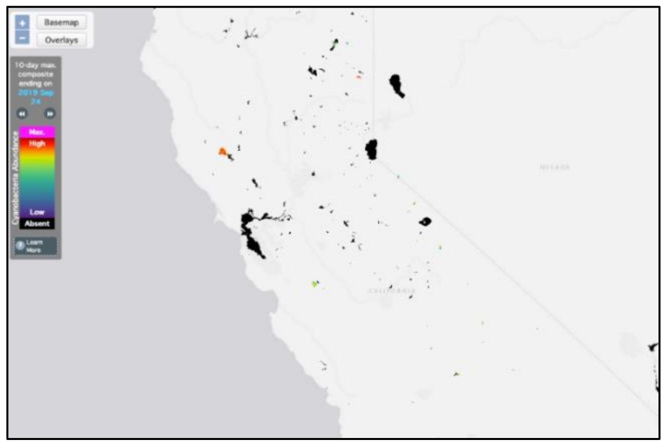
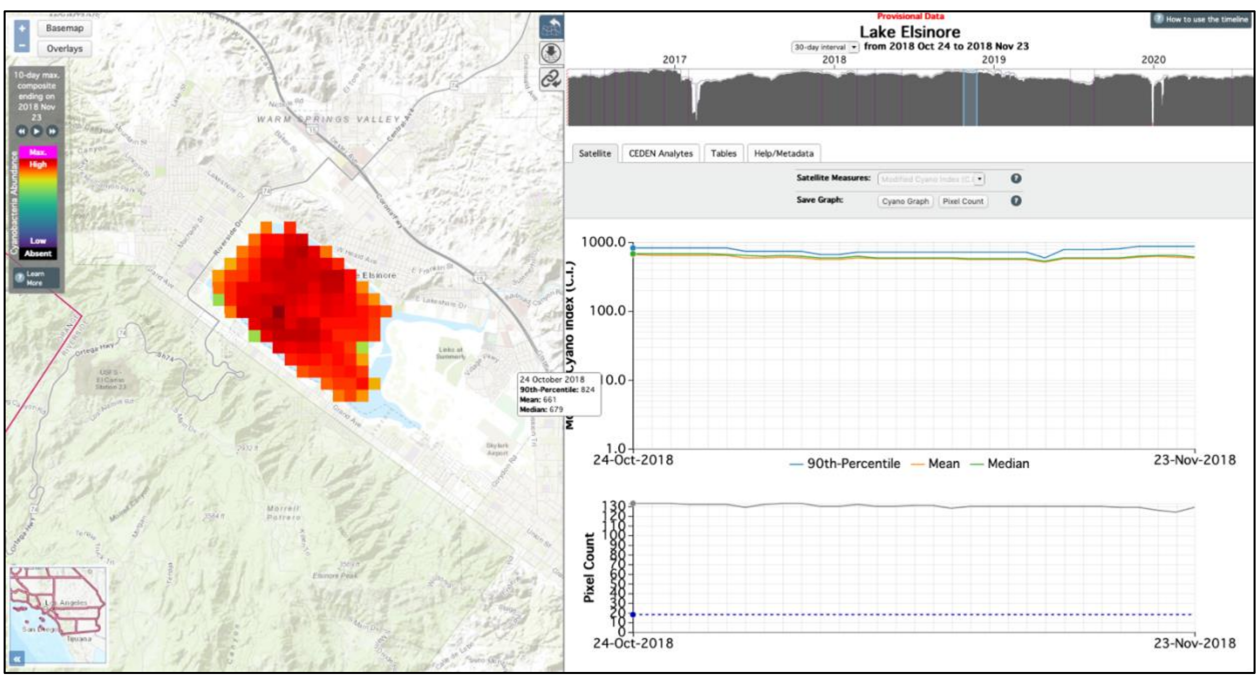


Figure 3.1. Top panel: View of large California lakes and reservoirs assessed with the Sentinel-3 sensor. Bottom panel: Example of the data provided on the satellite web tool for an individual waterbody, Lake Elsinore in Southern California.



3.1.2 Current Management Applications and Approach Strengths and Weaknesses

Satellite data are considered provisional and are not currently used to issue recreational advisories. The reliability of CIcyano values within and across waterbodies is difficult to quantify at present. Satellite derived data needs futher validation against *in situ* data to ensure reliability and to better understand the occurrence of false positives and false negatives in cyanobacterial abundance estimates. Work towards this goal (Coffer et al. 2020) has been promising, but more effort is needed to generate validation data to better quantify the uncertainty of these numbers.

Data from the tool are currently used primarily as a screening tool to provide an early warning that cyanobacteria blooms are beginning to form within a lake. As currently designed, the tool provides an automatic notification to Regional Board HAB staff when the modified CIcyano value exceeds a threshold of 3.2. Additionally, weekly summaries are automatically generated for each Regional Water Boards to catalog all waterbodies that exceed the threshold and compare the most current values to the previous week to track short term trends. Ultimately, this tool, as it currently exists can provide an early warning for managers to mobilize field crews to conduct a field assessment to track the potential increase of cyanotoxins. Currently, satellite data are not being used for any water quality or water policy regulation, such as 303(d) listing or TMDL development.

Satellite data has been used to assess trends in modified CIcyano values over time (Urquhart et al. 2017), although use of the tool for this purpose is minimal at this time.As noted above, there are some challenges in using the data in this manner due to the changes in satellites and imaging technology over time as well as the limited validation of satellite data in California lakes. A major hurdle that was identified was the lack of standardized methods for trend analysis with satellite imagery data, though the CyAN project has recently published multiple papers proposing methods for CIcyano analyses (Coffer et al. 2020; Urquhart et al. 2017; Mishra et al. 2019; Clark et al. 2017). An additional consideration is that modified CIcyano values only provide data about cyanobacterial dominance within a lake, but no data on cyanotoxins (which cannot be detected using satellite imagery approaches) or more broadly, CIcyano does not capture blooms from non-cyanobacteria that may precede a cyanobacteria bloom and/or could still result in negative impacts on water quality such as excessive pH during a bloom or reduced dissolved oxygen during the bloom crash. The existing satellite does capture these non-cyanobacteria signals within the CInon-cyano dataset which to date, has not been prioritized but could be useful. It is useful to understand which waterbodies might be more regularly dominated by cyanobacteria; however, the applications of this knowledge are not yet certain in a management context.

Satellite imagery’s key strength lies in the ability of this approach to provide wide spatial and temporal coverage with minimal staff time investments, which is impossible to replicate using field-based survey approaches. Broad spatial and temporal coverage has allowed for an initial assessment of status and trends in large lakes, which is particularly valuable since very little FHAB related data are available in these systems due to the lack of ambient programs in many of these lakes. This data can be used to prioritize which large lakes to include in other monitoring program elements, such as the partner or state coordinated field monitoring programs described in Sections 3.2 and 3.3. Archived data from MERIS can be analyzed back to 2002 to provide some information on historical conditions, although some issues with data transmission rates from MERIS in 2002-2007 limits the types of analyses that can be conducted across the entire lifetime of the MERIS platform (2002-2012). Nonetheless, this data can provide useful insights into conditions in large lakes in California when otherwise very little information is available.

There are some notable weaknesses in the current satellite tool. A fundamental limitation of the current satellite approach is that only large lakes are visible. Small lakes and other waterbody types such as rivers and streams are not visible with the current Sentinel-3 OLCI platform. As with all other satellite approaches presently available, only the upper one meter of water can be detected under ideal conditions and significantly less when surface scums are dpresent which could lead to underestimating biomass when blooms are not concentrated at the surface. Submerged aquatic vegitation and benthic mats close to the surface can be mapped but only in clear waters. Overall, without toxin data, satellite imagery does not provide data that is applicable to recreational health advisories. Imagery does not allow for the assessment of which specific cyanobacteria are present (e.g., toxigenic genera versus non-toxigenic genera) or if cyanotoxins are present. As described above, the current tool cannot effectively estimate cyanobacterial abundances near the shoreline due to the interference of aquatic vegetation and turbidity in these locations. This provides challenges in estimating recreational risks along the shoreline, but also complicates field validation efforts since field measurements need to be collected from regions of the lake only accessible by boat. Ultimately, this requires additional effort to provide field validation, which is crucial for better understanding false negatives and false positives in satellite derived data.

3.1.3 Recommendations to Strengthen FHAB Remote Sensing Approaches

The current satellite tool is primarily used for incident response purposes by managers via utilization of the web-tool. Additional uses of remotely sensed data are possible to help managers better assess the status and trends of FHABs in large lakes under their purview. For example, this type of data could be included in key management documents such as US EPA 303(d) Integrated Reports as a secondary line of evidence for FHAB impacts, if some *in-situ* data also exists. The following are recommendations to strengthen the FHAB Remote Sensing Program, and are discussed in detail below:

- **Technological improvements** that can greatly expand the extent of waterbodies characterized.
- **Standardized protocols and quality assurance and control:** Key investments to increase the accessibility and "ease of use" of existing satellite imagery data as well and towards the development of documentation and standardized methods for data analysis and quality assurance would support increased management utilization of this program.
- **Data communication, accessibility, visualizations, and reporting** that can increase the utility of the program for the Water Boards and their partners.

Technological Improvements

Technological improvements to the existing remote sensing program were envisioned by the TAC across two timescales: implementable within a 5-year timeline or within a 5 to 10+ year timeline. Implementation of technology based programmatic improvements was considered according to three factors: 1) if the technology considered is available, 2) if the technology is in a research and development phase or if it has been heavily vetted, and 3) the amount of infrastructure (e.g., hosting and sharing data products) required to implement a selected technology.

The satellites, sensors, and data products available to use in California's program, both currently and in the future, are a function of national and international agencies such as NOAA, NASA or the European Space Agency (ESA). Therefore, the improvements to satellite remote sensing programs are bound by the capabilities of current and future satellite missions conducted by those agencies. For example, a new NASA mission called GLIMR will be launched in the 2026-2027 timeframe. The satellite will feature 300-m resolution sampling of entire U.S. East and West Coasts at least 2-3x per day with hyperspectral from at least 350 – 890 nm, and a band at 1020 nm. Private satellites were not considered for use in this initial phase of improvements. Several key technologically based improvements were identified as high priority with moderate to high feasibility within a 5-year timeframe based on currently existing satellite products. Some strategic improvements that were considered include increasing:

- Spatial resolution to increase the number of remotely sensed waterbodies
- Number of FHAB and environmental context indicators
- Use of other remote approaches offer finer-scale spatial resolution could be possible, such as drone imagery or imagery from flight programs

Increase Spatial Resolution and Number of Remotely Sensed Waterbodies. Increasing the number of waterbodies visible within California's current satellite tool would significantly increase the ability of the tool to address key management questions and provide early warning of potential events. This would require utilizing data from high resolution satellite platforms, such as Sentinel-2 or Landsat OLI, which have a 10-60 meter spatial resolution, depending on the bands used (Table 3.1). Some key caveats do exist for this technology. Sentinel-2 generates imagery with a different spectral signature; therefore, these products cannot be used to calculate a CIcyano value. It is able to detect chlorophyll, which could provide data about overall algal biomass, but would not be able to effectively differentiate cyanobacterial from other algal types. Sentinel-2 does have the capability to differentiate cyanobacterial biomass from non-cyanobacterial biomass using Scattering Line Height, which is currently being implemented on a pilot scale by SFEI. Additionally, although Sentinel-2 produces data at a less frequent temporal interval than Sentinel-3 OLCI (5-10 days overpass time for Sentinel-2 versus 2 days for Sentinel-3), a significantly larger amount of data are generated by this platform due to the higher spatial resolution. The USGS hosts Sentinel-2 data, but pre-process data products from Sentinel-2 are not currently routinely available. Significant investments would need to be made to manage and use this data. Towards this end, we recommend a pilot project to use Sentinel-2 data in a regional or statewide status and trends assessment (**SS13, Appendix 6**).

Increase Use of FHAB and Environmental Context Indicators**.** Another addition to the current tool could be additional metrics of FHAB responses (Chapter 4) or drivers (Chapter 5; **SS7, Appendix 6**), particularly those that are already routinely available. Remotely sensed chlorophyll-a concentration and water clarity are readily available from current Sentinel-3 imagery products as well as from other satellite platforms such as Sentinel-2 (as discussed above). These metrics were largely supported by the TAC and California management groups queried since this data could provide information about lakes with high algal biomass, not just those dominated by cyanobacteria as currently indicated with the CIcyano metric. The addition of remotely sensed chlorophyll-a to the current tool would require the selection of a chlorophyll-a algorithm, as there is not one currently accepted algorithm for inland waters (Neil et al. 2019).

Several additional indicators (Table 3.1) could provide valuable contextual information that could be applied in risk estimation programs, but infrastructure would have to be developed to collect and process these data on a routine basis. Estimates of surface scums from satellite imagery could provide useful data about aesthetic impairments to waterbodies due to algal overgrowth, and there are current efforts piloting this capability in other regions of the United States. Currently, the algorithms to estimate the presence of scums are not fully developed and although useful, are not readily adoptable into the program in the near future. As these become more mainstream, surface scum metrics would be a useful addition to the program. Lastly, temperature is a currently available environmental context metrics and could be used in future risk modeling approaches (Chapter 7). Landsat temperature data are currently publicly available from USGS Earth Explorer Analysis Ready Data.

Another FHAB indicator that was discussed but highly discouraged by the TAC was estimating specific cell densities from satellite imagery. This approach is technically possible and has published methods, but there are a multitude of associated caveats with the approach. Despite being possible, this indicator was not suggested to be adopted to the program due to large amounts of uncertainty associated with cell density estimates.

Table 3.1. Currently used and recommended remotely sensed indicators and metrics.

Indicator Type	Metric	Comment	Currently Used by CA?	Metric Ref. No.
Current Response Indicators				
Cyanobacterial biomass	Envistat MERIS CIcyano Index (2002-2012)	Indirect inference to REC 1, REC 2, Aquatic life, source water protection	Yes (2002-2012 data currently available)	R12
	Sentinel-3 OLCI CIcyano Index (2016-~2023)		Yes (2016-present)	R12
Proposed Response Indicators				
Water clarity	Envistat MERIS and Sentinel-3 OLCI water clarity	REC2	No	R1
	Sentinel-2 MSI sensed water clarity		No	
Algal and cyanobacterial biomass	MERIS sensed chlorophyll a (2002-2012)	REC1, Aquatic life, raw source water protection	No	R8
	Sentinel-2 MSI sensed chlorophyll-a (2017-~2024)		No	
Drivers				
Internal Driver	Sensed Temperature (Sentinel-3 SLSTR, Landsat-8 TIRS, Aqua MODIS)		No	D16

Other Remote Approaches**.** Currently, some types of data are desirable but not achievable with current or upcoming satellite imagery. One key weakness of the satellite imagery is that it is unable to resolve shoreline pixels, and therefore FHAB impacts in prime recreating areas in a given waterbody are not quantified. With the known spatial variability of FHAB events, estimates of FHAB indicators from the middle of the lake might not be representative of events along the shoreline.

Finer-scale spatial resolution could be possible using other remote approaches, such as drone imagery or imagery from flight programs. Currently, drones are a promising technology; however, drones are spatially limited and restricted from use in many locations. Drones could help assess sub-pixel variability or provide high resolution for a single waterbody, stream reach, or portion of a watershed. Some considerations with this approach include using the imaging instrument on a drone to provide information of varying quality. Ideally, a drone should be equipped with hyperspectral or multi-spectral camera (good data with ~10 channels) for providing comparable data to existing satellite imagery products. An RGB camera would not provide data beyond the first optical depth (roughly the first Secchi depth), and it is difficult to differentiate algal blooms from dark water with this type of imagery. Drones could be piloted or have the potential to fly autonomously over specific areas. Drones have been piloted for autonomous flight in other environmental programs such as characterizing trash debris, where they have been able to autonomously conduct trash surveys in riparian areas. A special study could be conducted to explore the feasibility of generating drone imagery of waterbodies to assess FHAB extent and magnitude (**SS26, Appendix 6**). Conducting regular aircraft overflight programs is cost prohibitive; however, other agencies such as NASA and CalFire conduct overflights in California with hyperspectral cameras. This data could be leveraged to conduct high resolution surveys of waterbody status within the flight path. The data could also be leveraged for validation efforts, depending on timing.

Standardized Protocols, Quality Control and Documentation

Standardized protocols need to be developed to provide guidance on data and analysis. In particular, no standardized metrics exist in the current program for imagery data analyses to address status and trend management questions. Developing standardized recommendations for data analyses methods would support consistent interpretation of satellite data metrics (CIcyano values, chlorophyll-a, etc.) across different Water Boards programs. Standardized metrics for calculating spatial and temporal extent (for example, monthly maximum composites; Urquhart et al. 2017), temporal frequency (percent of pixels above a particular bloom threshold over time; Clark et al. 2017), magnitude (mean of max composite CIcyano and chlorophyll-a values over time; Mishra et al. 2019), trend analysis (Thiel-Sen’s slope/Kendall’s tau; Urquhart et al. 2017), and overall lake occurrence (percent coverage of lake to define a “bloom”; Coffer et al. 2020) should be assessed and defined**.** A special study could be conducted to recommend standardized analytical metrics for imagery data **(SS8, Appendix 6**).

The current remote sensing tool lacks quality assurance documentation or a standardized approach to estimate the uncertainty of the data. Given the wide range of environmental conditions for waterbodies across the state that are measurable with this tool, it is possible that data quality isn’t uniform across all waterbodies and seasons. Work is needed to better understand and quantify the uncertainty associated with imagery data and the subsequent indicators such as CIcyano values and chlorophyll-a (**SS9, Appendix 6**). Some work to quantify the uncertainty has been conducted in California through field verifications (Bouma-Gregson, unpublished), but additional data are needed, and results should be compared to field-verification studies conducted elsewhere (e.g., Tomlinson et al. 2016). Field verification data in multiple waterbodies over multiple conditions (e.g., during an FHAB event and when an FHAB is absent) are needed. Validation data could also be collected remotely via fixed *in-situ* sensor stations. Additionally, leveraged opportunities could include cross-platform verifications with airborne sensor flights. Statistical methods can be employed to better understand uncertainty such as developing metrics like signal to noise ratios. Comparisons to other remote sensing datasets that measure Chl-a could be helpful, as well as evaluating remote sensing estimates of water temperature and being able to assess whether false positives are produced at times when reservoirs are draw down. A special study to synthesize current understanding of the uncertainty of CIcyano values and to continue field verification in California would be beneficial (**SS10, Appendix 6**).

Communication, Data Accessibility, Visualization and Reporting

Remote sensing has the potential to provide great context and utility to FHAB partner program participants who monitor lakes and reservoirs. Currently, the existing FHAB satellite tool is capable of visualizing the magnitude and extent of remotely sensed CIcyano in a particular lake and understanding the trends in that lake over time (Figure 3.1.2). The web-tool currently does not provide a lot of information to contextualize and interpret status and trends beyond providing a visualization of the modified CIcyano values over time. Data from this program is envisioned to be communicated using a variety of approaches including: 1) "real-time" summary graphics and waterbody-specific graphics generated through an interactive website and 2) summarized findings in a report format, e.g., report card.

Annual or biannual reports could be published by SWAMP on a 1- to 2-year interval and would summarize FHAB indicator(s) from imagery data of visible waterbodies on a regional, watershed, and statewide basis. This type of report could also be integrated with data from other ambient monitoring programs such as the FHAB partner monitoring program or incident response program. A quality assurance process would need to be developed to make these comparisons appropriate, realistic, and useful for a lake manager; thus, it might be a function that is available for yearly data that has gone through such a review process and can be integrated with interactive website data visualization. A second recommendation is to push to include Sentinel 2 as an ongoing data source, as it has the potential to serve FHAB partner program participants by providing status (magnitude and extent) and trends for all California lakes and reservoirs (not just the lakes > 160 ha).

For the interactive website, one recommendation would be to *extend current data visualization capabilities* that would allow a lake manager to compare a particular lake against the population of lakes assessed through the remote sensing program, either through the MERIS/OLCI (large lakes only) or through the upcoming Sentinel-2 program (all lakes). One of the potential pitfalls of such an approach is the false positives associated with increased turbidity (post-storm or fire events) or shoreline aquatic vegetation. If some of the quality assurance measures used to make scientifically valid comparison, derived through the reporting process (above), can be automated, such comparisons could become more streamlined and updated on a frequent basis.

User-driven queries are another important feature of an interactive website. Developing the ability to directly query-specific waterbodies or temporal ranges increases the ease of use. As currently designed, the web-tool does not have this functionality as data are only downloadable by a given month. Additionally, the ability to download the raw CIcyano values instead of only 10-day maxima could increase the utility of the web-tool. Once standardized metrics for status and trends are identified (see above sections), a functionality to download these metrics or a tool to input raw data to calculate these metrics could be developed, which would minimize the time invested by water quality agencies to integrate this data into their reporting workflows.

The current web-tool interface could be enhanced to increase the utility for incident response and consideration in management. As currently formatted, the web-tool has been successful in tracking bloom development for the purpose of agency incident response. However, the tool could be enhanced by improving the utility for communicating potential FHAB risk to the public. Currently, the results from the incident response program are hosted in a different portal. Work could be done to integrate these data streams to improve communication about FHAB events to the public. An example of an important feature that might enhance remote sensing support for bloom management is the ability to expand an existing automated user notification email system that currently notifies SWAMP and Regional FHAB coordinators when chlorophyll-a or CIcyano index exceeds a threshold value (**SS11, Appendix 6**). This could allow for waterbody managers and other resource professionals to be notified about the onset and location of blooms to improve their incident response.

Once standardized metrics for status and trends are identified (see above sections), it would be advantageous to develop a screening tool for water quality managers, and potentially the public, to assess FHAB impacts over time to more easily determine which waterbodies might be prioritized for monitoring or to explore for FHAB impairments (**SS12, Appendix 6**). See Chapter 7 for the appropriate framing and discussion of these ideas.

3.1.4 Summary and TAC Recommendations: Remote Sensing Approach

The TAC strongly recommends strengthening the Californian FHAB remote sensing program in order to enhance our ability to assess status, trends, and drivers. Seven recommendations and related special studies were promoted by the TAC for consideration for how they might be prioritized in the strategy.

Table 3.2: Summary of specific recommended actions and special studies developed by the remote sensing TAC.

Specific Recommended Actions	Special Studies
Assess and describe data quality of remote sensed satellite algorithms for HAB detection.	Develop QA documentation for remotely sensed data products (SS9).
Establish standardized protocols for routine analytical metrics for use in satellite analysis.	Develop standardized analytical metrics for imagery data (SS8).
Conduct a status, trends and drivers assessment with current Sentinel-3 and MERIS satellite data (limited to lakes >160 ha).	Develop remotely sensed chlorophyll-a thresholds (SS11).
Add existing metrics (e.g., CI_noncyano and Chl-a) to current database and increase accessibility of data to the public.	Add available satellite derived FHAB response and driver metrics (SS7)
Enhance data management and data visualization platforms to ensure open and easy access to data for staff and public.	Develop a routine workflow to use satellite imagery data in reports and listing decisions (SS12).
Continue and expand collection of data to ground-truth satellite data and improve data quality characterization.	Develop CIcyano field verification protocols (SS10).
Incorporate high resolution satellite data into routine use for lake and reservoir status, trends and drivers assessments.	Conduct a pilot project to use Sentinel-2 data in a regional or statewide status and trends assessment (SS13).
Explore the feasibility of generating drone imagery of waterbodies to assess FHAB extent and magnitude.	Pilot use of drone imagery for FHAB ambient monitoring (SS26).

3.2 FHAB Partner Monitoring

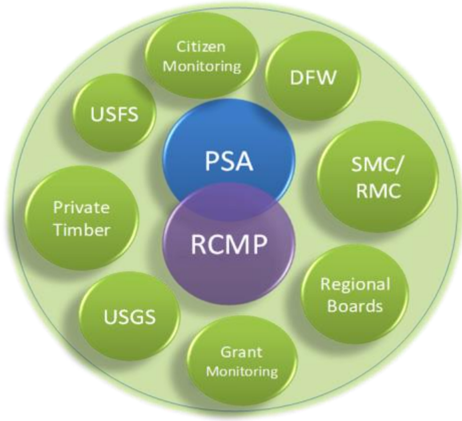
A core principle of the Surface Water Ambient Monitoring Program is the strong encouragement and support of partner monitoring that leverages limited resources and improves stewardship of the State's watersheds (see inset box: **Example of Partner Monitoring in the SWAMP Bioassessment Program**). This section establishes the foundational vision and programmatic elements for an FHAB partner monitoring program. It describes the motivation and goals, the program assumptions, definitions and focal management questions, the program design elements, partner responsibilities, and needed implementation plan components.

3.2.1 Motivation and Goals for an FHAB Partner Monitoring Program

This program is envisioned to involve the State Water Board as the primary coordinating agency with multiple partner agencies and groups that are all assessing specific waterbodies following a suite of standardized methods. The foundational principles that underpin the development of this program are that waterbodies need to be monitored on relevant spatial and temporal scales to accurately assess the status and trends of FHABs within these systems and the potential impairment of the health of human, dog and other domestic animals. The spatial and temporal variability of FHAB events and the toxins they produce makes the characterization of status and trends challenging. This is particularly so in California, which is a geographically large state with many waterbodies that makes monitoring for FHABs in all waterbodies at regular intervals prohibitively resource intensive. Therefore, this type of monitoring would the State Water Board to cultivate monitoring partnerships to accomplish this purpose.

This program is designed to provide the broad framework for other FHAB monitoring programs and efforts to partner with the State Water Board to address FHABs in their specific waterbodies. The goal of this program would be to support local level FHAB monitoring efforts by establishing a common monitoring approaches and leveraging resources. It is strategic to lay the groundwork for partner agencies throughout the state to monitor waterbodies in a way that maximizes output by leveraging resources. By working together to address FHABs, partners can play an active role in filling gaps by gathering vital data about their systems while also broadening the understanding of FHABs statewide. Ultimately, this program will function as a collaboration between the Water Boards and participating agencies. Partners include a range of entities including, but not limited to, tribes, local environmental health departments, parks departments, drinking water providers, private waterbody managers, or scientific non-governmental organizations. Other key partners who might not conduct waterbody monitoring but still provide data on FHAB impacts are veterinarians and healthcare professionals to track illness related to exposure to FHABSs. The State Water Board would provide infrastructure for this program while the participants conduct the monitoring within their target waterbody(ies), working collaboratively to better understand FHAB extent, magnitude, and impacts.

Example of a Partner Monitoring in the SWAMP Bioassessment Program



The Bioassessment Program is an example of a SWAMP program that has actively promoted the participation of collaborative partners. The SWAMP Bioassessment Program, managed by the CA Dept. of Fish and Wildlife, has invested in three core areas: 1) core monitoring, e.g., perennial stream assessment (PSA) and the reference condition monitoring program (RCMP), 2) collaboration to link and support numerous independent programs conducting targeted and probability surveys in California, and 3) infrastructure such as standardized methods and tools, partner training and documentation, and intercalibration to streamline their participation. Partners include the Regional Boards, USEPA's National Rivers and Streams Assessment, CDFW, Southern California Stormwater Monitoring Coalition (SMC), S.F. Bay Regional Monitoring Program, the Tahoe Regional Planning Agency, the Bureau of Land Management, and the U.S. Forest Service (USFS).

The TAC prioritized recreational health as the greatest concern for most agencies, and thus is the focus in the approach described in Section 3.2.3. However, this approach is also meant to be illustrative. The infrastructure described in Section 3.2.5 is meant to support monitoring related to multiple beneficial uses. This program is meant to be adaptable to help support the interests and information needs of the partner group. The program infrastructure and design recommendations can be adapted to address additional information needs about the impacts of FHABs on other core beneficial uses such as fishable, aquatic life, raw water protection, or for the waterbody assessment of FHAB drivers.

3.2.2 Program Assumptions, Definitions, and Focal Management Questions

This program was designed to be tiered so that it could be scaled to the capacity and resources of any participating group. It was recognized early in the design of this program that individual entities have a spectrum of available resources and information needs therefore, the program tiers are proposed. Tiers are designed to scale from groups with low resources to those with high resources. The scalability of this program is based on the recommended indicators and spatial and temporal design of each program.

This program also assumes that the participants of the program have **basic training in water quality monitoring**, including basic sample handling and quality control measures, regardless of available program resources. Ideally, one of the tiers of this program could be adopted into an existing water quality program, although that is not an explicit requirement.

Regardless of the level of resources available to an agency, the program prioritizes two **core monitoring questions** about FHAB status and trends: 1) *What is the overall extent and magnitude of FHABs in my waterbody or waterbodies?* and *2) To what extent are FHABs changing over time in my waterbody or waterbodies?*

Depending on the goals of the agency and indicators that they elect to implement, an **additional management question** about the basic drivers of FHAB events can be addressed within this program: 3) *What are the environmental factors commonly associated with FHABs?* Pairing core FHAB indicators with basic water quality indicators will aid in providing a better understanding of the environmental conditions within the system that are related to FHAB events.

An important caveat to this approach is that the degree to which management questions can be effectively addressed varies by the program tier implemented by the participants based on the selection specific indicators, spatial, and temporal design elements implemented. These specific caveats are discussed within the specific design sections below.

3.2.3 Partner Program Design Elements: Example of Recreational Health

The TAC prioritized the development of programs that can protect recreational health; therefore, we present an example module centered around a program that would be protective of swimmable uses. Core indicators and design elements outlined in Section 3.2.3 were developed to fundamentally address this **specific monitoring question**: *Are FHABs endangering human and animal health through recreational contact in my waterbody?* The degree to which these information needs can be addressed varies by the selection specific indicators, spatial, and temporal design elements implemented. These specific caveats are discussed within the specific design sections below. Ultimately, three tiers were envisioned for this program: 1) a recreational health focused program that can be conducted within a low resource tier; 2) a recreational health focused program that can be conducted within a higher resource tier; and 3) a waterbody assessment approach that, in addition to providing recreational health related data, also provides a basic drivers assessment for the waterbody.

Both the low resource program tier and high resource program tier consist of indicators that are defined as **core** and **optional indicators**. The core indicators vary based on the resource tier. Because of the focus on recreational health, sampling is focused on shorelines of recreational beaches of all waterbodies including lakes, streams, rivers, or coastal confluence areas. Due to this generalization, the TAC concluded that the spatial and temporal design elements cannot be overly prescriptive due to diversity of potential waterbody types that are used recreationally.

This section outlines the approach of the program, which will need to be customized for the specific waterbody following foundational design guidelines below and adopting the recommended indicators and SOPs. As envisioned, waterbody-specific design will be developed collaboratively when participants enroll in the program by the State Water Board, (or State Water Boards designee, such as a Regional Board HAB coordinator) to best follow the core recommendations based on the participant's available resources and information needs. The core information need addressed by both resource tiers of this component of the partner program is: "Is my waterbody safe to swim?" Information provided should be suitable to post or de-post public health advisories for recreational use. Another important use of these data are to understand how the waterbody is trending over time, either to motivate the public, local agencies, or elected officials to protect the waterbody from future events, seek solutions, or to understand the efficacy of solution(s) that have been implemented.

Recreational Use Indicators and Metrics

Core indicators are considered essential and must be measured at the minimum recommended spatial and temporal specifications in order to provide scientifically sound data and effectively protect recreational human and animal health. Indicators are unified across program tiers, meaning that low and high resource tiers have the same basic core measurements, but the high resource tier has more indicators within the core category which increase the cost of implementing that tier but provide additional useful measurements and insight. The core indicators in each program have strengths and weaknesses to assess FHAB recreational use impacts.

Optional indicators can be implemented in several ways at the discretion of the participating entity. The first implementation approach for optional indicators is to use the core indicators to select when optional indicators should be used. The specific indicators that were determined to be beneficial for this purpose are specifically identified as optional for that tier. For example, core biomass and FHAB community composition indicators in the low resource program tier can be used to select which samples should be analyzed for cyanotoxins to optimize toxin analysis resources by only measuring for cyanotoxins in samples dominated by a high biomass of toxin producing genera. Secondly, if this program is adopted into an existing program that already collects some of the optional indicators, these data can be paired and provide a greater understanding of the FHAB dynamics within a system.

A fundamental tension exists between an idealized program that monitors frequently enough to protect recreational uses and one that is affordable. The indicators and design decisions made by participants must be sustainable by that agency, but these selections have fundamental strengths and weaknesses in their utility to assess FHAB impacts on recreational uses. These considerations are discussed below along with how specific indicator and design decisions impact the ability to effectively address management questions about their waterbody.

Lower Resource Tier Program. The **lower resource tier program** has 2 key core metrics: a visual biomass assessment and microscopic assessment of cyanobacteria community composition to identify potentially toxigenic species (Figure 3.2). The microscopic identification data would provide a robust time-series of the presence and categorical density estimates of potentially toxigenic species in a waterbody which is currently a large data gap statewide. Specific guidelines would need to be developed for the handling and identification of planktonic samples and benthic mat samples, which can sometimes be identified based on macroscopic characteristics if mats are of a sufficient size. High biomass accumulation impairs aesthetics for non-contact recreational uses, and this program will provide data about the status and treads of FHAB impairments of REC2 uses in specific waterbodies across the state. Without the need to collect samples for laboratory analysis, this program was designed with a low entry barrier, with the hope that NGOs, citizen-science groups, and smaller entities with limited funds could participate and contribute beneficial data on recreational FHAB impacts.

Cyanotoxins are directly linked to negative human and animal health outcomes but are more resource intensive to analyze and therefore are an optional indicator for the lower resource tier. Nonetheless, a tier I caution advisory (Table 3.2) can be based on the core indicators of this tier (Figure 3.3). Even without routine toxin analyses, the lower resource tier program could be strategically adapted to allow for determining recreational postings and de-postings. As previously discussed, indicators of biomass and community composition can be predictive of whether cyanotoxin might be present and could be used to prioritize samples for toxin analysis. Lower resource groups could use their core indicators to prioritize high risk samples for toxin analysis, either via toxin dip stick or laboratory analysis. This approach is highly recommended, if feasible, for the lower resource tier since it enhances the capabilities of the program to provide data that supports recreational postings and de-postings. One caveat to this approach is that pre-selecting samples for toxin analysis based on biomass and community composition will provide a biased status and trends dataset for cyanotoxins compared to samples that are routinely measured for cyanotoxins, regardless of the data from the other indicators. This caveat is only noted since this approach could potentially limit long-term management actions such as waterbody listing based on chronic cyanotoxin production.

Table 3.3. Recreational Health Trigger Levels. Source: https://mywaterquality.ca.gov/habs/resources/habs_response.html#trigger_levels

Recreational Health Triggers	Caution Tier I	Warning Tier II	Danger Tier III
Primary Triggers[a]			
Total Microcystins[b]	0.8 µg/L	6 µg/L	20 µg/L
Anatoxin-a	Detection[c]	20 µg/L	90 µg/L
Cylindrospermopsin	1 µg/L	4 µg/L	17 µg/L
Secondary Triggers			
Cell Density (Toxin Producers)	4000 cells/mL		
Site Specific Indicators	Discoloration, visible scum, mats, suspected illness		

[a] The primary triggers are met when any toxin exceeds criteria
[b] Microcystins refer to the sum of all measured microcystin congeners
[c] Must use an analytical method that detects ≤ 1 µg/L Anatoxin-a

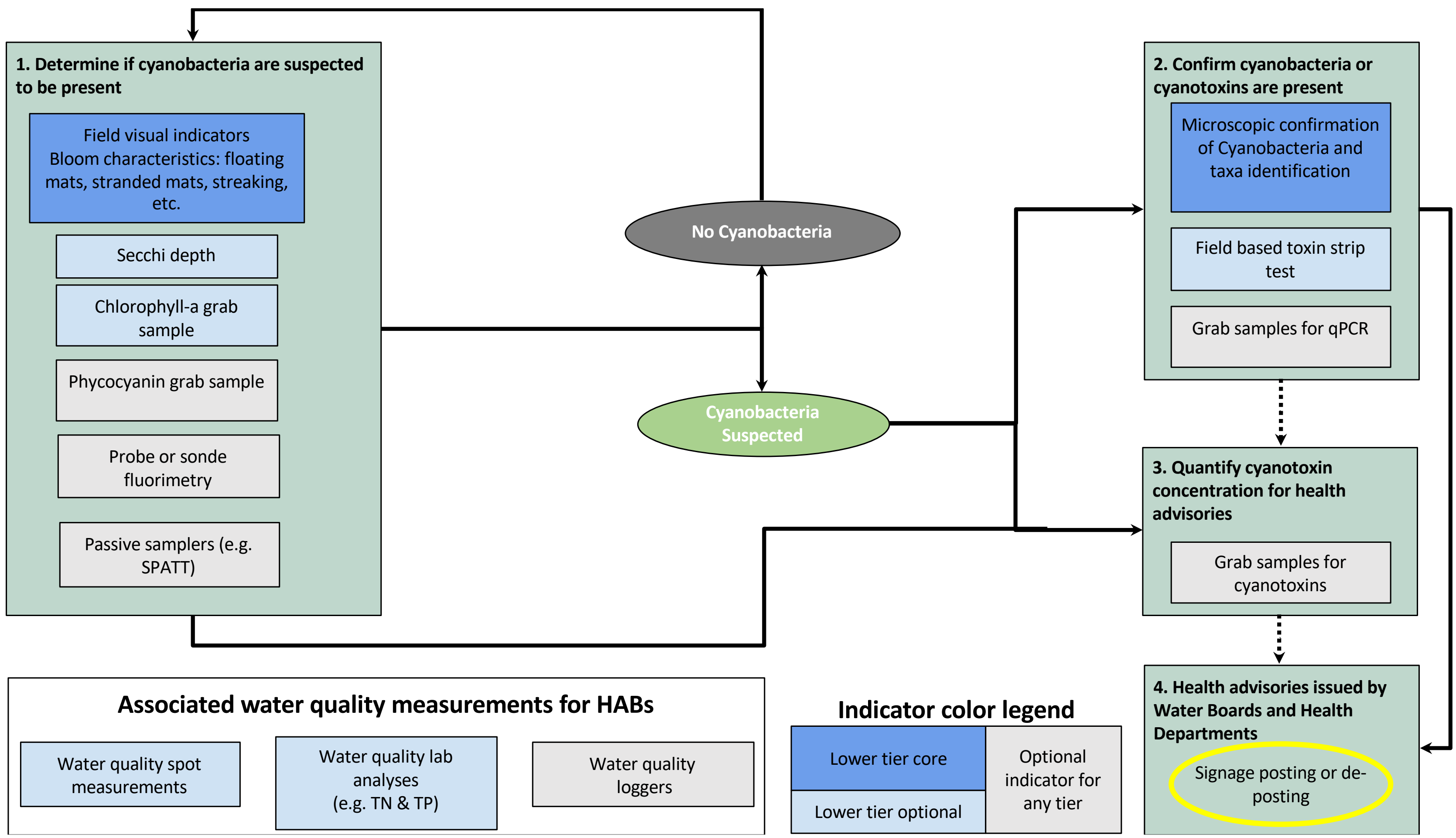


Figure 3.2. Flow chart of indicators recommended for a low resource partner monitoring program. Darker blue boxes are indicators that are recommended as core indicators for the high resource tier of the program, while light blue boxes are indicators that are optional indicators that provide useful contextual information about FHABs. Dashed arrow represent optional steps that would be conducted to be able to post a tier I (Warning) or tier II (Danger) advisory.

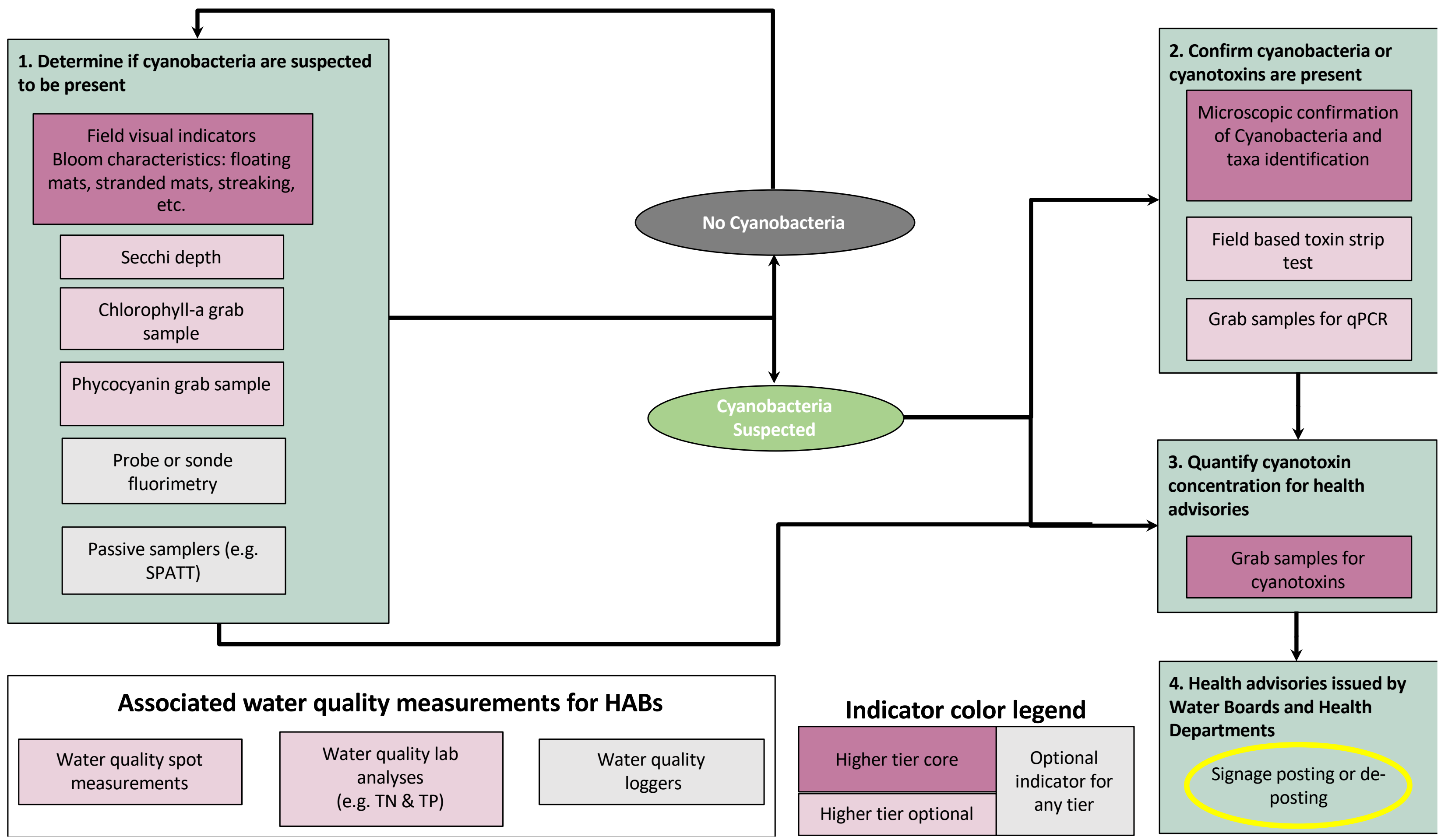


Figure 3.3. Flow chart of indicators recommended for a high resource partner monitoring program. Darker pink boxes are indicators that are recommended as core indicators for the high resource tier of the program, while light pink boxes are indicators that are optional indicators that provide useful contextual information about FHABs.

Additional indicators can also be beneficial to implement, as feasible, to provide additional contextual information about a potential bloom event and give the participant a better understanding of their system over time. A good example of this is chlorophyll-a or secchi depth which give context on how the water clarity in a lake is changing over time, which speaks to impacts on other beneficial uses such as aquatic life.

Higher Resource Tier Program. This tier was designed as an idealized program that is optimal for recreational health protection. This program was envisioned to be suitable for those partners that have internal laboratory capabilities and/or the capability to contract laboratories for analyses and that need robust assessments of FHAB status. This program has 3 core indicators: a visual biomass assessment, microscopic assessment of toxigenic cyanobacteria community composition, and cyanotoxin measurements (Figure 3.3). This program will provide a clear assessment of recreational risk based on toxins and will support accurate public health postings and de-postings (e.g., tiers I (Warning) and II (Danger), which are toxin-based postings) on a frequent basis. This will also provide the participant with a clearer understanding of the most prevalent toxins and causative organisms in their system and how these might change over time within their waterbody. This approach would provide a robust dataset to address status and trends of FHAB impairments to recreational uses based on all three indicators. Notably, the current cyanotoxin trigger levels are not protective of the health risked posed by benthic mats. Additionally, this higher resource program can be modified to address additional monitoring questions and focus on other core beneficial uses, which is discussed in Section 3.2.2 below.

Spatial and Temporal Design Considerations for Recreational Waters

Spatial Design. The target population of this program is recreational waterbodies of all types, including lakes, reservoirs, rivers, streams, and coastal confluences. In particular, the shorelines of recreational beaches of these waterbodies are prioritized as these locations represent where a majority of contact recreation would occur (Figure 3.4). Additional waterbody segments that are used in recreational fishing, boating, or other watercraft-based recreation are also included in the target population.

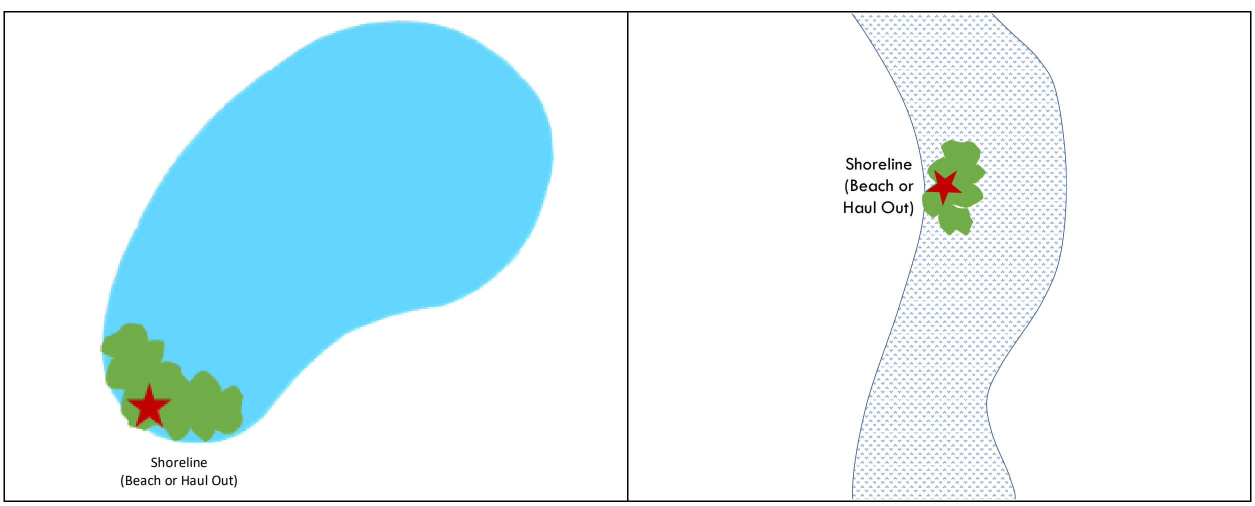


Figure 3.4. Examples of shoreline sampling locations in segments of a basin (e.g., lake or coastal river mouth, left panel) or a channel (e.g., river or stream, tidal channel) within a segment designated as a recreational-use area (see Section 4.1.1 for discussion).

This program recommends frequent sampling of core and optional indicators at one or more fixed stations, or index locations, to allow for robust determination of status and trends over time within the target waterbody (Figure 3.5). Shipboard stations in high-use areas can also be selected as fixed stations, but sampling from a vessel was assumed to be difficult for most agencies or would require the establishment of partnerships with the boating community in a given waterbody. Additional locations could be added ad-hoc in addition to but not in lieu of the routine fixed sampling stations, based on visual assessment of biomass. However, ad-hoc sampling locations provide less robust information for status and trends.

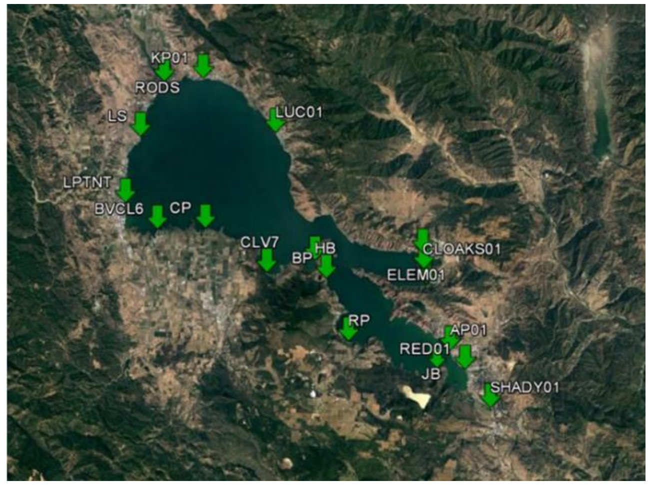


Figure 3.5. Examples of shoreline sampling locations in a large waterbody from Clear Lake's Recreational Monitoring Stations. Big Valley Band of Pomo Indians EPA

The total recommended number of fixed sampling locations varies depending on the waterbody size and should consider the high-use recreational shoreline within that waterbody for fixed stations. Ideally, a fixed station will be established on the shoreline of each known high-use beach or waterbody segment. At minimum, waterbodies should have at least one fixed sampling location that is measured on a routine basis. Larger waterbodies, such as large lakes, lakes and reservoirs with complex morphology, and rivers, will likely require a higher number of fixed stations to accurately assess recreational FHAB impacts, particularly since FHAB events can accumulate within specific regions (e.g., within a single lobe of a large lake, or within a swimming hole along a stream or river reach), resulting in a large amount of spatial heterogeneity. Under sampling a waterbody may poorly characterize recreational FHAB impacts. Under sampling could result in posting an advisory for an entire large waterbody when only a small beach segment was unsafe. Conversely, sampling a single location in a large waterbody could indicate that conditions are safe for recreation, but a bloom could be concentrated in a different region of the waterbody where conditions are unsafe for contact recreation.

Temporal Frequency of Sampling. Just as FHABs can be spatially patchy, there is also a large degree of temporal variation. Frequent sampling is required to adequately characterize risk to recreational use. While the TAC recognized that sampling frequency can rapidly increase the cost of a program, minimum frequencies were recommended to provide scientifically sound data related to recreational health impacts. The TAC recommended that sampling frequency could be modified based on the time of year in order to balance the need for data against cost. The highest frequency sampling was recommended during prime recreational months, regardless of resource tier. Prime recreational season statewide was identified as the period beginning two weeks before the Memorial Day holiday and ending two weeks after the Labor Day holiday. Within this period, the low resource program was recommended to sample a minimum of every 2 weeks although it was noted that FHABs can develop on shorter time scales (e.g., one week) and more frequent sampling is desired although possibly not feasible financially. The high resource program was also recommended to adopt a minimum frequency of every 2 weeks. In both resource tiers, it was also recognized that if an active bloom is detected, additional sampling events beyond the regular sampling schedule could be added to better characterize a bloom event. Following prime recreational season, year-round sampling was recommended for both resource tiers, but sampling frequency could be reduced to a minimum of monthly sampling of core indicators at the fixed sampling stations. Some waterbodies can experience year-round impacts FHAB events, therefore year-round sampling, even if at a reduced frequency, is recommended.

In situ continuous data measured via sondes are a convenient method to collect high frequency data on some FHAB responses and drivers. Examples of FHAB responses that can be routinely assessed with *in situ* probes include phycocyanin, chlorophyll-a and dissolved oxygen. Examples of environmental drivers include temperature, turbidity, light, water level and velocity, among others. Their advantages are many: 1) capture FHAB responses that can vary on the order of hours, days, weeks to seasons, 2) these data streams can be compared against environmental drivers of variable frequency, 3) innovations have made their use fairly streamlined without requiring a high level expertise and they can be visualized in real time through telemetry networks, 4) beyond the capital cost of purchasing and recurring costs of calibrating and maintaining the probe, costs for discrete sample analyses are not incurred. Disadvantages can include: 1) high capital costs, depending on the parameter of interest and the deployment environment, 2) instrument data can drift out of calibration, so frequent attention and maintenance is typically required, and 3) comparing data among multiple sondes is difficult and requires extensive inter-calibration.

3.2.4 Partner Program Design Elements: Other High Resource Modules

The higher resources module could be adapted to focus on additional beneficial uses or on assessing environmental drivers. The previous section highlighted how a recreational health program could be implemented for comparative purposes against the lower resource program. The key differences in these programs were the indicators, which allowed for different questions to be addressed. Similarly, additional indicators can support the goals of the partner agencies to address additional **specific monitoring questions** about the impacts of FHABs on other core beneficial uses or the basic drivers of FHAB events within a specific waterbody. Pairing one or more core FHAB indicators from the recreational health focused module with additional metrics (for example, the additional water quality indicators on Figure 3.2.2) can provide a better understanding of additional FHAB impacts or the environmental conditions within the system that are related to FHAB events. These additional monitoring questions that could be addressed are:

- *Are FHABs making fish and shellfish in my waterbody unsafe to eat?*
- *Do FHABs negatively impact aquatic life in my waterbody?*
- *Is the quality of the raw drinking water in my waterbody impacted by FHABs?*
- *What environmental factors in my waterbody are most commonly associated with FHABs?*

Indicators and Metrics: Other High Resource Modules

The higher resource module could include many of the different metrics shown in Table 2.5. These data which would be useful to the State and should be supported by the infrastructure development elements (field and lab SOPs, program documentation, data management, training, intercalibration and reporting) that are proposed in Section 3.2.5 below.

Other Beneficial Uses. Fishable beneficial uses could be assessed by partner agencies most directly through the measurement of cyanotoxins in fish or shellfish tissue, which is discussed extensively in Section 4.1.2. FHAB impacts on **Aquatic Life and Raw Water** can be assessed with many of the same indicators used to assess human recreational health impacts (e.g., toxigenic cyanobacteria community composition and cyanotoxins). A variety of other indicators could be added to assess impacts on these uses, but some readily accessible metrics include secchi depth, chlorophyll-a concentrations, taste and odor compound concentrations, and dissolved organic carbon.

Environmental Drivers. A true driver assessment for FHABs would be highly labor intensive and a wide array of metrics would need to be measured. Fundamentally, questions about "what are the factors related to bloom development, toxin production, and bloom frequency and duration in my waterbody?" are relatively complex and are best addressed with specific research studies. However, more basic, causal relationships within a waterbody can be addressed by pairing additional water quality indicators to the core FHAB recreational health indicators. These data are valuable to both the state as well as to the participants since ultimately, these data will allow for waterbody managers to pursue informed bloom mitigation actions and compare the conditions of their waterbody to those of other similar waterbodies.

Spatial and Temporal Design Considerations: Other High Resource Modules

The spatial and temporal design considerations of approaches focused these uses were not explicit conversations of the TAC and were deprioritized for this phase of the strategy development. These elements, along with specific SOPs for additional indicators relevant to waterbody-specific assessments of status, trends, and environmental drivers should be developed through a special study **(SS6, Appendix 6)**.

3.2.5 Entity Responsibilities

Lead Roles and Responsibilities

This program is envisioned as a partnership between the State Water Board and partner agencies; therefore, a clear identification of the lead versus partner roles and responsibilities was developed by the TAC. The State Water Board would be the lead overseeing this program and therefore has specific responsibilities related to providing support personnel, training and certification, SOPs, and program infrastructure related to data management and visualization. The number of dedicated support staff required will depend on the overall number of participants in the partner program. Dedicated staff could be at the State Water Board level and depending on the amount of participation within a given region, a dedicated Regional Water Board staff member was also envisioned.

Lead personnel will need to support the participant recruitment and enrollment process. State Water Board staff should prioritize the recruitment of participants to monitor high recreational use waterbodies, as these pose the greatest potential human and animal health risks. Initial recruitment could be informed by the Incident response program, since continued ambient monitoring of waterbodies with reported events was identified as a key strategic element in the 2016 assessment and support strategy. Satellite observations could also support identification of priority waterbodies.

Enrollment of partnering agencies in the program was envisioned to involve an initial design consultation process (as mentioned in the sections above) where the waterbody-specific spatial and temporal design elements and indicators would be decided upon based on participant resource levels following the guiding principles outlined above. These would be written into a waterbody-specific monitoring plan that would be mutually agreed upon by the lead and the participating agencies or organizations.

Although this program assumes basic training and experience with water quality monitoring procedures, it does not assume FHAB-specific experience. Some training and certification will be required for participants to ensure that high quality, comparable data are produced by the participants of this program, particularly if data are eventually going to be used for management decisions within that specific waterbody or region (which is an ideal outcome). The State Water Board will need to provide support for training and certification when participants enroll in the program, as well as “continuing education” on regular intervals to continually ensure data quality. Participation in training exercises could be developed to meet the state standard for education credits. Specific training of FHAB related indicators will likely include regular training sessions on toxigenic cyanobacteria taxonomy and taking photographs with a microscope since a core indicator is microscopic identification of key FHAB genera. Additional checks of this data, such as agency staff verifying pictures, should also be considered. Intercalibration exercises should be conducted on a routine basis for key indicators (e.g., cyanotoxins) in which the analyses are conducted within the participant’s laboratory or by laboratories contracted by participants.

The program lead should consider providing other infrastructure that would both support the quality of data generated by the program and promote the recruitment and retention of partners. Beyond the staff and training infrastructure considered by the TAC was the potential to enhance the partner program via supplying core equipment to participants and/or providing support for sample analysis of priority analytes. Core equipment could be supplied, in a prioritized manner, to agencies with a demonstrated resource need that could sample in a priority waterbody. One core piece of equipment that could be provided to partners is a microscope suitable for the microscopic characterization of FHAB community composition. Other supplies that could be strategically supplied are toxin dip sticks or other similar semi-quantitative field-based toxin tests. A final consideration would be to support sample analysis for priority analytes, such as cyanotoxins. Waterbodies for which analytical resources should be prioritized could be determined by previous reports of blooms in that waterbody from the incident response program or by providing analytical support to agencies that manage recreational waterbodies in low resource communities.

Data management infrastructure and IT resources will need to be supported by the program lead. Data management includes developing a user-friendly data submission portal for participants and involving multiple quality assurance checks on all submitted data to prevent data with keystroke errors from being entered into the database. Once submitted, data should be securely stored and archived by the program lead. It is recommended that the data management infrastructure should also provide data visualization and interpretation functionality for participants.

Retention of partners can be accomplished via some of the agency support elements described above, such as training and certification on a regular interval, providing data management, IT, and data visualization services via a centralized web tool. Any lead agency analysis of waterbody data should be shared with participants and any reporting should acknowledge the work or partnering agencies. Retention can also be promoted by providing supplemental equipment such as microscopes or supplemental analytical services or supplies such as support for toxin analysis or a yearly stipend of field toxin dip sticks.

Partner Agency Roles and Responsibilities

Partner agencies are envisioned to include a variety of agencies; therefore, consideration of previous training is important. For local, state, and federal agencies, training in basic best practices in water quality sampling could be determined based on job title classifications. In the case of NGOs that would involve a mix of NGO staff and community scientists, training would be a focal point to ensure capacity during the enrollment process.

Partners would participate in the enrollment process and collaborate with the lead agency to develop the waterbody-specific program. The partner agency would propose a design that could be sustained for the duration of the commitment period. Partners would also be responsible for participating in all trainings and certifications provided by the program lead to assure the generation of high-quality data. Towards that end, participants would receive sampling and analysis SOPs. Additionally, participants would participate in all continuing education, recertification, and intercalibration exercises to ensure data quality. Participants would be responsible for conducting sample and data QA/QC prior to submission.

Participants will be provided data submission and management infrastructure by the lead agency. The program participants will be expected to submit data to the lead agency through this infrastructure in a timely manner, particularly if recreational health posting might be needed.

3.2.6 Implementation Plan Components: What Is Needed?

A special study would be needed to develop the implementation guidance to administer the FHAB partner program, including standardized protocols and documentation, training and intercalibration, data management, and data visualization/reporting (**SS0, Appendix 6**). These components are discussed in detail below.

Standardized Protocols and Documentation

A fundamental component of this program is the development of standardized protocols and documentation that can be consistently applied by all participants. A Quality Assurance Project Plan (QAPP) and standardized protocols need to be developed for the collection of all measurements in the program and provide waterbody-specific collection protocols for shoreline and index sites. These protocols may not align with existing monitoring efforts at a given waterbody and specific guidance for addressing such differences needs to be developed to guide when and how exceptions to the program SOP can be made. These protocols and documents include a comprehensive field collection SOP, standardized data sheets, and SOPs for all field-based measurements. Standardized sample handling and analysis protocols and quality assurance documentation is also needed for all laboratory analyses within this program. Lastly, documentation will need to exist for data submission for all core and optional indicators.

Since the 2016 Assessment and Support document was drafted, SWAMP has developed multiple field sampling protocols used for agencies responding to FHAB events (https://mywaterquality.ca.gov/habs/resources/field.html). Some of these could be adopted into this program; however, SOPs are not currently developed for all potential indicators described in this program. Collectively, SOPs for the sampling of all recommended indicators need to be developed and officially adopted to support a partner program and should also be used by other field-based programs supported by the state (e.g., Incident response and any state supported ambient FHAB surveys). Together, the development of sampling and analysis SOPs for this program need to be developed into comprehensive Field and Laboratory Manuals and should be prioritized as a special study to develop the entire suite of protocols needed to underpin this program (**Appendix 6**).

Training & Intercalibration

Training for sample collection and analysis is critical to the success of this program. Although the participants are assumed to have basic experience, conducting training on the FHAB specific components of the program will ensure high quality data. Training can take multiple formats for training field protocols. Other multi-agency ambient programs such as the Southern California Stormwater Monitoring Coalition (SMC) and the Southern California Bight Regional Monitoring Program have in-person field crew training for new crews, followed by a less extensive annual short form training exercises including field crew audits and intercalibrations exercises (Mazor 2015). This model has proven successful for these programs in generating high quality, comparable data, and is recommended to be adopted within this program.

All 3rd party laboratory analyses (either those conducted by professional contract laboratories or directly in the laboratories of participants) will require a training program via a combination of in-person and remote training. Following an initial, more intensive training, less extensive annual short form training including laboratory audits and intercalibrations exercises should be conducted, similar to the training provided for field analyses. Specific laboratory indicators that will require training are cyanobacterial taxonomy since this is a core indicator for all program participants. Taxonomy training can be provided via in-person workshops as well as remote training sessions customized to the participant. SWAMP has an existing FHAB training program that could be expanded and leveraged. Other programs that use multiple agencies include the Phytoplankton Monitoring Network, which provides continual training on taxonomy to ensure data quality (Morton and Gano 2015).

Intercalibration exercises are key to high data quality and provide opportunities for continued education and specific exercises should be developed for planktonic and benthic HABs. Intercalibration exercises should be conducted on a regular basis for all core indicators. The frequency for which optional indicators should be calibrated across agencies should be at the discretion of the lead agency based on how many total participants elect to provide data for these parameters. Intercalibration exercises will need to be implemented by the lead agency or a designee of the lead agency and should follow the model of intercalibration exercises conducted by other multi-participant ambient monitoring programs such as the SMC and the Southern California Bight Regional Monitoring program. Intercalibration exercises will need to be conducted following a variety of approaches depending on the indicator and will include measurement of standardized reference materials, such as matrix spikes, for indicators where reference materials are available such as cyanotoxins. Other indicator types such as cyanobacterial community composition a different approach such as conducting a round-robin analysis by multiple labs on splits of an environmental sample. Specific protocols for conducting intercalibration exercises will need to be included in the quality assurance documentation.

Data Management

Standardized data submission protocols need to be developed for all FHAB indicators to optimize the management of data generated by all participants of this program. It is recommended that each participating agency should identify a point person that will be responsible for data submission generated by their agency. The lead agency should provide training and documentation for data management and submission. Ideally, data are submitted within a single portal that is optimized for easy data upload, as participants are asked to upload data regularly. The lead agency should develop data submission templates and workflows to streamline the data submission process, making data submission as simple as possible for participants. All indicators should have a single, designated unit (e.g., all total toxin concentrations are provided in micrograms per liter) and it is recommended that the data submission process, wherever possible, should include automated QA/QC for all measurements to flag data that may have keystroke errors. Data records should be maintained and stored by the lead agency, and participating agencies would also be recommended to store their site-specific data.

Communication, Data Visualization, and Reporting Frequency

The data generated by this program is meant to be publicly available for science and management applications. Data from this program is envisioned to be open and freely available to the public. Data products will be communicated using a variety of approaches including: 1) "real-time" summary graphics and waterbody-specific graphics generated through an interactive website and 2) summarizing findings in a report format, e.g., report cord or some other format. Reporting on the impacts of FHABs in all participating waterbodies could be summarized in annual reports published by the lead agency on a 1- to 2-year interval. This type of report would summarize the findings for individual waterbodies and could contextualize the conditions of the individual waterbodies against all participating waterbodies on a regional, watershed, and statewide basis. This type of report could also be integrated with data from other ambient monitoring programs such as satellite-based observations. Data can also be made available in a raw format for use in reporting by other agencies and to be drawn into and distributed in existing data portals.

A key potential benefit of an FHAB Partner program is the ability to visualize and report on waterbody-specific status and trends, particularly if given within the context of other waterbodies in the region or state (see inset box: **The Power of Comparative Assessments: Beach Report Card Example**). Section 3.1 provides examples of what these key graphics currently look like with existing remote sensing approaches (Figure 3.1). Section 3.2 provides discussion of the types of assessment questions and key graphics that would be generated for an individual waterbody under the low resource and high resource program requirements. Generically, examples of such questions include: *"Last year, how often was my beach closed by FHAB for recreational use?"* or *"How have my actions at site X changed FHAB risk over time?"* Beyond generating graphics on their own waterbodies, one of the major motivations for agencies to participate in a statewide or regional monitoring programs is to have the ability to compare the monitoring sites within their jurisdiction against that of the resource base as a whole. This answers the types of question, such as: "*Which beach should I go to that has the least risk of FHABs*?" or "*How does my site(s) compare to others in the county, region, or state?*" or *"Are my sites the worst in the county, region, or state and therefore need to be prioritized for action?"*

The Power of Comparative Assessments: Beach Report Card Example

Heal the Bay's (HTB) beach water quality report card illustrates the power of comparative assessments of a 3rd party monitoring program. HTB's health grades are used either as a point of pride for a county or city (e.g., consistent high-quality scores could be advertised to draw tourism) or used to motivate local action due to consistent low quality scores (e.g., beach bummers) or even to shine a spotlight and applaud where improvements have been made (e.g., Colorado Lagoon). Many local agencies further publicize these report cards to the public. Inland recreational use water quality graphics could be produced from a high-resource voluntary program for river recreational beaches, allowing individual beach grades to be contextualized within a county wide sampling of beaches.

Honor Roll	Summer Dry	Winter Dry	Wet Weather
Malibu, Las Tunas County Beach	A+	A+	A+
Cabrillo Beach, ocean side	A+	A+	A+

Beach Bummers	Summer Dry	Winter Dry	Wet Weather
Mother's Beach, Marina del Rey	D	F	F
Long Beach, projectioon of Coronado Avenue	F	B	F
Cabrillo Beach, harborside at restrooms	D	F	F

Example of the "honor roll" beaches with high quality health grades and "beach bummers" with poor health grades. Source: HTB 2019.

	2018-19			2017-18			2016-17			2015-16			2014-15			2013-14		
	Summer Dry	Winter Dry	Wet Weather	Summer Dry	Winter Dry	Wet Weather	Summer Dry	Winter Dry	Wet Weather	Summer Dry	Winter Dry	Wet Weather	Summer Dry	Winter Dry	Wet Weather	Summer Dry	Winter Dry	Wet Weather
Colorado Lagoon - North	A	B	C	A	B	D	n/a	n/a	n/a	A	A	F	A+	A+	F	A	A+	F
Colorado Lagoon - South	A	C	F	A	B	F	n/a	n/a	n/a	A	A+	F	A+	A+	F	A	A	F

Example of how monitoring data can show improvement in health grades over time: Spotlight Colorado Lagoon improvements in dry weather. Source: HTB 2019.

Los Angeles County Grades	2018-2019						5-Year Avg. (2013-2018)					
	Summer Dry*		Winter Dry		Wet Weather		Summer Dry*		Winter Dry		Wet Weather	
	#	%	#	%	#	%	#	%	#	%	#	%
A	76	85%	51	55%	21	21%	78	87%	63	75%	31	35%
B	5	6%	14	15%	9	9%	6	7%	9	11%	10	11%
C	5	6%	19	20%	8	8%	2	2%	5	6%	8	9%
D	2	2%	3	3%	6	6%	2	2%	2	2%	5	6%
F	1	1%	6	6%	55	56%	2	2%	5	6%	35	39%
Total	89		93		99		89		84		89	

Long Beach Grades	2018-2019						5-Year Avg. (2013-2018)					
	Summer Dry*		Winter Dry		Wet Weather		Summer Dry*		Winter Dry		Wet Weather	
	#	%	#	%	#	%	#	%	#	%	#	%
A	10	59%	8	53%	0	0%	11	77%	9	64%	0	3%
B	2	12%	3	20%	0	0%	3	18%	3	22%	0	0%
C	3	18%	4	27%	0	0%	1	5%	1	10%	0	3%
D	1	6%	0	0%	0	0%	0	0%	0	3%	1	4%
F	1	6%	0	0%	17	100%	0	0%	0	1%	13	90%
Total	17		15		17		15		15		15	

Example of a comparative report card that could be produced for FHAB recreational use impacts on river, lake and reservoir beaches for City X within a County Y. Source: HTB 2019.

Data from the partner program is envisioned to be shared within the existing FHABs portal for incident response or in a similar platform which is publicly available and updated regularly to be used for determining impacts of FHABs on recreational activities. Outreach activities should be prioritized to increase public awareness of these resources as they become available. Toxin data are most clearly interpretable by the public as these data translate to a recreational advisory and can be displayed following the same conventions already implemented in the existing FHABs portal. The TAC had concerns about how to disseminate data related to community composition and visual indicators in a public database in a way that the general public would be able to interpret about overall FHAB risk in a waterbody. Data such as percent cover or photographs could also be useful to the public since these data relate to potential aesthetic impairments but is not as easily interpretable to communicate risk to public health. One solution discussed was that this data could be summarized by a single recreational HAB index that could be interpreted like the caution, warning, and danger advisories for locations where only observational indicators are collected by partners, which would need to be developed as a special study (**SS1, Appendix 6)**.

3.2.7 Tribal HAB Monitoring Programs are a Unique Partnership Opportunity

Tribes are sovereign nations that are self-governing, and many tribes have developed their own water monitoring programs. The Water Boards and other public agencies should prioritize empowering and collaborating with tribes to monitor FHABs, particularly as it pertains to FHAB impacts on Tribal and Cultural Uses (**Figure 2.3, SS2, Appendix 6**). Ultimately, tribal monitoring programs are established by tribes for the benefit of tribal members. The program designs developed by each tribe are focused on specific questions and concerns by a given Tribal Government and are centered around that Tribe's values and priorities. Collaboration and sharing of monitoring data with the State should not be assumed; however, many tribes conducting water quality monitoring would like to see their data being used in management decisions and welcome collaborations to achieve shared goals towards improved water quality.

Invest in Tribal partnerships for FHABs monitoring

Tribes are promising partners for FHABs monitoring. With mandates to protect the public and environmental health of their members, many tribes have robust water quality monitoring programs and are exceptional environmental stewards. Currently, there are 56 tribes monitoring water quality in California, though few include FHAB indicators. Beyond the spatial coverage of tribal data, it is of high quality with federally required Quality Assurance Project Plans (QAPPs) written for each monitoring project. Working closely with State and local agencies, tribal governments can help expand the resources available for FHABs monitoring. The addition of FHABs data collected by tribes into State databases would help fill data gaps for waterbodies with minimal monitoring by other entities. This key partnership would provide better information to guide management decisions and improve water quality protection. Considering tribal partnerships should be central to all FHAB monitoring programs at the State, regional, and local scales.

3.2.8 Summary and TAC Recommendations: FHAB Partner Monitoring Program

The TAC strongly recommends developing and implementing an FHAB Partner Monitoring Program to enhance our ability to assess status, trends, and drivers. Eight recommendations and related special studies were promoted by the TAC for consideration to prioritize in the Strategy.

Table 3.4. Summary of specific recommended actions and special studies developed by the partner monitoring TAC.

Specific Recommended Actions	Special studies
Identify scope, scale, and budget of FHABs partner program focused initially on recreational and fishable uses. Decide what level of resource investment to support partner efforts is sustainable.	Proactively identify partners, focusing on tribes, communities of color and economically disadvantaged groups (SS1)
Develop infrastructure to support the program, e.g., write SOPs and sample design documents for partners, develop training modules. Engage with existing state/regional programs to pursue opportunities to incorporate FHAB indicators	Develop the partner program implementation guidance components (SS0) Develop a recreational HABs Risk Index based on visual indicators (SS2) Develop cyanotoxin triggers appropriate to assess risk of impacts of FHABs to tribal, cultural uses including subsistence fishing (SS3) Develop an algal condition index for lakes, reservoirs and estuaries and an FHAB specific component for routine application in waterbody assessment. (SS19-21)
Inventory recreational and fishable use sites and identify where monitoring partners and interest already exist	
Create data management and visualization infrastructure, including means for partners to rapidly visualize their data	Develop partner program open data systems (SS4) Determine user needs for FHAB decision support systems (SS5)
Recruit and train partners	
Dedicate staff at SB and RB to coordinate program	
Continued funding of supplies and data management identified above	
Expand infrastructure for partner program to address other beneficial uses and incorporate environmental drivers	Develop partner program elements for additional beneficial uses (SS6)

3.3 State-Coordinated Field Surveys

3.3.1 Motivation and Goal for State Coordinated FHAB Field Surveys

Ambient field surveys have been the cornerstone of national, state, and regional programs across the U.S. California has experience implementing various types of ambient field surveys, from targeted to probability-based, to support a variety of management questions for different waterbody types and spatial scales, from statewide, regional, and watershed scale. These state-coordinated ambient field surveys have a proven track record of cost-effectively addressing management questions and associated information needs related to status and trends and environmental drivers of FHAB blooms and associated toxins (Table 3.3).

Table 3.5. The management questions (status, trends, and environmental factors) and management information needs that could be addressed by state-directed field surveys at a statewide, regional, or watershed scale.

Category	Statewide, Regional, or Watershed Scale (State-directed)	
	Management Questions	**Examples of Information Needs That Are Supported by Monitoring**
Status	What is the overall magnitude and extent of FHABs within the state, its regions, or a watershed scale?	Prioritize watersheds or waterbodies 305(b) report Briefings for Legislature and State Water Board Status and trends report to public on MyWaterQuality portal
Trends	How are magnitude and extent changing over time?	
Environmental Driver (Natural or Human)	What are the major drivers of FHABs across waterbodies or within a watershed?	Biostimulatory objectives and implementation policy Environmental flow policy State/regional NPS control strategies Irrigated lands program/Ag waiver requirements

The goal of implementing field surveys is to provide information on the status and trends of FHABs impacts on core uses and drivers of FHABs in Californian surface waters. These data would inform actions such as: 1) 305(b) report and decisions on 303(d) listing, 2) briefings for Legislature and State Water Board, 3) decisions on triennial review priorities for Basin Plan objectives, biostimulatory objectives and implementation plan, point and nonpoint source control strategies, environmental flow policies, 4) allocation of monitoring or staffing resources, and/or monitoring orders to support heathy watershed initiatives, and 5) TMDL studies, permitting actions, or other management actions. Currently, the overall status of FHABs is not known in the majority of waterbodies in California. FHABs are anticipated to increase due to increasing eutrophication, hydrodynamic modifications, and warming due to climate change. FHAB trends analyses are not feasible with data from the incident response program, nor is it possible with data derived from waterbody-specific monitoring around the state.

3.3.2 TAC Deliberations on Field Surveys

FHABs present a unique monitoring challenge compared to other statewide SWAMP surveys meaning any statewide survey would need to be specifically designed to address FHABs. TAC discussions of the ambient monitoring considered what approaches might be appropriate to improve ability to answer statewide, regional or watershed-scale status and trends, and environmental drivers. The approach described in Section 1.6 was useful to structure TAC discussions; monitoring objectives, spatial and temporal design considerations, important indicators, desired key graphics to communicate findings, and opportunities for coordination and leveraging of existing resources were explored. For status and trends, discussions of appropriate indicators and sampling approaches were specific to core uses (swimmable, fishable, aquatic life, and raw drinking water source). For both status/trends and environmental drivers, specific indicators and design considerations were discussed by waterbody types and this information is summarized for status/trends for the core uses (Chapter 4) and environmental drivers (Chapter 5); some survey designs integrate status, trends, and drivers, and are presented in Chapter 5.

An assessment the impacts of FHABs on recreational uses in inland water beaches and shorelines was designated by the TAC as the highest priority of an integrated FHAB monitoring program. The results of such monitoring speak to the heart of a key issue with FHABs: *Is the public health of Californians and their domestic animals (dogs and livestock) being endangered through recreational contact with FHABs in our lakes and reservoirs, rivers and streams, and coastal beaches?* Several optional approaches were considered for field survey designs to address recreational use (see Section 4.1.1, Chapter 4). The relative merits of targeted and high frequency intensive surveys versus probability-based, statewide surveys designs were discussed (see inset: Targeted Versus Probability Based Survey Designs). The intent of recreational use targeted surveys is to frequently measure FHABs in order to <u>assure the protection of public health</u>. Surveys across waterbodies are intended to report out how FHABs are impacting recreational use across the state, but because of the spatial scale being assessed, they cannot assess frequently enough to assure that public health in sampled waterbodies are being protected. This is a fundamental tradeoff for managers to consider and considerations for the selection of priority waterbodies is discussed in Chapter 4. The TAC recommended a high frequency sampling design in order to protect public health. We note that these approaches are not mutually exclusive; some hybrid versions could be considered.

Targeted Versus Probability Based Survey Designs

There is a long-standing tradition in environmental monitoring to use sampling designs based on directed or targeted site-selection. Targeted designs are well-suited for documenting condition or trends at a specific location and are commonly used in compliance monitoring. Water Board staff has used this approach to allocate limited monitoring resources toward areas of known or suspected impairment. This tendency to monitor problem areas is extremely useful for identifying candidates for Water Board action. However, targeted data often are not representative of the overall condition of a resource. Comparisons of results from targeted and probability-based stream surveys indicate that targeted monitoring tends to be strongly biased toward assessing impaired areas (Rehn and Ode 2009).

In probability surveys (also known as sample-surveys or statistical surveys), sampling sites are selected randomly. Each sampling site represents a specific portion of the total resource or population of interest such as all stream length or all lakes and reservoirs. Because of the statistical nature of site selection, results from the sample population can be extrapolated to the entire population. For this reason, probability surveys are well suited for making unbiased assessments of the condition of an entire resource across large geographic areas without monitoring every waterbody. Probability surveys are not designed to supplant targeted monitoring designs but to provide context for their interpretation. For example, some designs combine probability and targeted designs to provide managers with information on the condition of the entire watershed and to put local monitoring results into a watershed perspective. At the statewide level, resource managers can use information from probability based to identify significant patterns and prioritize restoration and protection efforts. However, the cost-effectiveness of probability-based designs are typically based in an approach of a single sampling event during an index period, an approach that in the past has under-characterized risk from FHAB toxins.

Surveys for other core uses (fishable, aquatic life, raw source water protection, tribal) were not discussed in detail by the TAC. The design fundamentals discussed in Chapter 4 are sourced from literature and comparable state programs. The TAC did agree that, because of the expense, fishable FHAB toxin surveys should only be prioritized where FHAB problems are known to occur.

Leveraging existing ambient monitoring to address FHAB management questions is an important opportunity to more cost-effective monitoring. Opportunities to leverage existing programs are explicitly considered (Table 3.6) and discussed in Chapter 4 (status and trends) and 5 (environmental drivers). Within Chapters 4 and 5, a general orientation of the intent and major components of the survey and presented specific design elements are discussed in order to clarify the utility of potential leveraging opportunities. Options for partnering on these existing monitoring programs exist, ranging from: 1) acquire data, since information on FHABs is already being generated, 2) add or modify SOPs used to maximize data on FHABs (e.g., add toxin measurements, etc.), 3) increase frequency of sampling at locations already designated by the partner program, and 4) add new locations to sample to intensify spatial characterization. In some cases, data on FHABs are already being generated and thus can already be used to report on FHABs (e.g., National Aquatic Resource Surveys, SWAMP wadeable stream perennial stream survey, and reference condition monitoring program), though caveats exist regarding the interpretation of these data generated through single sampling event assessments. The TAC did not discuss in detail these leveraging opportunities and thus had no recommendations regarding their priority in the strategy.

Table 3.6. Partial list of statewide field surveys considered for potential partnerships to conduct FHABs monitoring. CDPH = California Department of Public Health. US EPA = U.S. Environmental Protection Agency, Headquarters. Other regional surveys such as those by DWR, CDFW, DBW, USBR, NOAA, etc. can also be considered

<table>
<tr><th>Type(s)</th><th>Program or Survey Name</th><th>Lead Agency</th><th>Applicable Waterbody Type</th><th>Section(s)</th></tr>
<tr><td rowspan="2">Recreational Use</td><td>Beach Safety Monitoring Program-AB 411 (1997)</td><td>State Water Board</td><td>Coastal Confluences</td><td rowspan="2">4.2</td></tr>
<tr><td>Pre-Holiday FHAB Recreational Use Assessment</td><td>State Water Board</td><td>Rivers, Lakes and Reservoirs</td></tr>
<tr><td rowspan="2">Fishable Use</td><td>SWAMP BOG Mercury “Bass Lakes” Survey</td><td>State Water Board</td><td>Lakes and Reservoirs</td><td rowspan="2">4.2</td></tr>
<tr><td>Marine Biotoxin Monitoring Program</td><td>Calif. Department of Public Health</td><td>Coastal Confluences</td></tr>
<tr><td rowspan="3">Aquatic Life

Raw Drinking Water Source Protection

Environmental Drivers</td><td>SWAMP Wadeable Stream Bioassessment—Reference and Perennial Stream Survey</td><td>State Water Board</td><td>Perennial wadeable streams</td><td rowspan="3">4.2

5</td></tr>
<tr><td>Stream Pollution Trends Program (SPOTS) Survey</td><td>State Water Board</td><td>Large Rivers (wadeable and non-wadeable)</td></tr>
<tr><td>National Aquatic Resource Surveys</td><td>US EPA</td><td>Rivers, streams, lakes and reservoirs</td></tr>
</table>

3.3.3 Summary and TAC Recommendations: Field Surveys

State coordinated field surveys of FHAB status, trends, and drivers are by far the most costly of the three approaches (relative to remote sensing and FHAB Partner Monitoring Program), but also have the potential to specifically address pressing Water Board management information needs regarding public health protection and water quality management. The TAC prioritized the development and implementation of a recreational use field survey in inland beaches and shorelines across the state (lakes, reservoirs, rivers, and some coastal confluences). Leveraging opportunities exist to extend the assessment of FHAB status, trends, and drivers to other core uses; these opportunities need to be weighed against the cost of leveraging, given available resources for the program. The details of these options are explored at length in Chapter 4 and Chapter 5 of this report.

4. APPROACHES TO MONITOR STATUS AND TRENDS OF FHABS

This chapter presents the basic monitoring principles and designs that could be used to assess statewide or regional status and trends of FHAB impacts to each of the core uses: swimmable, fishable, aquatic life, and raw water source protection. For each use, two components are presented. First, **priority indicators** and **spatial and temporal design considerations** that are broadly applicable to both **statewide/regional** and **waterbody-specific monitoring** are discussed as part of core implementation guidance. Second, we present **options** for how the State Water Board could implement these concepts in **specific survey designs** and **identify leveraging opportunities** with other existing monitoring programs that can be used to cost-effectively answer the question of status and trends. The potential contributions of both the state-implemented FHAB monitoring program and partner monitoring to describing status and trends will be considered.

The monitoring objective of statewide or regional status and trends assessment is to assess the status and trends of FHAB impacts on swimmable, fishable, aquatic life, and raw (drinking) water source uses of California lakes, streams, rivers, and coastal confluences. At the state level, information from status and trends are used in briefings for Legislature and State Water Board, which can further direct resources towards FHABs monitoring, management, and mitigation strategies (Table 4.1). Examples of these types of management decisions and actions include 1) triennial review priorities for Basin Plan objectives, 2) biostimulatory objectives and implementation planning, 3) implementation of point and nonpoint source control strategies, 4) environmental flow policies, and 5) allocation of monitoring or staffing resources and/or monitoring orders to support heathy watershed initiatives, actions taken to address 303(d) listing including TMDLs and implementation plans, permitting actions, or other management actions that can help to remediate HAB problems.

Table 4.1. Recap of management questions and information needs supported by status and trends assessment.

Category	Statewide, Regional, or Watershed Scale (State-led)		Individual Waterbody (3rd Party Monitoring)	
	Management Questions	**Examples of Decisions That Are Supported by Monitoring**	**Example of Parallel Management Questions**	**Examples of Decisions That Are Supported by Monitoring**
Status	What is the overall magnitude and extent of FHABs within the state, its regions, or a watershed scale?	Prioritize watersheds or waterbodies 305(b) report Briefings for Legislature and State Water Board Status and trends report to public on MyWaterQuality portal	Are FHABs degrading water quality in the waterbody and what is the timing of when FHABs occur	303(d) listing TMDL compliance Catchment conservation/ protection
Trends	How are magnitude and extent changing over time?		Are FHAB in the waterbody/watershed getting better or worse over time?	

At a waterbody-specific scale, the monitoring objective of a waterbody-specific assessment is to inform waterbody managers and the interested public whether a waterbody in their watershed/region has a problem, the timing of FHAB occurrence, and whether it is getting better or worse over time. Examples of actions that are informed by this information: 1) waterbody posting and de-postings of public health advisories, 2) public support and motivation of public elected officials to investigate causal factors and seek management actions and/or solutions to reduce FHABs. Example actions include 303(d) listing and subsequent management actions, TMDL, basin stormwater and NDPES permitting, etc., nutrient source control and BMPs, hydromodification retrofits, catchment stream and floodplain restoration actions, land conservation actions or improved management practices (etc.), waterbody FHABs mitigation measures (e.g., aeration, etc.), and 3) Waterbody managers can assess the monitoring data to develop mitigation strategies for FHABs in their waterbodies.

4.1 Basic Survey Design Concepts to Assess Status and Trends

4.1.1 Swimmable Uses

Swimmable includes many contact and non-contact recreation uses of waterbodies. Recreational uses are impacted by both planktonic and benthic FHABs through a variety of pathways (Figure 2.2). Direct impacts to the health of humans, pets, and other domestic animals health (REC1 and tribal and cultural uses) from toxin exposure are significant concerns; direct contact, or direct ingestion may result in skin, eye, respiratory irritation, and neurological damage. Non-contact recreational experiences (REC2) are impacted by respiration of aerosols, poor aesthetics that result from visual scums and filamentous mats, poor water clarity, the "pea green soup" of high biomass blooms, and odor and taste that can result from decaying algal or bacterial biomass, or compounds produced directly by certain species of cyanobacteria. Additionally, non-contact recreation can impact dogs that accompany individuals when recreating. Swimmable uses are inherently associated with environmental justice issues, as economically disadvantaged communities have diminished access to swimming pools and thus might tend to seek out waterbodies with free access (e.g., flood control or irrigation canals, streams or lakes, regardless of FHAB event status; Taylor et al. 2007; Kim et al. 2019).

The TAC designated the FHAB recreational use assessment as the highest priority field survey of an integrated FHAB monitoring program. The results of such monitoring speak to the heart of a key issue with FHABs: the protection of human, dog and domestic livestock health.

Priority Indicators and Metrics

Priority indicators and metrics were identified that could contribute towards recreational use status and trends (Table 2.3). The highest priority are direct toxins measures that can be used to identify whether REC1 and REC2 uses are being impacted (R22-24). Of these metrics, toxin concentrations in water samples are the most applicable because they are directly linked to California-adopted trigger levels for human and animal health (Table 3.2, see Section 3.2). Benthic toxin or mat toxin concentrations and passive sampler toxin concentrations do not have regulatory triggers but should at minimum be secondary triggers indicating potential health hazard. Improved triggers are needed to characterize the human and domestic pet impacts of benthic mats, chronic toxin exposure and exposure to multiple toxins **(SS32, Appendix 6**). Metrics that are useful, but a lower priority include toxin gene counts (R23-24); while useful to understand the potential scope of the problem, the analyses are not directly actionable for posting and waterbody assessment. FHAB cell density, visible indications of a scum or remotely sensed CIcyano values are considered secondary triggers; they are useful to trigger more intensive monitoring but can only be used to post a caution recreational health advisory.

FHAB abundances that reduce aesthetics are an indicator of recreational use impairment; the TAC noted that while the precedent exists for their use as TMDL targets, thresholds for aesthetic impacts are not routinely used for 303(d) listing. A special study is needed to synthesize the basis for triggers for lakes, streams and rivers, and coastal confluences (**SS2, Appendix 6**). Notably, Water Board biostimulatory objectives are narrative and, with the exception of the San Diego Water Board basin plan, numeric translators for aesthetic impairments but have not yet been adopted into an amended policy. Remotely sensed Chl-a or CIcyano values are not intended to be used as primary lines of evidence for 303(d) assessment and listing of lakes and reservoirs. Triggers could be developed, however, that could define the probability of exceeding *in situ* chlorophyll-a as a function of remotely sensed Chl-a, improving their utility as a supporting line of evidence (**SS11**, **Appendix 6**).

The lack of routine monitoring on FHAB status and trends limits the understanding of the extent and magnitude of FHABs in the state, as well as the socioeconomic and social impacts of FHABs on disadvantaged communities. The lack of understanding of both these issues perpetuates the allocation of insufficient funding for FHAB monitoring, resulting in management actions that fall short of what is actually required to mitigate impacts. At a minimum, several special studies are needed to quantify the socio-economic and cultural impacts of FHABs in California and identify key indicators for monitoring these impacts **(SS31, Appendix 6**).

Spatial Design Considerations

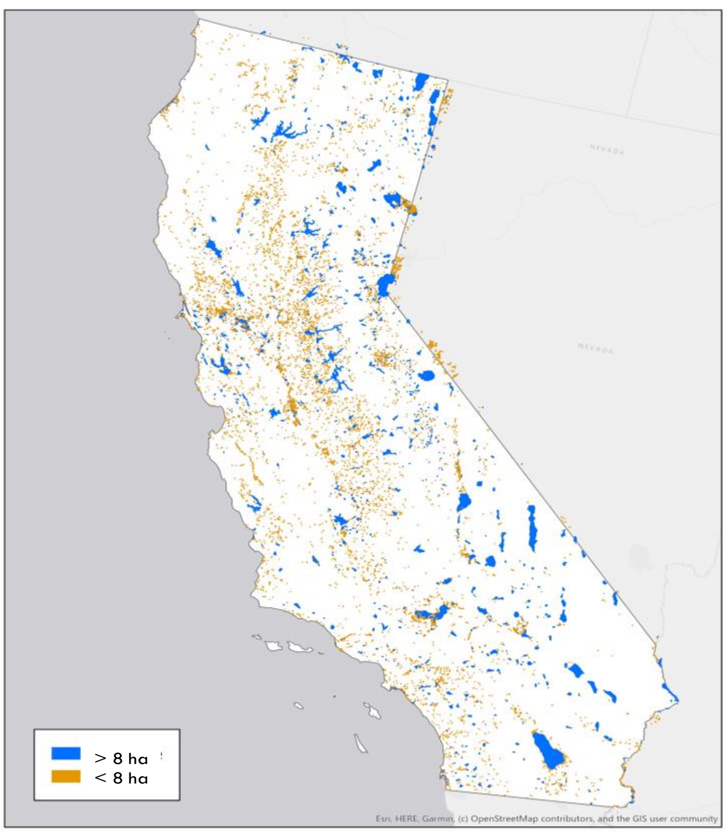


Figure 4.1. Spatial distribution of California lakes and reservoirs > 8 ha (blue) and < 8 ha (orange).

The focal waterbody components to be monitored in lakes and reservoirs, rivers and streams, and coastal confluences are the marine and estuarine beaches (e.g., enclosed beaches as are currently sampled by Beach Safety Monitoring Program - AB411 (1997)) and inland waterbody recreational beaches, haul outs, or swimming holes used for wading or bathing, fishing, rafting, boating and other related activites. For coastal confluences, this would apply to enclosed beaches or beaches proximal to a freshwater source. Refinement of this target population of "beaches" in a recreational use assessment is an important decision that has tremendous implications for monitoring program cost, regardless of whether we are considering a partner program or ambient assessment. The TAC discussed several options for how to narrow: 1) use areas within easy access of roads, 2) size of lake, 3) eliminate waterbodies that are within catchments that are likely to be in pristine condition, and 4) focus on the most popular sites within each regional board.

Use of a California lake and reservoir inventory illustrates some of these decisions**.** Just for California lakes and reservoirs alone, more than 10,000 waterbodies meet the criteria of greater than 1 ha and within a 0.5 km of a road (Figure 4.1, Table 4.2). Focusing on larger lakes and reservoirs nominally defined as > 8 ha dramatically reduces the number of lakes (~1,100), but still represents a formidable challenge that would need to be addressed in considering each element of the FHAB monitoring program (partner monitoring, ambient surveys, etc.).

Table 4.2. Effect of applying size and accessibility criteria to the population of lakes and reservoirs that could be sampled under a recreational use assessment.

Size	Distance from Nearest Paved or Unpaved Road	
	All lakes	**Within 0.5 m of a road**
> 1 ha	13,363	10,162
> 8 ha	1,343	1,065

Regardless of the criteria taken to reduce the number of waterbodies to sample, a recreational use survey would require an inventory of the sites for each of the focal waterbody types across the region or state, a task that is challenging because a statewide inventory of such locations does not currently exist. FHAB monitoring program partners (Regional Boards, tribes, county, and municipal governments) would need to collaborate to create a comprehensive inventory of locations across the state**.**

For field sampling, **index areas**[12] would be chosen to sample the status and trends of recreational uses (Figure 3.4). For the purposes of a state-led survey, the TAC specified that these sampling locations are readily accessible shoreline locations within each segment that would be chosen to represent the "worst condition" (i.e., most protective to assess recreational use). The location would be chosen based on the presence of a visible FHAB issue or windward side of the segments (if no FHAB issue is visible). For the partner program, the TAC specified that the location(s) would be chosen to represent a high recreational use location or based on frequency of use.

Temporal Design Considerations

FHABs can occur throughout the year. For statewide or regional surveys, the TAC recommends an index period of two weeks before Memorial Day through two weeks after Labor Day, reflecting the period of the highest intensity of recreational use. For watershed or waterbody-specific monitoring (e.g., partner program), the recommendation is year-round where appropriate (where the lake does not freeze or become inaccessible due to snow).

Frequency of field sampling to characterize risk of recreational use was vigorously discussed, recognizing that frequency of site visits and number of toxin samples exerts a multiplier effect on the cost of the FHAB monitoring program, be it state-led ambient monitoring or partner program. Figure 4.2 illustrates the core problem with under sampling by a low frequency of site visits on a seasonal or interannual basis; a one-time and two-time random selection of weekly grab samples of

[12] An index area is a targeted location within a waterbody that is intended to be representative of other comparable locations. For lakes, the shoreline beach or deepest point of the lake are considered "index areas."

Pinto lake during selected months over the period of 2011-2018 _poorly characterized risk_, relative to the mean and median of all samples during those selected months. **This has clear implications for monitoring of status and trends of FHABs effects on recreational use:**

1) To characterize status of impacts on uses throughout a recreational season, site visits should occur at minimum biweekly, but optimally weekly. A single site visit can be used to characterize only that point in time (e.g., pre-holiday assessment).

2) Trends assessment should be conducted with site revisits each year (e.g., not once every 5 years).

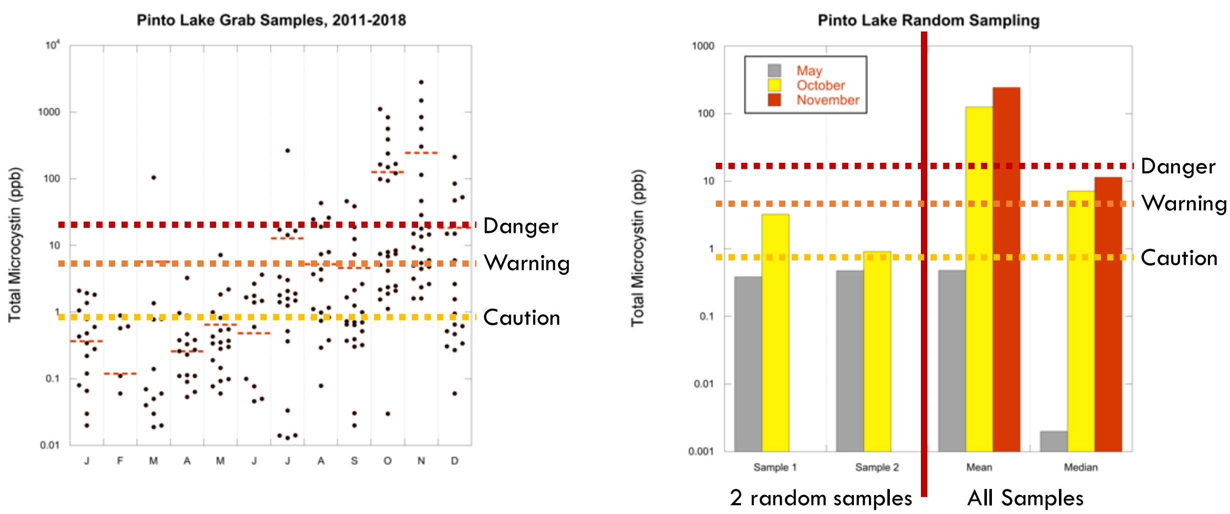


Figure 4.2. Weekly microcystin toxin grabs in Pinto Lake throughout the year over the period of 2011-2018 (left panel) can be used to show the probability of capturing a toxic event (right panel) through 1 and 2 random samples, versus the mean and median microcystin concentration throughout the year. Months of May, October and November were chosen from the dataset arbitrarily.

Reporting frequency was an important point of discussion among the TAC. For the information produced to be timely, recreational use field survey monitoring data must be made available **immediately upon completion of laboratory analyses**, a timeframe that is atypical of SWAMP workflows. The TAC stipulated that uploading of "provisional" results to make them available to waterbody managers would be essential to FHAB monitoring program effectiveness. The QA status of "provisional" could be amended to "final" once the QA process has been completed. They noted that use of "rapid tests" that are relatively inexpensive (e.g., positive/negative dipstick tests) could provide limited information even faster than the "provisional" results from more-standard tests like ELISAs, which might take a bit longer to complete. Frequency of statewide or regional written reports would generally need to be every one to two years, for the purposes of inforning management, though a public health information system would need to disseminate information to recreational users immediately (see discussion on decision support, Chapter 7).

4.1.2 Fishable Uses

Fishable beneficial uses are impacted through several pathways (Section 2.5). Among these, the TAC prioritized recreational health as the most significant concern; ingested toxins accumulate in shellfish and fish tissue (SHELL and COMM) and can also bioaccumulate to have far reaching effects downstream or far afield of their point of origin, particularly in coastal confluences (Miller et al. 2010; Kudela 2011). Tribal or subsistence fishing uses can be greatly impacted, and thus environmental justice issues are inherent in FHAB monitoring of fishable uses. Monitoring of fish and shellfish toxins can directly inform fish consumption advisories and fishery closures, a key action to protect recreational health (USEPA 2000).

The TAC agreed that monitoring of inland water tissue toxins was a lower near-term priority than recreational use assessment (section 4.1.1); however, the TAC recommended that SOPs and data submission capabilities be developed to speed acquisition of data through partner intensive monitoring. Monitoring should be prioritized for waterbodies with known eutrophication or HAB problems that have fishable designated uses. This concept is consistent with the tiered approach suggested by EPA to evaluate chemical contamination of fish and shellfish (EPA 2000).

Priority Indicators and Metrics

Priority indicators and metrics were identified that could contribute to FHAB fishable status and trends (Table 2.3). The highest priority are tissue toxin measures that can be used to identify whether fishable uses are being directly impacted (R25) and because they are directly linked to California-adopted trigger levels for human consumption of toxins (Table 4.3). The TAC noted that evaluation guidelines currently in place by OEHHA (Butler et al. 2012; Gassel and Brodberg 2005) do not account for the higher consumption rates of fish and shellfish or use of whole fish by tribal members; a special study is needed to revise these guidelines specifically to evaluate tribal fishable uses (**see SS3, Appendix 6**).

Table 4.3. Cyanotoxin Tissue Toxin Action Levels. From SOURCE: OEHHA 2012

Toxin	Action Level1 (ng/g tissue ww[3])
Total Microcystins[2]	10
Anatoxin-a	5000
Cylindrospermopsin	70

1 Based on typical consumption rate of self-caught fish in California (one meal per week) and body weight of 70 kg. Children are assumed to eat smaller meals (2 - 4 ounces uncooked).
2 Apply action levels to the sum of all detected microcystins until subchronic toxicities of the other variants are clarified.
3 Wet weight. Action level units assume fresh (or wet) weight of the fish tissue.

Ambient total toxin concentration (R22, R27), FHAB relative abundance or cell densities (R18-20), and bulk algal biomass measures (R7, R10, or R12) are considered important collateral data to interpret tissue toxin information or to evaluate linkage to eutrophication/biostimulatory objectives. For inland waters (and where FHAB species composition suggest it to be an issue), tissues can also be tested for MIB and geosmin (taste and odor compounds; R25), which may be helpful for commercial aquaculture operations. Metrics that are lower priority included passively sampled toxins (R23) and FHAB biomass measures (R13-16); while useful screening tools to understand the potential scope of the problem, these metrics are less useful in this context because the metrics themselves are not directly actionable (action levels). Finally, indicators of algal community and trophic structure, water quality, and benthic habitat quality could be used to assess impacts to fisheries yield (R2-R16). However, these would be considered low priority indicators for a status and trends monitoring program, because without a full faunal community survey, these indicators are not be readily interpretable.

An important consideration in monitoring of FHAB impacts on fishable uses is the focal organism(s) to measure tissue toxins. Cyanotoxins in fish/shellfish tissue are fundamentally different from bioaccumulative legacy chemicals like mercury and polychlorinated biphenyls whose concentrations in environmental media and fish/shellfish tissue are more stable and are the framework for which the state and federal fish tissue monitoring, and advisory programs were developed. Cyanotoxins are likely to bioaccumulate to differing degrees in fish and shellfish, depending on the pathway of exposure, waterbody type, etc. Three general philosophies are apparent in previous surveys used to select the focal organism either for FHAB toxins or other toxic contaminants: 1) monitoring of toxin contamination in a particular fishery, e.g., salmon fishery, 2) survey of sport or recreational use fish to identify the appropriate indicator organism, and 3) choice of a sentinel organism, e.g., mussels, that act as an appropriate bioindicator of safety of fish/shellfish consumption. Aquaculture species should also be considered explicitly (Smith et al. 2008).

For a regional or statewide status and trends assessment, a sentinel organism that is comparable across spatial scales is needed. In the BOG lakes study, "bass fish" were selected after a screening study because they were ubiquitous throughout California lakes and accumulators of mercury. For coastal confluences, marine bivalves are an example of a sentinel organism. The rationale in choice of bivalves as biotoxin indicators is several-fold: 1) are filter feeders and would represent a conservative estimate of exposure to biotoxins, 2) methods to deploy are logistically easier than methods to harvest or capture fish, and 3) methods to measure toxins are standardized in SOPs and are adaptable to biotoxins. In estuarine and marine waters, the CDPH Biotoxin monitoring program relies on this approach in marine waters for marine algal toxins. Currently, no standardized approaches for analyzing cyanotoxins in mussel tissue exist; however, current federally funded efforts via the Monitoring and Incident response for Harmful Algal Blooms (MERHAB) NOAA grant program are underway to develop standardized protocols for measuring microcystins in marine bivalve tissues (PIs C. Gobler, SUNY and R. Kudela, UCSC). These efforts could be leveraged for statewide efforts to monitor microcystins in bivalve tissues through the adoption of the standardized methods developed in this project. This project will also generate a timeseries of microcystins in bivalve tissues in several coastal confluence locations in California that could be used as baseline data for any future monitoring data.

For waterbody-specific assessments with known FHAB problems, OEHHA (2005) and USEPA (2000) recommend an initial screening of waterbodies to determine which commercial, recreational, or sport fish or shellfish exceed human consumption levels of potential concern. If exceedances of tissue toxins are detected, then a Tier II intensive follow up of those waterbodies would be warranted to identify the magnitude and geographic extent of contamination and to inform advisories or closures (waterbody wide or specific geographic areas). A study of fish filet and mussel tissue contamination conducted in the Klamath River are examples of screening studies in a watershed with a known FHAB problem (Kann et al. 2010; Kanz 2008). Kanz (2008) conducted a screening level analysis of accumulation of microcystin in yellow perch (*Perca flavescens*) from the reservoirs, Chinook salmon from Iron Gate (IG) Hatchery, and freshwater mussels (*Gonidea angulata*) from the Klamath River below IG dam. He found bioaccumulation of the toxin to be transitory in nature, being present in tissues when the toxin and algal blooms are present, and that depuration occurred in the absence of the toxin in the water. Kann et al. (2010) found microcystin was consistently detected in freshwater mussel tissue samples and exceeded tolerable daily intake values (Ibelings and Chorus 2007).

Spatial Design Considerations

The focal waterbodies for fishable status and trends assessments include lakes and reservoirs, streams and rivers, and coastal confluences that are used for subsistence, sport, recreational, or commercial harvesting of fish and shellfish or aquaculture. In lakes and reservoirs, recreational fishing is the priority. In rivers and streams and coastal confluences, target waterbodies could vary as a function of a particular fishery of focus (e.g., salmonids), recreational and sport fisheries, or sentinel organisms (crayfish, freshwater, or marine shellfish). As with recreational use sites, a comprehensive inventory of these waterbodies does not exist. Refinement of the target population can be iterative. As an example of how this was done, the SWAMP Bioaccumulation Workgroup (BOG) took an iterative approach to define the target population of lakes over a series of surveys (Bonnema 2017). In 2007, they chose 272 high use "bass lakes," including 222 popular lakes and 50 random lakes, to assess status in mercury in sport fish (e.g., black bass). Based on this assessment, they picked 190 lakes of the highest interest to revisit on a 10-year cycle (38 lakes per year) to track status and trends in mercury in sport fish tissue over time.

The precise spatial design appropriate for a regional/statewide status and trends or waterbody-specific assessment will depend on focal indicator organism. However, USEPA provides some general guidance on spatial sampling that can be extrapolated to FHABs: 1) proximity to known problem areas of recurrent blooms (FHAB impacts), 2) proximity to pollution sources that are biostimulatory, 3) popular fishing holes or areas of intensive harvest or collections, 4) proximity to established areas of water and sediment sampling in order to correlate fish or shellfish tissue with toxin concentrations in order system compartments (water, sediments), and 5) accessibility of the site. The actual habitat sampled and how that is integrated over space is also a consideration. An example from the SWAMP BOG mercury bioaccumulation survey lakes shows how bottom feeders (left panel) sampled differentially from predators (right panel), with the locations of fish representing how fish would be sampled over space (Figure 4.3; SWAMP 2008).

Temporal Design Considerations

Temporal design considerations are important, because though to some extent tissue toxin concentrations integrate exposure over time, toxin concentrations would expect to vary widely as a function of bloom status and toxicity, as tissue toxin concentration depurates once the toxic bloom event has passed (Kanz 2008). Depuration rates may vary based on specific fish or bivalve species, but several studies have indicated that toxin concentrations in tissues remain detectable for two or more weeks (Gibble et al. 2016; Peacock et al. 2018; Smith and Haney 2006). For shellfish biotoxin monitoring, a minimum sampling frequency would be biweekly to monthly; more frequently is suggested in order to improve assessment of risk.

Recreational and sportfishing can occur all year in some parts of the state. Sampling could occur over an index period from spring through late fall (April – November), though the exact timing depends on climate and other factors which vary throughout the state.

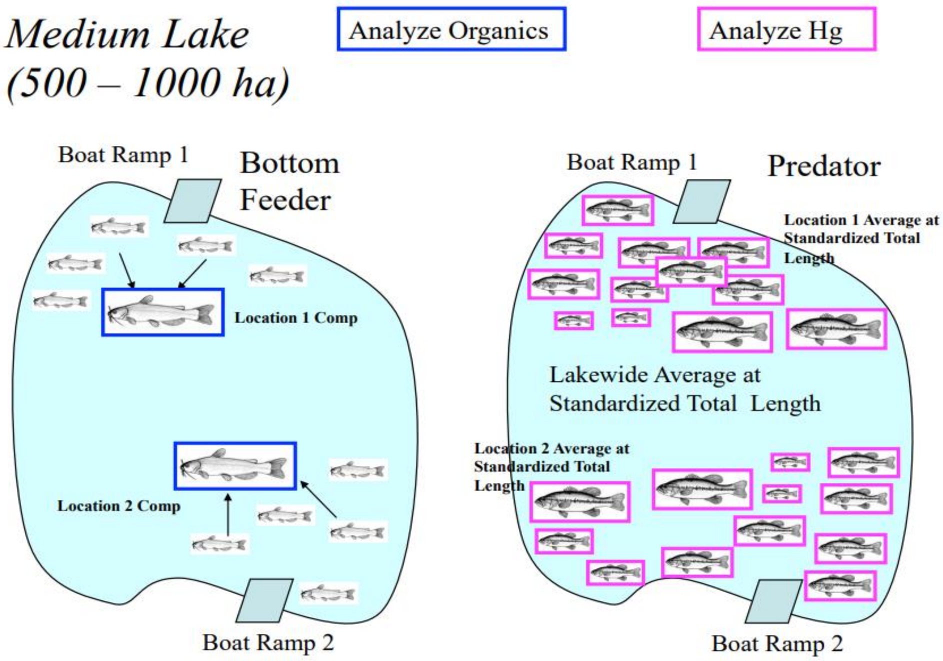


Figure 4.3. Example of sampling design used to collect fish for tissue contaminants in the SWAMP BOG Long-term Monitoring of Bass Lakes and Reservoirs in California (comp. = composite sample), showing conceptually the analyses of both bottom feeders and predators.

Reporting Frequency. For the information produced to be timely, fishable use field survey monitoring data must be made available **immediately upon completion of laboratory analyses**, a timeframe that is atypical of SWAMP workflows. The TAC stipulated that uploading of "provisional " results to make them available to waterbody managers would be essential to FHAB monitoring program effectiveness. The QA status of "provisional" could be amended to "final" once the QA process has been completed. Frequency of statewide or regional written reports would generally need to be every two years, with a formal report akin to what BOG typically has produced.

4.1.3 Tribal and Cultural Uses

Each tribe[13] in the State is a sovereign nation with distinctive cultural practices and traditional uses of waterways. Therefore, tribal and cultural uses of waterbodies are very specific to each tribe and it is difficult to summarize the diversity of uses simply (Figure 2.3). These uses of the water are often extensive and involve significantly more and different types of exposure than recreational uses. Depending on the specific tribe and tradition, exposure pathways can vary and can occur through multiple routes. Exposure pathways can involve direct ingestion of water or ingestion of particles or aerosols. Uses can be repetitive, gender assigned, and long-term; therefore, depending on the use and tradition, men and women can have large differences in the route and duration of exposure. Traditions can occur with extensive activity in or near a waterbody in particular seasons or on an annual basis. These types of exposure are unique from recreational exposure and require

[13] Some tribal nations are not federally recognized. As many as 50 tribes statewide have not been recognized because the United States disputes, denies, or has yet to make a decision on their petition for federal acknowledgement.

special consideration. Exposure can also occur via the ingestion or handling of plants or consumption of contaminated food items. In particular, tribes may consume fish or shellfish for subsistence, therefore, the ingestion rates of contaminated food items can be much higher than consumption from recreational fishing.

Many of the basic designs and indicators described in Recreational and Fishable Uses designs outlined in Sections 4.1 and 4.2 can serve as a starting point for monitoring the status and trends of FHABs impacts on tribal and cultural uses, augmented with monitoring approaches customized based on the unique elements of tribal tradition and culture that occur within a given waterbody. Ultimately, design decisions should be made by or in collaboration with tribal partners. General principles for assessing the status and trends of FHAB impacts on tribal and cultural uses are considered below.

Priority Indicators and Metrics

Tribal and cultural uses represent many different uses of the water; therefore, impacts from FHABs can be related to waterbody aesthetics, and suitability of the habitat for culturally significant species to thrive as well as multiple toxin exposure pathways including contact, consumption. and inhalation. Priority indicators can vary depending on the nature of the tribal traditions for which the waterbody or waterbodies are used, but many indicators are shared with other beneficial uses (Table 2.3). Two key considerations are worth noting. First, assessment guidelines used for other beneficial uses, such as Recreational Health Trigger Levels (Table 3.2) may not be sufficiently protective of tribal uses since the assumption underpinning exposure frequency and severity do not account for tribal uses. Similarly, consumption guidelines developed by OEHHA may not be suitable for evaluation of tribal subsistence due to higher consumption rates. **These thresholds should be carefully evaluated and determine if alternative assessment guidelines that take more relevant exposure scenarios into account are needed (SS3, Appendix 6).**

Second, while generally the indicator in concept could apply (toxin tissue concentrations), where and specifically how it should be measured should be carefully considered and adapted for tribal and cultural uses. For example, toxin concentrations on the leaves and stems of wetland plants that are used in traditional uses (baskets or mats) could be assessed as a potential exposure route. Inhalation of aerosolized toxins is another example of an exposure pathway not well understood. Special studies are needed to determine how these additional exposures may negatively impact tribal members.

Spatial Design Considerations

Focal waterbodies or watersheds should be determined based on the locations with specific tribal and cultural significance. The specific spatial design components to assess the status and trends of FHAB impacts on tribal and cultural uses need to be watershed- or waterbody-specific. In many cases, there are specific, place-based cultural practices that need to be considered. An example is the World Renewal Ceremonies, which have been practiced by the Karuk Tribe at specific locations in the Klamath Basin since time immemorial. Overall, tribal and cultural uses are far too diverse for effective assessment of status and trends on a statewide level and should be assessed in collaboration with individual Tribes.

Priority monitoring locations should vary based on the cultural uses at a given waterbody and should consider the practices of all tribes that use a waterbody since in many cases, waterbodies hold cultural significance for multiple Tribes. In many cases, this should also consider upstream and downstream impacts. Spatial design may include sites that might differ from traditional recreational sampling. For example, specific features such as shorelines with tule (*Schoenoplectus acutus*) on Clear Lake might be a specific priority for sampling since many traditional practices of the Tribes in the region involve collecting and using tule. Ceremonial sites and traditional fishing locations should also be prioritized in sampling. In some cases, there may be overlap with other recreational or fishable use monitoring or surveys. This data should be shared collaboratively with tribes to inform their understanding of water quality in these sites.

Temporal Design Considerations

Temporal design considerations are generally similar to those of recreational and fishable uses (Section 4.1.1). During peak use of a waterbody, sampling should occur biweekly at a minimum for recreational related uses and weekly if possible. The overall period in which biweekly sampling should occur depends on the cultural traditions practiced on the waterbody. In some cases, cultural practices may coincide with peak recreation periods, but in other cases, uses may extend over a longer period of time or occur during a different season. In other cases, a shorter high frequency sampling season may be appropriate if cultural practices only span a short period of time. Generally sampling activities should commence prior to significant place-based practices so that data are available in advance to allow Tribes to make informed decisions about their uses of the waterbody.

Sampling for the assessment of tribal subsistence fishing is recommended to occur at a frequency similar to sampling indicators for direct exposure, particularly if an active FHAB event is occurring. The cyanotoxin uptake and depuration rates of many culturally significant fish and shellfish species are not known. Special studies, such as the studies led by the shoreline tribes of Clear Lake or the Karuk Tribe described in Appendix 4, should be conducted to assess these rates in order to better understand how long lasting FHAB effects may be to tribal subsistence fishing.

4.1.4 Aquatic Life Uses

Effects of FHAB on aquatic life and terrestrial wildlife occur via a variety of pathways (Table 2.3), including 1) increased abundance and toxicity of FHAB species, 2) increased biomass of non-toxic and toxic species which outcompete microalgae and submerged aquatic vegetation, changing food web structure, 3) altered physical habitat for invertebrates and fish through altered water clarity, dampening of velocity or increased organic, 4) increased extent, frequency, and duration of low DO and pH and/or dissolved inorganic carbon, as well as large diurnal swings in DO and pH, and 5) enhanced survival and regrowth of pathogenic bacteria and can result in clogging of gills, infectious disease, and poor feeding behavior, etc. (Stocking and Bartholomew 2007). Poor habitat quality and imbalances in primary producers causes shifts in the invertebrate composition and decreased growth rates, reduced reproductive success, increased stress and disease, and increased larval and adult mortality, though measurement of those attributes alone cannot be attributed to FHABs without additional evidence. Higher trophic level consumers, such as fish, birds, amphibians, and other wildlife that prey upon these primary and secondary consumers experience reduced food availability and quality, and decreased growth rates.

Priority Indicators and Metrics

Priority indicators and metrics were identified that could contribute towards FHAB aquatic life use status and trends (Table 2.3). For aquatic life, the TAC did not specifically prioritize one group of indicators over the other. The applicability of each indicator group depends on the type of survey (statewide screening, waterbody-specific study including Endangered Species Act assessments, etc.) as well as the specific waterbody types. Here, we discuss relative utility of metrics within each grouping. In terms of statewide screening assessments, the TAC did recommend some sound basic principles to consider: 1) Evidence of toxigenic species could trigger more expensive toxin analyses, and 2) more cost-effective measures of high biomass or organic matter to better link FHAB impacts related to biostimulatory substances and conditions.

Toxin, Taste, and Odor Measures. The highest priority toxin measures are direct measures, e.g., total water column, benthic, or sediment toxin samples (R22-25, R27) that could indicate whether aquatic life uses are being impacted. However, we note that evaluation guidelines are not specifically available to assess impacts on aquatic life. A special study **(SS27, Appendix 6)** is specifically needed to review and suggest, based on existing literature, if sufficient information exists to develop evaluation guidelines for aquatic life. The TAC discussed to what extent sediment toxin measures integrate toxin exposure over time due to either an ongoing or senesced planktonic FHAB bloom or benthic FHAB sources. In either case, they recommended a special study to investigate this question, as it has bearing on the utility of such an indicator used in a status and trends assessment (**SS28, Appendix 6**). Metrics that were useful but have lower priority are passive sampler toxins or toxin gene expression (R23-24); while useful to understand the potential scope of the problem or potential pathways for impact, these metrics are less useful to assess direct impacts on aquatic life.

Abundance of Toxigenic FHAB Species. A second measure is the relative abundance or biomass of toxigenic FHAB species as an absolute measure and as a fraction of the total biomass. FHAB cell density, toxigenic species abundance (qPCR), or toxigenic FHAB species relative abundance via molecular barcoding could apply to all waterbodies. Remotely sensed CIcyano applies specifically to lakes and reservoirs but has the drawback that it represents surface blooms; such methods do not apply to benthic FHAB blooms or those that might be dispersed in the water column. Remotely sensed data cannot discriminate between toxin producing and non-toxin producing strains (Stumpf et al. 2016). *In situ* planktonic or benthic phycocyanin fluorescence measures may have similar issues, unless calibrated relative to discrete data.

Molecular barcoding and qPCR approaches to assess abundance have particular promise because they avoid existing problems with taxonomic standardization and laboratory capacity in California (R17, R19). These approaches are currently under development by various research labs within California; a special study (**SS23, Appendix 6)** is needed to specifically develop capabilities and standardized operating procedures to use these approaches to assess and report out on toxigenic FHAB species abundances for all waterbody types. Work is also needed to build out the molecular reference library of California species. Molecular FHAB assessments can be immediately streamlined into existing bioassessment methodologies for wadeable streams. An algal stream condition index (ASCI; Theroux et al. 2020) has recently been completed that uses the diversity of benthic algal abundances relative to minimally disturbed reference sites to assess biological integrity of wadeable streams. ASCI has been developed specifically to be compatible with a molecular barcoding approach. An FHAB species condition index, similar to ASCI, could be developed that specifically reports out on the diversity and relative abundance of FHAB species relative to a network of reference sites. We recommend that this be completed under a special study **(SS19, Appendix 6**) and could utilize the same underlying data as ASCI in order to leverage bioassessment program sampling to increase FHAB aquatic life assessments. Extension of algal condition indices to lakes, reservoirs and estuaries has been an explicit recommendation of the bioassessment workplan. We highly recommend these activities be pursued (**SS20** and **SS21**, **Appendix 6**), and they will greatly streamline and make more cost-effective FHAB assessments in these waterbodies applicable to <u>all core beneficial uses</u>.

Total chlorophyll-a, organic carbon, phosphorus, or nitrogen representing live and dead organic matter are important indicators of total FHAB biomass (toxigenic and non-toxigenic taxa) or biostimulatory impacts in general (R7-R10; Sutula 2011; Sutula et al. 2021). As mentioned in Section 4.1, Water Board biostimulatory objectives exist as narratives and numeric translators for aquatic life have not yet been adopted into an amended policy, though science supporting their use has been developed for wadeable streams (Sutula et al. 2021), estuaries (Sutula et al. 2014), and is in development for lakes and estuaries. Remotely sensed Chl-a or CIcyano is not intended to be used in 303(d) assessment and listing of lakes and reservoirs; however, triggers could be developed that could define the probability of exceeding *in situ* chlorophyll-a or CIcyano as a function of remotely sensed Chl-a (**SS11, Appendix 6**). Macroalgal percent cover in wadeable streams has a poor relationship with aquatic life and is therefore not specifically recommended here.

Water Quality indicators are relevant for aquatic life assessments, including dissolved oxygen and pH (and/or related carbonate saturation state parameters). Basin plan objectives exist specifically for DO in inland as well as estuarine waters. However, instantaneous measurements of DO are typically not useful; continuous data are required for deployment periods > 48 hours (streams) and > 4 week (estuaries) to acquire interpretable information. Light penetration (photosynthetically available radiation) to benthic primary producers is important in shallow water habitats of lakes and estuaries and enclosed bays, but no specific evaluation guidelines exist currently in California. DOC is a useful indicator of impacts to carbon cycling and roughly correlates to biological oxygen demand, but evaluation guidelines have not been proposed nor are in common practice in the scientific literature.

Primary Consumers. Benthic invertebrate community composition has been a cornerstone of wadeable stream and estuarine bioassessment and is being implemented as part of an ambient bioassessment monitoring throughout various state and regional programs. As such, invertebrate species composition and abundance can serve as a helpful check on potential FHABs effects on aquatic life. If FHAB abundances are high or toxins are detected in the water column, low scores in benthic invertebrate indices of biological integrity may point to an impairment in aquatic life. However, alteration in benthic invertebrate communities cannot easily be ascribed to a single stressor, FHAB or otherwise. Development of rapid causal assessment metrics (e.g., invertebrate-specific responses) that are FHAB-specific would be essential in the causal assessment toolkit. Studies can be conducted to quantify toxin concentrations in macroinvertebrates and assess their impact on survival.

Spatial Design

The spatial domain of interest to assess FHAB impacts on aquatic life use in all lakes and reservoirs, streams and rivers, and coastal confluences—a large resource base; the TAC discussed options to narrow to a more focused list. One TAC suggestion was to focus aquatic life assessments where some screening level assessment (See Chapter 7) has designated that waterbody or segment a priority; another emphasized a broad survey, in order to get a better understanding of how aquatic life may be impacted as a whole across the state.

An important component of ambient aquatic life assessments is the inclusion of a network of minimally disturbed reference sites, against which the ambient population of sites can be compared (Ode et al. 2016). This element is important in aquatic resource surveys because interpretations of effects require some understanding of the baseline perturbations caused by "natural variability." Thus, the range of variability of aquatic life indicators in reference waterbodies with low levels of disturbance set the benchmark of expected biological, chemical and physical condition. In the case of FHABs and their toxins, which are naturally occurring, the monitoring question becomes: "What is the extent and magnitude of FHABs and associated toxins in minimally disturbed reference sites?". Defining reference is a challenge in a landscape such as California's that has been highly modified. The SWAMP bioassessment program was successful in establishing a reference network for perennial wadeable streams (Ode et al. 2016). Minimally disturbed lakes and coastal confluences that qualify as "reference quality" will be more difficult to identify.

The precise spatial design appropriate for a regional/statewide status and trends or waterbody-specific assessment will depend on the specific monitoring objectives, but generally the approach is that of an index area in which an integrated sample can be taken. For small lakes, a single index site may be appropriate, but multiple sites representing multiple lake segments would be required for larger waterbodies. Standardized protocols exist that could be expanded or adapted specifically for FHAB aquatic life use sampling in wadeable streams (Ode et. 2016), lakes and reservoirs (US EPA National Lakes Assessment), and coastal confluences (McLaughlin et al. 2014). For water column indicators in lakes, including biological, physical and chemical, this index area is typically recommended as the deepest point of a lake or the lake segment being characterized (Figure 4.4) and a depth-integrated sample taken over the water column at that point. Benthic indicators submerged aquatic vegetation, or physical habitat indicators can be assessed at shoreline stations (Figure 4.4).

In wadeable streams, this typically is represented as reach (e.g., 150 m if < 10 m wide channel or 250 m if the channel is > 10 m wide) in which instream measurements are conducted (Figure 4.5). In the SWAMP bioassessment procedures, algae and benthic macroinvertebrates are both sampled and composited over 11 transects including pool and riffle sequences part of a multihabitat sampling approach (Ode et al. 2016). Hydrologic, physical habitat measures, and algal cover are measured at 10 inter-transects.

The approach in coastal confluences is similar to lakes; specific approaches are applied depending on whether the FHAB manifests in planktonic blooms in surface waters, mats on the intertidal flats, benthic (intertidal or subtidal) or rafting or epiphytic mats intercalated with submerged aquatic vegetation (SAV; Figure 4.6). For planktonic blooms, index areas mid-channel are typically chosen at which depth integrated samples are taken either at a single site or a suite of stations along the spine of the channel (typically at the thalweg). For benthic or drift algae, or epiphytic algae associated with SAV in subtidal habitat, a grid approach is recommended to characterize FHAB indicators within a segment (Figure 4.7, top left panel). For benthic mats in intertidal habitats, shoreline transects are established (Figure 4.7, bottom panels).

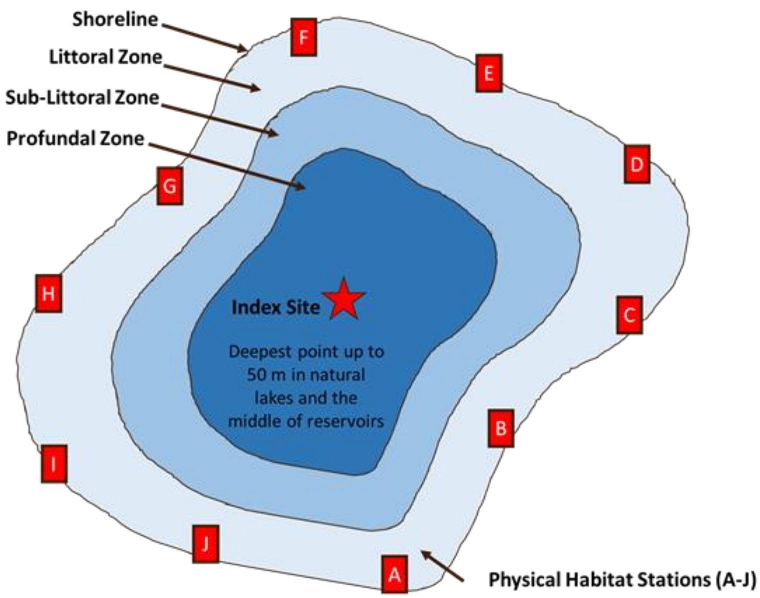


Figure 4.4. Example of spatial sampling schematic for aquatic life in lakes, showing location of index site for water column indicators and shoreline stations for benthic or physical habitat indicators. Adapted from NLA 2017 Field Operations Manual (USEPA 2017a).

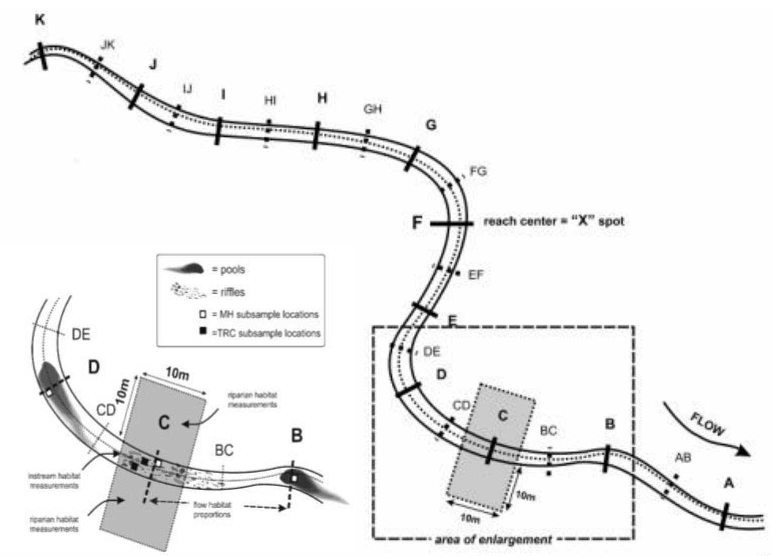


Figure 4.5. Example of spatial sampling schematic for aquatic life sampling in wadeable streams, showing location of index site for water column indicators and shoreline stations for benthic or physical habitat indicators. Source: Ode et al. (2016).

Figure 4.6. Examples of FHABs in different habitat types: mats on the intertidal (upper left), rafting mats on seagrass (upper right), floating mats in closed river mouth estuary (lower left), rafting mats in SAV in a closed lagoon (lower right).

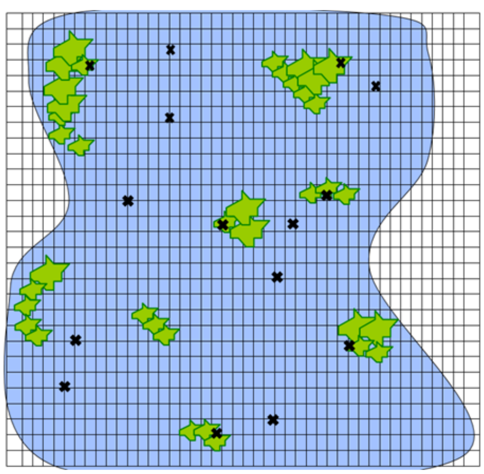
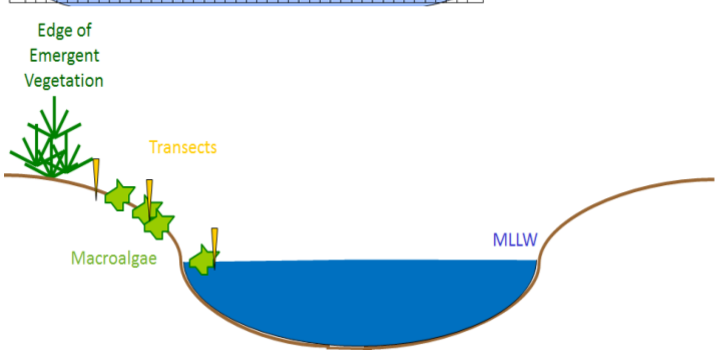
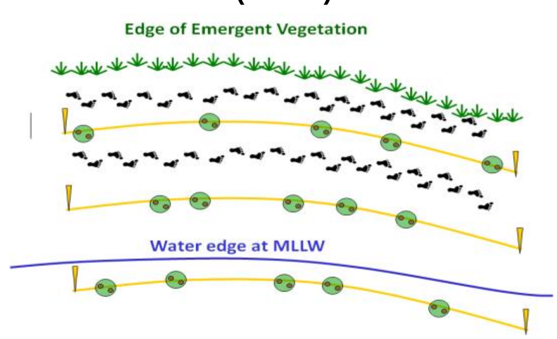


Figure 4.7. From McLauglin and Sutula 2021. Top left panel: Example of a grid layout over estuary segment. Black X represents the random sampling points where drift and benthic algal indicators will be collected, along with sediment and water column physical and chemical characteristics. Bottom left panel: Cross sectional view of one intertidal station with three transects shown as yellow lines. One transect is laid out near the emergent vegetation, another between the vegetation and MLLW, and a third within the shallow subtidal. Bottom right panel: Top-down view of transect layout at one station in the intertidal flats and shallow subtidal. Three transects per station are set along the shore with one transect near the emergent vegetation, another transect between the vegetation and mean low low water (MLLW).





Temporal Design

Temporal design considerations are important, as FHABs can occur throughout the year. Generally, the aquatic life assessment index period would be the "growing season" — April through November, though FHABs can certainly occur during the wintertime periods. The ideal index period would likely vary by waterbody type and seasonality of the impact that needs to be captured. For example, in some estuaries, peak blooms often occur in late spring or early summer and are dominated by high biomass but non-toxic species, while peak cyanobacterial biomass occurred later in the season (McLaughlin et al. 2014). Species composition in lakes is variable and not predictable (Figure 4.8; Howard et al. 2021). Frequent temporal sampling is required to capture the range of variability in species composition and abundance. The exact frequency of field sampling to characterize aquatic life was not specifically discussed but can be extrapolated to that from recreational use; first, we recognize that frequency of site visits and number of toxin samples exerts a multiplier effect on the cost of the FHAB monitoring program, be it state-led ambient monitoring or partner program. General TAC comments on this topic for recreational use also apply to aquatic life use assessment:

- For toxins, attempts to characterize the seasonal assessment of aquatic life use effects on <u>less than a minimum of monthly site visits</u> during the index period risks missing a peak toxic event. Single site visits can be used to only characterize that point in time.

- Trends assessment should be conducted annually at sites.

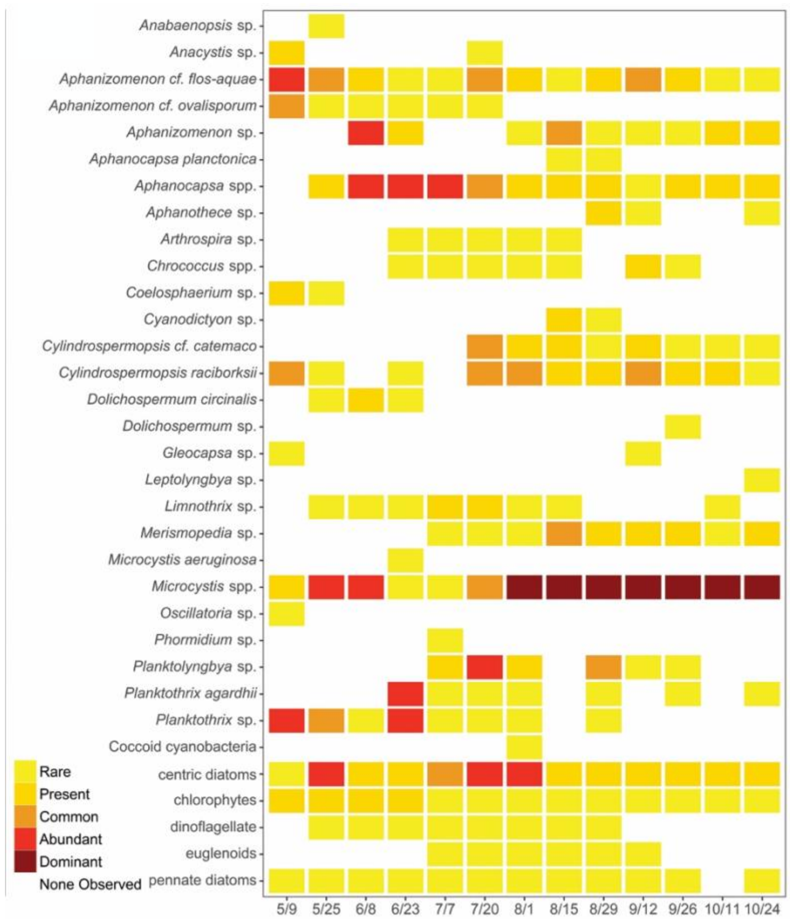


Figure 4.8. Variability of algal and cyanobacterial species composition sampled on a biweekly frequency in Lake Elsinore, summer 2016. Colors represent the relative abundance of the genus or species indicated on the y-axis in relation to the rest of the community as determined from microscopy Adapted from Howard et al. (2021).

Reporting Frequency. For the information produced to be timely, the frequency of statewide or regional written reports would generally need to be every two years, with data uploaded to state databases upon completion of quality assurance checks.

4.1.5 Raw Water Resource Protection

The pathways of impacts from FHAB on raw drinking water sources are several-fold (Westrick and Szlag 2018). First, chronic toxic FHAB events or those with taste and odor compounds require improved and higher cost treatment to remove these toxins from finished water products. Water withdrawals from streams and lakes outside municipal or county water systems (housing in unincorporated areas, drinking water for backcountry hiking, etc.) are a common occurrence and pose a high risk when FHABs are present, because of the lack of monitoring and prescribed treatment for such systems. Second, FHAB species can contribute to taste and odor problems in raw drinking water sources. Third, increased DOC results from "leaky" algal blooms translate to increased quantities/costs of disinfectants required to achieve treatment goals. DOC, algal metabolites and other decomposition products, when present in raw water and chlorinated or brominated by treatment processes, can produce carcinogenic THM. Finally, high biomass blooms and aquatic vegetation impede municipal or industrial water intakes.

This section provides a summary of cyanotoxin monitoring related to raw water protection. Already, more detailed guidance and recommendations for cyanotoxin monitoring for drinking water systems have been developed by the American Water Works Association[14], US EPA[15], and World Health Organization (Chorus and Welker 2021). Therefore, development of specific cyanotoxin monitoring programs for raw or source water in California can reference content provided by these entities (as well as other resources) and should also be accomplished in collaboration with the Water Boards' Division of Drinking Water.

Indicators and Metrics

Direct and indirect toxin measures. For raw water source protection, direct toxin measures are useful (total toxins and SPATT), but toxin gene expression becomes a more useful measure, as this information could provide early warning on the possibility of a toxin bloom (Otten et al. 2015), before high concentrations of toxins are detected in surface waters. This metric has been applied in public water monitoring in other states, such as Ohio (Kasich et al. 2014) Analyses of taste and odor compounds (R25) also becomes important (Table 2.3).

Abundance of Toxigenic FHAB Species. A second measure of change for raw water source assessments is the relative abundance or biomass of toxigenic FHAB species as an absolute measure and as a fraction of the total biomass. FHAB cell density, toxigenic species abundance (qPCR) or toxigenic FHAB species relative abundance via molecular barcoding could apply to all waterbodies. Remotely sensed CIcyano applies specifically to lakes and reservoirs but has the drawback that it represents surface blooms; such methods do not apply to benthic FHAB blooms or those that might be dispersed in the water column (near drinking water intakes). Molecular barcoding and qPCR approaches are favored and are currently under development by various research labs within California; a special study (**SS23, Appendix 6)** is needed to specifically develop capabilities and standardized operating procedures to use these approaches to assess and report out on toxigenic FHAB species abundances for rivers and streams, lakes and reservoirs and coastal confluences. As with aquatic life uses, extension of algal condition indices to lakes, reservoirs and estuaries has been an explicit recommendation of the bioassessment workplan. We highly recommend these activities be pursued (**SS20** and **SS21**, **Appendix 6**), and they will greatly streamline and make more cost-effective FHAB assessments in these waterbodies applicable to <u>all core beneficial uses</u>.

Total chlorophyll-a, organic carbon, nitrogen, and phosphorus represent live and dead organic matter are important indicators of total FHAB biomass (toxigenic and non-toxigenic taxa) or

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[14] AWWA Resources on Cyanobacteria/Cyanotoxins: https://www.awwa.org/Resources-Tools/Resource-Topics/Source-Water-Protection/Cyanobacteria-Cyanotoxins#9640306-technical-resources

[15] USEPA Managing Cyanotoxins in Public Drinking Water Systems: https://www.epa.gov/ground-water-and-drinking-water/managing-cyanotoxins-public-drinking-water-systems

biostimulatory impacts in general (R8-11; Sutula 2011; Sutula et al. 2021). Indicators that apply well for ***aquatic life*** also apply for ***raw drinking water source*** assessments. Some of these same water quality metrics are relevant to ***raw drinking water source*** assessments. For example, DO (particularly when hypoxia or anoxia exist) can be indicative of heterotrophic, particularly enteric, bacteria proliferation. Removal of turbidity and total suspended solids causes higher treatment costs and thus be useful measures. DOC is an important indicator because increased disinfection rates and the potential to create cancer causing THMs.

Spatial Design Considerations

The target population of waterbodies includes the population of lakes and reservoirs, streams and rivers, and coastal confluences currently captured by the waterbody definitions (Figure 2.1). The priority among these would be waterbodies with established intakes, but subsistence withdrawals from lakes and rivers occur and could be included if their locations are known. The precise spatial design appropriate for a regional/statewide status and trends or waterbody-specific assessment will depend on the specific monitoring objectives, but generally the approach is that of an index area in which an integrated sample can be taken. Sampling sites should be added near intake pipes, in addition to or in lieu of specific protocols suggested for aquatic life. Standardized protocols that exist or need to be adapted for aquatic life should also serve well for raw water source assessments.

Temporal Design Considerations

For raw drinking water source assessment, the recommended frequency of field sampling is year-round with increasing frequency of monitoring during the warmer months of the year. Sampling schedules can be determined by the types of cyanobacteria occurring in the source water (scum forming types can quickly change their distribution and density in the water column) and time of day to sample buoyant cyanobacteria (Sklenar et al. 2016). Near intakes, installation of continuous sensors to monitor chlorophyll-a and phycocyanin, for example, would provide incredibly useful data on relative algal biomass and provide early warning onset of blooms (Algae: Source to Treatment M57 (awwa.org)).

4.2 Survey Options and Leveraging Opportunities

The TAC considered two types of FHAB monitoring that have the potential to contribute to FHAB status and trends: 1) remote sensing and 2) FHAB ambient recreational use assessment (partner program, state-implemented, or a hybrid).

Because monitoring of FHABs in an inherently expensive proposition, leveraging provides an opportunity to conserve resources by aligning or adding methods to optimize information or adding additional sampling effort to improve frequency or extend the extent of resources covered. Leveraging at times can make monitoring implementation more complicated for all parties involved. For that reason, in this report, we attempt to identify opportunities for leveraging, but leave the detailed consideration and weighing of cost/benefits to a subsequent stage, understanding that these existing programs may have significant constraints to such a collaboration. We note that barriers to leveraging may be substantial.

4.2.1 Remote Sensing

Remote sensing of lakes and reservoirs and, in some applications, coastal confluences can provide a source of information on waterbody chlorophyll-a and CIcyano index values for statewide status and trends assessments of **multiple uses: recreational, aquatic life** and **raw drinking water source protection** (see Section 3.1 for details). This approach provides has some distinct advantages that merit its incorporation into status and trends, including: 1) ongoing temporal coverage allows assessment of monthly, seasonal and interannual trends, with some caveats, and 2) wide spatial coverage across the state with minimum staff time associated with data collection. Such data could allow a tiering of lakes and reservoirs in categories of potential FHAB risk; high risk sites that haven't been previously sampled could be prioritized for field sampling of FHAB impacts to core uses. Disadvantages and caveats exist (see chapter 3).

Overall, the TAC felt that the advantages far outweigh the disadvantages and that the remote sensing approach is currently an underused resource that merits further investments to fully realize its potential for status and trends. Two recommendations are provided below:

1. **Utilize existing OLCI data to summarize status and trends in CIcyano AND chlorophyll-a in lakes over time.** Currently, the existing satellite FHAB tool only provides information on CIcyano index values on individual lakes; remotely sensed chlorophyll-a is also available but is not being used. The TAC recommends: 1) acquiring the chlorophyll-a data from NOAA and 2) each year, summarizing the seasonal (winter, spring, summer, fall) and interannual trends in CIcyano index values and chlorophyll-a across lakes and reservoirs in the state. This action represents the lowest hanging fruit and can be implemented now. A core component of this work (**SS11, Appendix 6**) involves the development of robust data management, quality assurance and data analyses to make routine queries of the OLCI data to produce this status and trends annual report. CYAN has developed appropriate workflows that can be adapted for California status and trends assessments in lakes and reservoirs (Mishra et al. 2019). Linking these data to *in situ* values of phycocyanin and chlorophyll-a would make the outputs from such analyses more actionable (**SS10, Appendix 6**)

2. **Conduct a special study to acquire Sentinel 2 chlorophyll-a data for all lakes for a pilot status and trends assessment across all California lakes (SS13, Appendix 6).** Sentinel 2 data will not be routinely available from USGS for ~5 years. However, the opportunity exists to work with national partners to process and assess changes in remotely sensed Chl-a for all California lakes > 1 ha. This would be an extremely valuable data set that would serve as a cornerstone for status and trends assessment of REC2 and as well as other uses into the future (i.e., aquatic life, Section 4.3, and raw source water protection, Section 4.4). An important component of this study would be to identify minimally disturbed "reference" lakes that could serve as a target population for further in depth characterization to answer the questions: "What is the magnitude and frequency of FHABs in all lakes and reservoirs, compared to those that are minimally disturbed (e.g., natural background)?" and "How is climate change impacting the magnitude and frequency of FHABs in lakes and reservoirs across California?" We note that special studies of this type provide opportunities to train scientists and Water Boards employees or state partners.

4.2.2 Ambient Field Surveys

The TAC considered two types of FHAB monitoring that have the potential to contribute to FHAB status and trends: 1) state-implemented (i.e., SWAMP) and 2) partner ambient surveys. The potential contribution of each approach is discussed below for each of the core uses (recreational, fishable aquatic life and raw water) and leveraging opportunities with existing efforts are discussed. Assessment of tribal and cultural uses is in essence both a partner monitoring program and leveraging opportunity. Therefore, the focus is in that section on how the State Water Board could effectively partner with tribes on assessment of these uses.

Recreational Use

Options for Ambient Recreational Use Field Surveys
Partner Implemented Field Surveys – Basic design – **Leveraging option**: Beach **Safety Monitoring Program-AB 411 (1997) for fecal pollution**
State Implemented Field Survey – Basic state implemented design – Hybrid design (with partners) – **Leveraging option**: aquatic resource surveys (e.g., perennial stream assessment)

Several optional approaches were considered for field survey designs to address recreational use. They range from partner implemented, targeted surveys to SWAMP surveys across waterbodies (probability or targeted). Here, the difference between waterbody-specific assessments versus surveys across multiple waterbodies is the goal. The intent of these targeted intensive surveys is to frequently measure FHABs in order to assure the protection of public health. Surveys across waterbodies are intended to report out how FHABs are impacting recreational use across the state, but because of the spatial scale being assessed, they cannot assess frequently enough to assure that public health in sampled waterbodies are being protected. <u>This is a fundamental tradeoff for managers to consider</u>. We note that these approaches are not mutually exclusive, and some hybrid versions can also be considered. Since this is a priority TAC recommendation, an important implementation action would be to develop a design for a state-coordinated recreational fish survey (**SS14, Appendix 6**).

State Implemented Field Surveys

State Implemented Survey Design. The TAC discussed statewide survey designs that might be cost-effective to assess how FHABs are impacting recreational use across the state, with the caveat that at the spatial scale being assessed, such <u>designs cannot assess frequently enough to assure that public health in sampled waterbodies are actually being protected</u>, other than on the days that were assessed. They discussed a design that could occur a minimum of three times during a peak recreational use season (two weeks before Memorial Day to two weeks after Labor Day) at shoreline sites, with FHAB total toxins, and algal and cyanobacterial community composition (benthic and or planktonic, depending on waterbody type and habitat sampled; see high resource module, Figure 3.3). Sites could be chosen probabilistically from a sample frame of all recreational sites in the state (or just focus on one waterbody type, e.g., lakes).

Conceptually, a state coordinated (e.g., SWAMP) ambient assessment has some potential advantages that made it worth considering to assess status and trends of recreational use: 1) it can be customized to the management information needs of the state with unbiased site selection and sampling across waterbody types within regions or statewide, and 2) SWAMP surveys typically have smaller field teams that have the ability to mandate higher training, intercalibration and quality assurance of data collected, thus assuring higher data quality. However, due to the required minimum frequency of sampling at each site (≥ 3), this is not likely to be the most cost-effective approach; repeat sampling may be cost prohibitive and logistically intractable with a finite set of field crews.

The TAC discussed several options for how to address the issue of cost-effectiveness. The first option was a statewide survey design in which an "end of season" sediment toxin sample would be collected to represent seasonally integrated FHAB toxic burden. Two other options conducted across priority waterbodies in a region or focused specifically on priority watershed would integrate status and driver assessments. Either of these options could be implemented as part of a tiered approach that included screening (see Chapter 7) to identify waterbodies or watersheds that are considered high priority. These three survey designs are presented in Chapter 5.

State and Partner Implemented Hybrid Survey Design. The SWAMP FHAB Program is currently implementing a recreational use survey that represents a hybrid between state-implemented and a partner implemented assessment: the pre-holiday FHAB assessment. As background, the FHAB pre-holiday assessment has been a cornerstone of HAB reporting on the MyWaterQuality website since 2017. Each year, it sends out a request for partners to participate in the assessment. Roughly 50-60 high recreational use waterbodies are selected, representing high intensity use lakes, reservoirs and rivers with existing FHAB problems. Partners collect the samples for toxin and assess visual indicators of blooms. The Water Boards SWAMP program pays to analyze the toxin samples. Recommended advisory levels are based on cyanotoxin testing results and/or visual indicators, and recreational sites are posted accordingly. Results of the pre-holiday assessment can be viewed by the public through an interactive website.

This hybrid concept has some significant strengths to assess statewide status: 1) It does not attempt to extrapolate risk to recreational uses over the entire season. Rather, it characterizes risk during a snapshot before a time period with the peak recreational use — a summertime holiday (e.g., Labor Day), and 2) it addresses the intractable problem of field crews needing to be in all places at once by employing partners to conduct the field sampling for seasonal recreational use assessment. For this reason, four possible design modifications were proposed to the existing approach for the pre-holiday FHAB assessment concept, in order to consider how such an approach could contribute to an assessment of statewide or regional status and trends: 1) expand the target population, 2) expand the temporal coverage, 3) include explicit resampling to report on trends, and 4) expand indicators to increase actionable information.

Partner Implemented Field Surveys

Waterbody-specific status and trends of FHAB impacts on recreational uses would be most readily assessed through the low/high resource monitoring approach outlined in Section 3.2. Monitoring frequency would be biweekly or if possible, more frequently at shoreline recreational use sites in lakes and reservoirs, rivers and streams, and coastal confluences. Priority indicators and metrics were identified for the low resource tier and high resource tier that could contribute towards recreational use status and trends (Figures 3.2 and 3.3).

Collectively, core indicators of toxigenic cyanobacteria dominance and aesthetic impairment can be used to derive a recreational "grade" to specific waterbodies over time. This recreational “grade” system would be similar to the beach grade assigned by Heal the Bay that assesses available fecal pollution data, mostly produced by the BSMP (AB 411) that routinely monitors fecal pollution at public beaches. The waterbody could receive a recreational use “grade” based off a combination of spatial percent cover and toxigenic cyanobacteria dominance reflective of impairment and risk for toxins based on what genera are dominant. The BSMP (AB 411) is a great example of what can be accomplished through partner recreational use monitoring and is also an important leveraging opportunity (Figure 4.9). The BSMP (AB 411) was established in response to Assembly Bill 411 that was approved in 1997 to require local health agencies to monitor fecal pollution at public beaches[16] and posting to inform the public of beach sanitation. In 2012, administration of the program was changed from the California Department of Public Health (CDPH) to the State Water Board.

A partner program has tremendous potential to contribute to statewide or regional status and trends of FHABs impacts on recreational use. However, reliance on a partner program alone may be problematic, for several reasons. First, the utility of a partner program to contribute to statewide picture of status and trends depends on the extent of enrollment (and coverage of recreational beaches), their commitment to providing data (i.e., not just data for the sites that have low risk), and the level of participant training and data quality assurance/control. If the program is indeed voluntary and the number of enrolled sites limited, the statewide status and trends based on these sites have an inherent bias and no ability to speak to the entire recreational resource base as a whole. Second, quality assurance and intercalibration can be more problematic with program participants. These important implementation components would need to be condition of participation by stipulating that: 1) the program participant have a quality assurance project plan, in which the sampling plan has been reviewed and approved and 2) the program participants participate in regular intercalibration exercises.

Leveraging opportunities

Two major types of leveraging opportunities were considered: 1) BSMP (AB 411) and 2) existing SWAMP aquatic resource surveys.

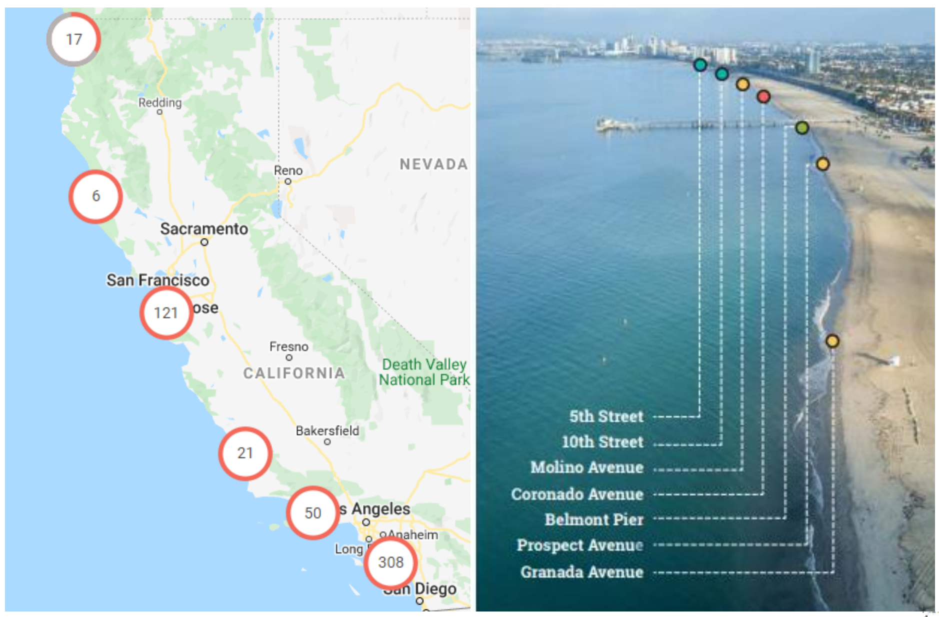
The BSMP (AB 411) could be leveraged to monitoring FHAB recreational risk. Along the coast, open ocean (88 locations), storm drain (222 locations), and enclosed beaches[17] (92 locations) are sampled for BSMP (AB 411). Enclosed beaches and perhaps even the urban areas with storm drains are synonymous with the target population of coastal confluences of interest for FHAB recreational use sampling. We recommend consideration of the possibility of leveraging BSMP (AB 411) sampling at these enclosed beaches to include FHAB risk assessment. At minimum, a special study **(SS15, Appendix 6**) could be conducted at enclosed beaches to assess the summertime FHAB health risks to beachgoers. A similar recommendation could be directed at leveraging the BSMP (AB 411) for inland waters, though admittedly the inland program does not have the strength of the coastal program.

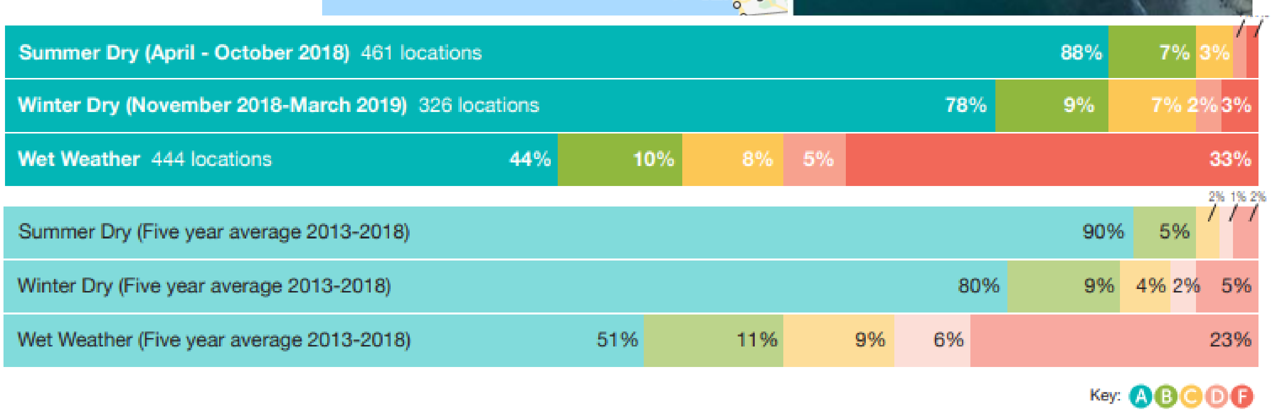
[16] Public beaches are defined in AB 411 (1997) as a beach located within the coastal zone, as defined in section 30103 of the Public Resources Code. Generally, these public beaches are visited by more than 50,000 people annually and located on an area adjacent to a storm drain that flows in the summer. Monitoring sites are at public beaches and waters adjacent to public beaches.

[17] Enclosed beaches are defined in the Beach Safety Monitoring Program (AB 411) as those that *“have obstructions like a land mass or wall blocking the beach from the open water. Therefore, these beaches do not receive waves and have poor water circulation. Enclosed beaches are usually found in lagoons, marinas, and harbors. Due to their calm waters, enclosed beaches are popular areas for small children and are frequently named ‘baby beach’ or something similar.”*

It is worth considering how to strengthen monitoring of inland beach (rivers, lakes, and reservoirs) recreational health risk from both fecal indicator and HABs, since the sampling approaches are compatible. A combined inland beach and safe-to-swim program could leverage resources from the FHABs Monitoring program and public health fecal indicator bacteria (FIB) monitoring could increase the capacity of both monitoring efforts. An Inland Beaches Workgroup, under the Safe-to-Swim Network exists in the California Water Quality Monitoring Council (https://www.mywaterquality.ca.gov/monitoring_council/swim_workgroup/), and already, many entities are collecting FIB data at inland beaches across California (https://mywaterquality.ca.gov/safe_to_swim/). Having staff collect both FHAB and FIB data would maximize the use of their time, and results could then be communicated in an integrated way. Currently in the Russian River, Sonoma County Environmental Health monitors for FIB and FHABs, but the messaging and public communication are independent for both these indicators. An inland recreational use monitoring program modeled on BSMP (AB 411) that combines FHABs and FIB indicators would be most efficient at utilizing state financial and personnel resources and provide a more comprehensive evaluation of swimming safety to communicate to the public, than if FHAB and FIB monitoring continue to be siloed.

Figure 4.9. Top left panel: Distribution of BSMP (AB 411) beach sampling sites across the state. Top right panel: examples of specific beach locations shown for Long Beach. Bottom panel: Overview of Heal the Bay's water quality health grades for California beaches. Colors represent letter grades ranging from A (blue, excellent) to F (red, very low).





The TAC considered the merit of conducting recreational use sampling in tandem with existing aquatic resource surveys that presented leveraging opportunities, but ultimately did not recommend the following options for recreational use assessment: 1) SWAMP perennial stream assessment (PSA), and 2) National lakes and stream assessments. **Both have inherent design components that prevent leveraging these to assess status and trends of recreational uses.** For the SWAMP Perennial Stream and the National Rivers and Streams Survey (NRS) aquatic resource surveys, the sampling locations are probabilistically chosen on the basis of a sample frame that represents a continuous resource (i.e., stream drainage network), rather than a segment that contains a recreational use area. Thus, when a stream site is chosen, there is no guarantee it will be a recreational site. With the National Lakes Assessment (NLA), a similar problem exists. States do not have control over criteria for site selection[18]. Thus, PSA and NLA fundamental site selection is incompatible with that needed for a resource use survey (i.e., stream segment that contains a recreational use site). Second, these types of surveys (PSA, NLA and NRS surveys) are based on a one-time site visit. *For these reasons, the TAC did not recommend that any of these national aquatic resource survey leveraging opportunities be pursued for recreational use status and trends assessment.*

Fishable Uses

State Coordinated Field Surveys

Options for Fishable Use Ambient Field Surveys
Partner Implemented Field Surveys – Basic Design – **Leveraging option**: CDPH Biotoxin Monitoring Program
State Coordinated Field Survey – State implemented (statewide, regional, and watershed designs-presented in Section 5.2) – **Leveraging options**: BOG “Bass Lakes” Status and Trends Assessment and SWAMP SPoT Program (Large Rivers)

The TAC considered statewide survey designs to assess how FHABs are impacting fishable use across the state, with the caveat that at the spatial scale being assessed, such designs cannot assess frequently enough to assure that fishable uses in sampled waterbodies are actually being protected, other than on the days that were assessed. They discussed a design that could occur during peak fishing use season (two weeks before Memorial Day to November, depending on latitude and elevation) at shoreline sites, with FHAB fish toxins, water column and sediment total toxin, and algal and cyanobacterial community composition (benthic and or planktonic).

Cyanotoxins do not persist as long as other contaminants, such as lead, that are monitored by the state in fish tissue. Therefore, new monitoring protocols and procedures for cyanotoxin monitoring need to be developed de novo. Additionally, for appropriate cyanotoxin concentration thresholds to be set, special studies to fill data gaps will be required prior to threshold development. For these reasons, a *de novo* SWAMP survey of FHABs in fish and shellfish was not prioritized by the TAC for early implementation in an FHAB monitoring program. The central TAC recommendation was that FHAB fishable use assessments should be prioritized in waterbodies with known FHAB problems. Therefore, this section focuses on the potential leveraging opportunities and protocol development that could be used to implement such an approach, either through state-supported or partner monitoring.

[18] States can intensify sampling of the NLA by adding site, but they must bear the costs of sampling and laboratory analyses.

Partner Implemented Field Surveys

The central TAC recommendation was that fishable use FHAB impacts should be prioritized in waterbodies with known FHAB problems. Gassel and Brodberg (2005) and USEPA (2000) recommend an initial screening of waterbodies to determine which commercial, recreational, subsistence, or sport fish, or shellfish species exceed human consumption levels of potential concern. If exceedances of tissue toxins are detected, then a Tier II intensive follow up of those waterbodies would be warranted to identify the magnitude and geographic extent of contamination and to inform advisories or closures (waterbody wide or specific geographic areas).

A general protocol exists for sampling of fish tissue assessing mercury and/or methylmercury concentrations in freshwater fish and shellfish (Gassel and Brodberg 2005); this protocol serves as the basis for OEHHA fish advisories. We recommend that a new standardized FHAB fish and shellfish biotoxin monitoring protocol be developed, for which a special study is needed (**SS16, Appendix 6**). This protocol should be accompanied by standardized data transfer formats for uploaded to statewide databases (e.g., CEDEN), plus appropriate training modules to ensure consistent implementation.

FHAB impacts to both fishable and recreational uses are potential human health risks. Aquaculture (shellfish, inland and estuary finfish) and stocked "fishing" ponds could be considered for routine (weekly to biweekly) FHAB toxin testing, as is required by the CDPH for marine biotoxins (see leveraging opportunity below). The Water Boards and other state agencies could collaborate to consider specific agency programs where such monitoring could be specifically required.

Leveraging Opportunities

Three major leveraging opportunities exist: 1) CDPH Marine Biotoxin Monitoring Program, 2) SWAMP field surveys, and 3) regional monitoring partnerships.

OEHHA, CDPH, and CDFW collaborate on the monitoring of marine biotoxins in recreational and commercial seafood. Much of this effort is, at least for the commercial side, under the regulatory framework of FDA and the Interstate Shellfish Sanitation Conference (ISSC).[19]

The CDPH Marine Biotoxin Monitoring Program represents a potential leveraging opportunity for an FHAB fishable monitoring program component. A potential partnership with CDPH could consist of adding tissue cyanotoxins to their analyte list (**SS17, Appendix 6**). Additional collateral indicators of interest could be: 1) integrated chlorophyll-a sample, 2) FHAB relative abundance and 3) total water column toxin concentrations. Inland sites could also be added to pair coastal confluence with source but would increase the burden of sampling. Beyond the significant advantage of cost savings and leveraging, other advantages include: 1) overlap of target population (coastal confluences), including <u>all shellfish growers</u>, 2) achieving the optimal temporal frequency of sampling (weekly), and 3) sampling approach that is compatible for collection of FHAB shellfish tissues (wild and cultured shellfish). The only apparent disadvantage, without CDPH program expansion, would be the limited number of locations currently sampled (~20-30 along the coast) that represents about 5% of the roughly 400 coastal confluences). This could be expanded by identifying additional voluntary groups along the coast willing to undertake such a sampling for a screening level study of coastal confluences; alternatively, if need be, the target population of

[19] Chapter 6: Natural Toxins August 2019; Appendix 5: FDA and EPA Safety Levels in Regulations and Guidance March 2020; https://www.fda.gov/food/seafood-guidance-documents-regulatory-information/fish-and-fishery-products-hazards-and-controls

waterbodies could be narrowed down by prioritizing those watersheds based on: 1) presence of waterbodies with FHAB problems, 2) where passive sampling has demonstrated moderate to high degree of cyanotoxin presence, or 3) areas where moderate to high nutrient loading or other eutrophication risk indicators exist. A special study could investigate whether existing recommended precautions for fish and shellfish consumption based on visual indicators and cyanotoxins in water and existing marine shellfish is sufficient to address any occurrence of elevated fish/shellfish tissue concentrations in edible tissues **(SS18, Appendix 6).**

Two SWAMP field surveys have the potential to contribute additional information to effects of FHABs on fishable uses: 1) SWAMP Bioaccumulation Oversight Group (BOG) "Bass Lake" status and trends bioaccumulation survey, and 2) SWAMP Stream Pollution Trends Program (SPoT). Cost savings of partnering can be considerable, since program implementation and field sampling alone typically represent about 60-75% of total monitoring costs. Evaluation of the utility and specific indicators, focal species, and temporal and spatial design considerations are given below.

The SWAMP BOG Status and Trends assessment of "Bass Lakes" representing an important resource that supports a popular sports fishery in California. BOG conducts a long-term status and trends assessment program consisting of ~190 lakes of highest priority to Regional Water Boards, in which 38 lakes are revisited every two years on a 10-year cycle for status updates. Sport fish and prey fish tissue are sampled, mainly via boat with electroshocking equipment. Sampling occurs during one event throughout April – September; the number of stations varies with lakes size (e.g., ranging from one for small lakes (< 500 ha) to 4 stations for very large lakes (> 5000 ha)). Fish tissue contaminant concentrations are analyzed, along with morphometrics, moisture, and lipid content. Visual observations of blooms are now being noted.

A potential partnership with BOG could consist of adding tissue cyanotoxins to their analyte list. Additional collateral indicators of interest could be: 1) integrated chlorophyll-a sample, 2) FHAB cell density, and 3) total water column toxin concentrations. Strong synergies exist including: 1) overlapping target population (popular sport fishing lakes), 2) compatible targeted index period, though early season visit (April-June) are not ideal for FHAB sampling, and 3) sampling approach that is compatible for collection of FHAB fish tissues. Disadvantages exist: 1) the single sample event under characterizes FHAB fishable risk, and 2) it is unclear whether focal species, which were optimized for mercury bioaccumulation, are the most reasonable choice for FHAB toxin analyses. To address this issue, a pilot project (**SS18, Appendix 6**) could be implemented during a single year that collects fish in ~3-5 sports fishing lakes with chronic FHAB problems to identify the species most likely to exhibit FHAB toxins (Hardy et al. 2015). That special study would need to investigate depuration rates of cyanotoxins exhibited by these different species. Adding sampling events to better characterize risk would greatly increase program cost. Additionally, BOG could partner with FHAB to collaboratively co-fund a new cyanotoxin monitoring program.

The Stream Pollution Trends Program (SPoT) Survey assesses contaminant concentrations in selected large rivers throughout California (SWAMP 2008; see SPoT factsheet). SPoT is designed to improve understanding of watersheds and water quality by monitoring changes in both over time, as well as evaluating impacts of land use and development, and assessing the effectiveness of regulatory programs and conservation efforts at the watershed scale. The SPoT Survey measures contaminant concentrations and toxicity in sediments that accumulate in the lower reaches of large watersheds; 100 sites have been analyzed annually since 2008 for industrial compounds, legacy and current-use pesticides, and metals, as well as tested for toxicity to a resident aquatic crustacean, the amphipod *Hyalella Azteca*. In 2013, SPoT carried out a pilot study to assess the extent of sediment algal toxin concentrations. Preliminary data show up to 29% of samples had microcystin detections. Future research highlight interest in analysis of spatial and temporal patterns in toxicity and its correspondence to FHAB toxins (Phillips et al. 2016).

Though the SWAMP SPoT Survey is designated as an aquatic resource survey, opportunities exist to leverage this program to improve information on FHAB effects on fishable uses. A potential partnership with this program could consist of collection of freshwater mussels on site and analysis of tissue cyanotoxins. Additional collateral indicators of interest could be integrated (benthic or water column) algal discrete sample, used to quantify: 1) benthic Chl-a, 2) FHAB cell density or relative abundance, and 3) sediment toxin concentrations. The most significant advantage is that it addresses a target resource (100 large rivers) that are otherwise difficult to comprehensively sample. The two significant disadvantages include: 1) a single summertime sample event under characterizes FHAB fishable risk; adding one or two more sampling events would significantly increase the cost of the survey overall and 2) adding additional field indicators may present logistical issues to field crews by lengthening the field day and reducing the number of site visits achievable per day.

Finally, leveraging opportunities exist with long-standing regional monitoring programs. An example of this is the San Francisco Bay Nutrient Management Strategy monitoring of shellfish biotoxins, including cyanotoxins (Gibble et al. 2016; see inset box), which presents an important leveraging opportunity. Other regional programs such as the Southern California Bight Regional Monitoring Program have monitored shellfish and invertebrate biotoxins (Smith et al. 2021) and represent a future leveraging opportunity.

Aquatic Life and Raw Water Uses

State Coordinated Field Surveys

Optimal field survey designs would generally follow the design approaches of typical aquatic resource assessments (Wadeable Streams PSA and RCMP, SWAMP SPoT Survey, etc.): 1) probability-based to assure balanced sample of the aquatic resource, 2) integrated sampling of the water column or benthic habitat, and 3) to the extent possible, integrated assessment with environmental drivers. While optimized for aquatic resource assessment, this approach is generally consistent with that used for raw source water characterization. At bare minimum, DOC could be added as a routine water quality measure or, flagged specifically for toxin or taste and odor measurements where MUN is a designated use of a site being sampled, or upstream of drinking water designated lakes and reservoirs.

Options for Aquatic Life Use Ambient Field Surveys
State Coordinated Field Survey – State implemented (statewide, regional and watershed designs-presented in Section 5.2) – **Leveraging options:** Wadeable Streams PSA and RCMP, SWAMP SPoT Program (Large Rivers), and National Lakes Assessment
Partner Implemented Field Surveys – Basic design – **Leveraging options**: state/federal and regional aquatic resource monitoring programs

As with recreational use, a state directed (i.e., SWAMP) ambient assessment of aquatic life and raw drinking water sources has many potential advantages that made it worth considering for assessing FHAB risk to these uses. However, recommended frequency of sampling to some degree limit the utility of state-led ambient assessments (or leveraged one time national or statewide aquatic resource surveys) to contribute an adequate characterization of risk, especially on a statewide scale, particularly with respect to toxin concentrations. The TAC considered four new survey designs that scale from statewide to watershed; these are integrated with environmental drivers and therefore are presented in Section 5.4.

Partner Implemented Field Surveys

Partner monitoring holds great promise to expand information on condition of aquatic resources and raw water sources. An opportunity exists to strengthen approach to partner implemented FHAB assessments and to provide a pathway through these data could be harvested to build towards a picture of aquatic life and raw water source impacts. One of the successes of the SWAMP Bioassessment Program has been the investment in the “infrastructure” that allowed a proliferation of partner bioassessment monitoring. Today, these data represent ~40% of all records in the statewide wadeable streams bioassessment database and ~80% in southern California alone. Specifically, the “infrastructure” provided by the SWAMP Bioassessment Program was focused on: 1) standardized methods and tools to conduct bioassessment, 2) core monitoring to generate multiuse data sets, and 3) collaboration to leverage (partner program) partnerships to expand the body of knowledge and tools. A key to the success of SWAMP’s Bioassessment Program is the role it has played in standardizing protocols, training and supporting numerous independent entities conducting probability surveys, including EPA’s National Rivers and Streams Assessment, Southern California Stormwater Monitoring Coalition, Bay Regional Monitoring Program, Tahoe Regional Planning Agency, Bureau of Land Management, and U.S. Forest Service. Data from these programs contribute a substantial proportion of the records available in the bioassessment statewide database.

Strategic investments in FHAB “infrastructure” within the SWAMP Bioassessment Program could yield important early dividends to improve our characterization of the State’s surface waters. We recommend that a partner program for aquatic life and raw water sources be developed. These investments in this infrastructure should be extended for all waterbodies – wadeable streams, lakes and reservoirs, and coastal confluences. Examples of low-hanging fruit include the development of SOPs, data management and training modules to conduct lake bioassessments, focusing first on algal indicators (abundance, algal community composition via molecular barcoding) and toxin measures (**SS22, Appendix 6**). ASCI FHAB indices could be developed for both streams and lakes, which could use a combination of the relative abundance of toxigenic FHAB to total algal species. The investments can be paired with collaborations within Water Boards programs to incorporate monitoring of FHAB status, trends and drivers into implementation of new or amended policies (biostimulatory objectives) and water quality programs (NPDES, irrigated lands, municipal stormwater, etc.).

Leveraging Opportunities

Three existing statewide surveys could be leveraged to provide data on statewide status and trends on aquatic life and, with modifications, could provide additional information on raw water source protection*:* 1) SWAMP perennial wadeable stream assessment (PSA) and Perennial Wadeable

Stream Reference Condition Management Program (RCMP), 2) SPoT Survey, and 3) National Aquatic Resource Surveys (lakes and streams).

PSA and RCMP Assessments of Wadeable Streams. The PSA is a long-term statewide status and trends survey of the ecological condition of California wadeable perennial streams and rivers throughout California. PSA collects bioassessment data on aquatic life indicators (benthic macroinvertebrates [BMI] and algae), chemical constituents (nutrients, major ions, etc.), and physical habitat assessments for both in-stream and riparian corridor conditions. To date, data from thousands of sites have been collected by PSA and its partner programs. The RCMP is California's program for establishing and maintaining a network of reference sites for wadeable streams and rivers throughout California and utilizes the same protocols as the PSA. This network is used to maintain the definition of biological conditions expected in healthy streams when human activity in the environment is absent or minimal. Currently a total of 615 sites have been assessed in the RCMP and they continue to assess ~ 55 reference sites per year. The RCMP will continue to benchmark expected reference conditions for BMI (California Stream Condition Index, Mazor et al. 2016) and algal-based indices of biotic integrity (Figure 4.10, ASCI, Theroux et al. 2020). It is supplemented by reference programs of several partner agencies (e.g., U.S. Forest Service, Tahoe RPA, and the USEPA).

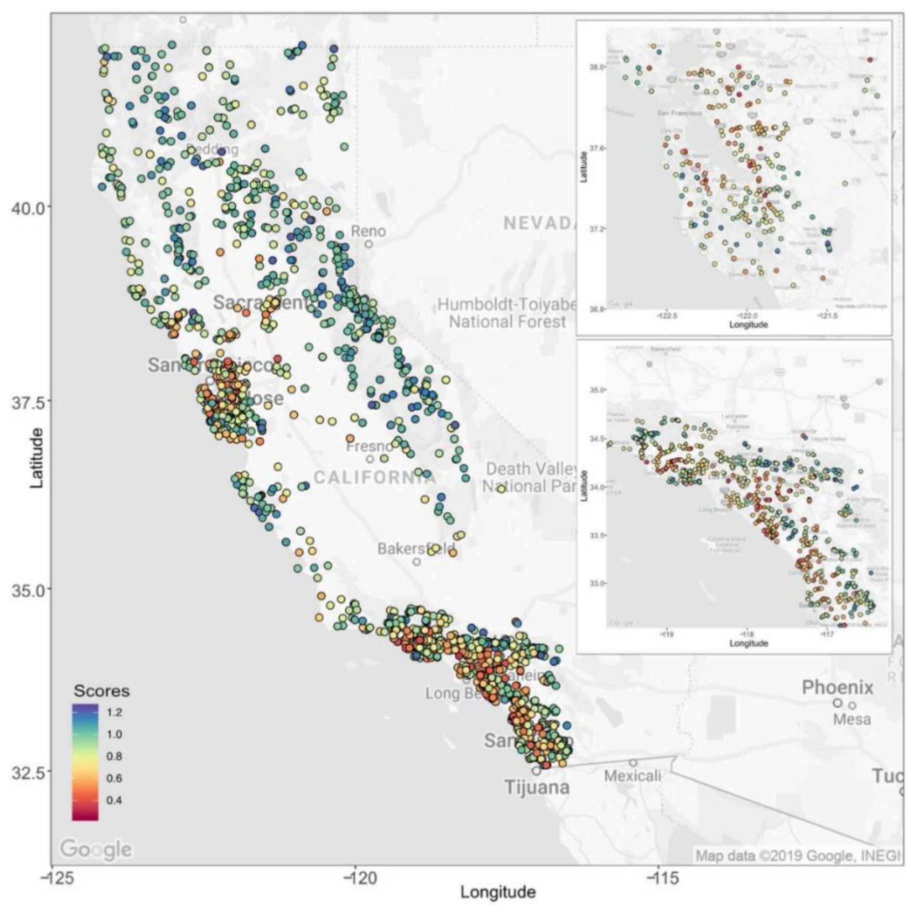


Figure 4.10. Results of the PSA showing the condition of California perennial wadeable streams using the ASCI Hybrid multimetric index, with inset detailed view of Bay area (top) and Los Angeles (bottom). From Theroux et al. (2020). Scores range from > 0.95 (likley intact), 0.88- 0.95 (possibly altered), 0.78 – 0.88 (likely altered), < 0.78 (very likely altered).

The PSA and RCMP are one of the most significant leveraging opportunities to assess FHAB effects on aquatic life and raw drinking water source status for wadeable streams. Advantages include: 1) statewide status and trends design that could be used to extrapolate to the a important component of the streams and rivers target population, 2) well established, extensive reference network that can allow an improve understanding of the "natural background" of FHAB magnitude and how climate change (e.g., drought, increased temperatures, and changes in precipitation patterns, etc.) may impact their prevalence in the future, 3) high quality standardized operating procedures, data management, quality assurance and training, and 4) assessment of algal community and abundance indicators and a large suite of environmental drivers, including a significant push towards molecular barcoding. SWAMP has already summarized the status of algal abundance in the state and within each ecoregion relative to reference (Fetscher et al. 2013).

Significant disadvantages also exist. First (and the most significant), the temporal frequency of sampling (single event) under characterizes the risk of FHABs. TAC members were not united on a recommendation, but a minimum of three times was suggested. Second, the bioassessment index window, which is optimized for BMI may not be capturing peak abundances (Fetscher et al. 2015). Adding even one or two more sampling events would significantly increase the cost of the survey. Third, the bioassessment protocol for algae is optimized for bioassessment (taxonomic composition) and is only semi-quantitative for biomass measures of benthic Chl-a and ash-free dry mass (Sutula et al. 2021). Adding additional field indicators will present significant logistical issues to field crews by lengthening the field day and reducing the number of site visits achievable per day. Given the richness of this dataset, particularly with respect to potential environmental drivers (see Chapter 5), we recommending leveraging the SWAMP Bioassessment program as follows:

1. Use wadeable streams bioassessment data (algal abundance measures and dominance of toxigenic species) as FHAB screening level data to identify sites or catchments in watersheds that require additional more intensive monitoring (e.g., 3 times per season in intermittent and 5 times per season in perennial sites).
2. Revise the algal SOP to include collection and analyses of total benthic or water column toxins.
3. Develop an FHAB-specific ASCI index, which could use a combination of the relative abundance of toxigenic FHAB to total algal species **(SS19, Appendix 6**).
4. Improve quantitative assessment of biomass and consider measures of total organic carbon and nitrogen that can be used to assess total organic matter accumulation and distinguish between algal/microbial versus refractory organic matter (by C:N ratio; **SS22, Appendix 6**).

The Bioassessment Workgroup has already considered streamlining the algal SOP to improve cost effectiveness. These FHAB recommendations should be considered as the review is undertaken.

Stream Pollution Trends (SPoTs) Survey. The SPoTS is an aquatic resource survey that assesses contaminant concentrations in selected large rivers throughout California (SWAMP 2008; see SPoTs factsheet and previous brief discussion for fishable uses). The SPoTs is an important leveraging opportunity to assess FHAB impacts on aquatic life use and raw water because: 1) SPoTs stations are at the terminus of major watersheds and thus can integrate inputs from their catchments; 2) they represent large rivers (many of them non-wadeable) as well as, where applicable, the terminal point of freshwater inputs to coastal confluences; and 3) additional collateral indicators of interest could be integrated (benthic and/or water column) algal discrete sample, used to quantify planktonic and/or benthic Chl-a, FHAB cell density or relative abundance, and sediment toxin concentrations. We noted two significant disadvantages that also apply here: 1) a single summertime sample event under characterizes FHAB fishable risk; adding one or two more sampling events would significantly increase the cost of the survey overall, and 2) adding additional field indicators may present logistical issues to field crews by lengthening the field day and reducing the number of site visits achievable per day.

The recommendation for the SWAMP PSA and RCMP program also applies here. Data from a partnership with the SPoTs program can be considering screening level, with additional follow up at site flagged for more intensive monitoring. To accomplish this, new indicators must be added to the SPoTs protocol. We recommend that the algal abundance and molecular barcoding samples be collected to screen for impacts due to FHAB high biomass or dominance of toxigenic FHAB species. FHAB toxins in freshwater mussels and sediments could be analyzed as a lower tier of priority, pending excursions of high biomass or presence of toxigenic species or available resources. If this recommendation is adopted, then a special study is needed to adapt benthic and pelagic algal bioassessment protocols specifically for these large river systems to minimize burden on field staff and keep costs low (**SS22, Appendix 6**).

US EPA National Aquatic Resource Surveys. The National Aquatic Resource Surveys (NARS) are probability-based surveys designed to assess the status of and changes in quality of the nation's coastal waters, lakes and reservoirs, rivers and streams, and wetlands. They provide a snapshot of the overall condition of the nation's waters (Pollard et al. 2018). Because the surveys use standardized field and lab methods, results are compared from different parts of the country and between years to assess overall status and trends. EPA works with state, tribal, and federal partners to design and implement the National Aquatic Resource Surveys to answer questions such as: 1) What percent of waters support healthy ecosystems and recreation? 2) What are the most common water quality problems? and 3) Is water quality improving or getting worse? The NARS are made up of four individual surveys (coastal, lakes, rivers and streams, and wetlands) that are implemented on a rotating basis, roughly every 5 years. NARS is already integrated with wadeable stream PSA (and therefore accounted for in the above discussion); the design of national coastal assessment tend to focus on large enclosed bays and harbors and have a sampling design that is not relevant for FHABs; therefore, potential leveraging opportunities with NARS exist for lakes and reservoirs (National Lakes Assessment, NLA, https://www.epa.gov/national-aquatic-resource-surveys/nla), because SWAMP does not currently have a bioassessment program for lakes.

The NLA offers an important leveraging opportunity to assess aquatic life especially since collecting a sampling at the deepest point in the lake requires boats that make relying a partner program to fill this void more problematic. The question is how to incorporate the data NLA produces to serve the status and trends goals of California. Towards this end, we recommend that NLA data be considered (particularly total nitrogen and phosphorus and chlorophyll-a), along with remotely sensed Chl-a and CIcyano as HAB screening level data to identify sites or catchments in watersheds that require additional more intensive (high frequency) monitoring. Sites that have excursions of recommended thresholds for water column Chl-a measures and dominance of toxigenic species could be flagged for follow up for intensive monitoring.

Partner Regional Monitoring Programs. We recommend partnerships with regional monitoring programs be specifically pursued, because of the potential to contribute large regional datasets. Examples include Bay-Delta Monitoring (Interagency Ecological Assessment Program (IEP), the San Francisco Bay Nutrient Management Strategy monitoring of water column FHAB indicators, including particulate toxins and shellfish biotoxins, including cyanotoxins (Gibble et al. 2016), which presents an important leveraging opportunity. Other regional programs such as the Southern California Bight Regional Monitoring Program are focused on aquatic life and have monitored FHAB and eutrophication indicators (McLaughlin et al. 2014) and total water column and tissue toxins in shellfish and invertebrate biotoxins (Smith et al. 2021); as such they represent an important future leveraging opportunity.

Tribes and Cultural Uses

Tribes are sovereign nations that are self-governing, have an excellent track record of environmental stewardship and many tribes have developed their own water monitoring programs. These tribal monitoring programs are established by tribes for the benefit of tribal members. The program designs developed by each tribe are concentrated on specific questions and concerns by a given Tribal Government and are centered around that Tribe's values and priorities. Currently, 56 tribes have water quality monitoring programs with federally accepted quality assurance project plans (QAPP). These monitoring programs have data submitted to the federal Water Quality Exchange (WQX) database. Collaboration and sharing of monitoring data beyond date submitted to WQX with the State should not be assumed; however, many tribes conducting water quality monitoring would like to see their data being used in management decisions and welcome collaborations to achieve shared goals towards improved water quality. Partnerships between tribes and public agencies should be explored to strengthen and integrate FHAB monitoring programs at State, regional, and local scales.

Several tribal monitoring programs are focused around FHABs and represent partnerships between multiple tribes with state, local, and federal agencies to protect tribal and cultural beneficial uses along with recreational uses. **Appendix 4** gives two examples of collaborative monitoring programs led by Tribes to protect tribal beneficial uses in culturally significant waterbodies: 1) Clear Lake and 2) the Klamath River in California. These programs serve as models for the types of partnerships that the Water Boards are seeking for their FHAB partner programs.

Examples of Tribal Monitoring Programs for FHABs
Clear Lake Cyanotoxin Monitoring – Collaborative effort between Big Valley Band of Pomo Indians and Elem Indian Colony – Initiated in 2014 by tribes following several years of large bloom events – Data used to protect both tribal beneficial uses and recreational uses, submitted to federal WQX database and also appears in the SWAMP Incident response
Klamath River HAB Monitoring – Initial monitoring grew to a consortium of Karuk Tribe, Yurok Tribe, Hoopa Valley Tribe and Quartz Valley Indian Reservation. – Initiated in 2005, expanded through several partnerships – Data are collected/used to protect both tribal beneficial uses and recreational uses, submitted to federal WQX database and also appears in the SWAMP Incident response

Tribal and cultural beneficial uses are distinct from the other beneficial uses considered in this strategy. With varied tribal and cultural uses across the state, no single monitoring design could encompass the diversity of cultural practices of Tribes in California. Monitoring efforts to protect tribal beneficial uses should be centered around the individual tribal needs and values and ultimately the design decisions should be governed by individual Nations. With the diversity of tribal uses of waters for cultural practices comes a diversity of cyanotoxin exposure pathways. Indigenous people can be uniquely impacted by FHABs and in many cases they experience longer, more varied exposure pathways compared to the types of exposure that generally occur during recreational uses. This is a unique consideration, and ultimately, health thresholds should be carefully evaluated to determine when alternative assessment guidelines are warranted for tribal uses of water and for tribal subsistence fishing.

4.3 Summary of Survey Approaches to Assess Status and Trends

Many remote sensing and field surveys (state-led and partner-led) approaches to assess FHAB status and trends across each of the five core beneficial uses were discussed in the previous sections. These efforts have the potential to specifically address pressing Water Boards management information needs regarding public health protection and water quality management. Throughout the strategy development process, recreational, fishable and tribal and cultural uses were prioritized by the TAC for initial implementation. The TAC and State also sought to determine leveraging opportunities wherever possible to fill information needs. Multiple state and federal use surveys assessing aquatic life were discussed, which all represented leveraging potential to increase the data available about the status and trends of FHAB occurrence. These efforts can be leveraged following the development of specific protocols and indices through targeted special studies. See Section 3.1 for specific recommendations to augment use of remote sensing and Table 4.4 for summary of field survey options for status and trends assessments of core uses.

Table 4.4. Overview of field survey options to assess the status and trends of recreational, fishable, aquatic life and raw water source uses. Elements of these designs are applicable to tribal and cultural uses, so tribes are an important partnership.

Targeted Uses	Recreational Use	Fishable Use	Aquatic Life and Raw Water Source Uses
Key Indicators	FHAB toxins, FHAB species composition, visual indicators	FHAB toxins in fish/shellfish tissues and in ambient water samples, FHAB species composition	FHAB toxins in ambient water samples, FHAB species composition, FHAB biomass (Chl-a) and organic matter indicators, remotely sensed CIcyano, Chl-a and water clarity
Target Population	Recreational beaches (coastal confluences, lakes, rivers and streams)	Commercial and recreational fishing locations (lakes and reservoirs, rivers and streams, coastal confluences)	All lakes and reservoirs, rivers and streams, and coastal confluences
Spatial Design	Shoreline or beach index area	Index areas targeting specific habitats	Index areas targeting an integrative sample (deepest part of lake, river or stream segment targeting multihabitat riffles and pools) or near water intakes
Temporal design	Minimum of biweekly is recommended	Biweekly, depending on intensity of use, bloom status, habitat and focal species of interest	3-5x/yr for aquatic life and biweekly throughout year for raw water source)
Advantages	Optimal approach to protect public health Can incorporate the use of partners to collect data to make more cost effective Logistically feasible to sample from shoreline Can be used for trends assessment	Can be used for trends assessment Can incorporate the use of partners to collect data	Can be integrated with assessments of drivers
Challenges	Expensive to implement Has time sensitive data management and posting requirements for which public-facing decision support is needed (see chapter 7, public health decision support tool)	Logistically more difficult, because involves the use of a water craft Expensive to implement Has time sensitive data management and posting requirements for which public-facing decision support is needed (see chapter 7, public health decision support tool)	Expensive to implement Need to consider both benthic and pelagic habitats/species Logistically more difficult, because involves the use of integrated water or benthic sampling protocols for aquatic life
Major Options to Consider	Options include: 1) Routine partner implemented recreational use program 2) Pre-holiday statewide assessment recreational use status and trends (before major summer holidays)	Only strongly recommended in waterbodies with known HAB problems or if leveraging makes cost-effective. Design options that are relevant include regional and watershed specific designs presented in Section 5.2	Options include: 1) Use statewide SWAMP and NARS assessments as "screening" to identify sites with high risk of FHABs, then conduct regional and watershed specific designs presented in Section 5.2 and 2) Invest in de novo aquatic life FHAB assessment
Recommended leveraging opportunities to consider	Options include: 1) BSMP (AB 411) and 2) Augment pre-holiday assessment to assess "statewide" status of recreational use	Options include: 1) CDPH Biotoxin monitoring program for shellfish (coastal confluences), 2) BOG Bass Lake Status and Trends Assessment and 3) SWAMP SPoT Program (large rivers)	Options include: 1) Wadeable streams PSA and RCMP, 2) SWAMP SPoT program (large rivers), 3) National lakes and rivers assessments, 4) Regional monitoring programs (Stormwater monitoring program, SF Bay RMP, Delta RMP or IEP) and 5) Partner monitoring including drinking water agencies, lake managers, tribes
Relevant Special Studies	Create the design for a state-led recreational use survey (SS14); Assess FHAB impacts on enclosed beaches in partnership with BSMP (AB 411) (SS15); Develop REC 2 triggers (SS1); Quantify the socio-economic and cultural impacts of FHABs (SS31)	Develop a standardized cyanotoxin tissue analysis protocol (SS16); Conduct a pilot project to routinely monitor shellfish cyanotoxins in coastal zones (SS17); Assess toxin bioaccumulation and depuration rates in recreational fish in California lakes and rivers (SS18)	Develop FHAB species condition indices in wadable streams, lakes and reservoirs, and estuaries (SS19 - SS21); Adapt existing algal bioassessment protocols to improve quantitative measure of abundance and extend protocols to assess lentic systems (SS22); Develop standardized molecular methods for FHAB monitoring (SS23); Develop assessment thresholds for cyanotoxin impacts on aquatic life (SS27)

5. APPROACHES TO ASSESS ENVIRONMENTAL DRIVERS OF FHABS

This chapter presents the basic monitoring principles and designs that could be used to assess the environmental drivers of FHABs. We begin with an introduction to **key terms** and **concepts**, then proceed with **basic design** concepts applicable to both statewide/regional and waterbody-specific monitoring, including **priority indicators** and **spatial and temporal design considerations**, organized by type of driver (external to the waterbody versus within the waterbody). Second, we present **options** for how to implement these concepts in **specific survey designs** and **identify leveraging opportunities** with other existing monitoring programs that can be used to cost-effectively answer the question of status and trends. The contributions of both the state-implemented program and partner monitoring to describing status and trends will be considered.

5.1 Introduction to Ambient Monitoring of FHAB Environmental Drivers

Basic Concepts and Terms. In order to understand relevant monitoring approaches for FHAB environmental drivers, some basic concepts and definitions of terminology are needed.

"Environmental driver" is a nuanced term, used by different scientists to refer to different things. As an example of the two extremes, to a landscape ecologist, it might mean landscape processes that influence the prevalence of FHABs in a watershed. To an algal physiologist, it might mean intracellular processes that trigger toxin production or the factors that promote the growth of one harmful species over another. Here, it is meant to refer to **all environmental factors**, both **natural** and **human-influenced**, that control the magnitude, frequency, and extent of FHABs (and for a subset of FHABs, toxic events). Because this strategy focuses on characterizing the status, trends, and environmental drivers at a statewide to watershed scale, in this context, we will emphasize measures of external[20] and internal[21] drivers that are typically associated with a given FHAB response. This strategy does not attempt to be prescriptive about watershed- to waterbody-scale driver assessments. The monitoring design, indicators, and metrics to monitor at those scales must emerge from an informed conceptual model of what specifically is driving FHAB problems in that particular watershed or waterbody, which are best achieved via focused special studies and experimental work.

In the USEPA's terminology of *causal analysis* (USEPA 2017b), the rationale for monitoring, synthesis, and analyses of environmental drivers and FHAB responses is to **determine the likely cause(s)** of an observed condition. At statewide to watershed scales, **inferences** on relationships between environmental drivers and FHAB responses in monitoring data are **associative**[22]. They can be used to **hypothesize causal relationships** or become **a line of evidence in causal assessment**[23] based on abductive inference[24].

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[20] Landscape-scale biogeochemical and hydrological and factors outside of the waterbody that can influence FHABs

[21] *In situ*, within waterbody factors that can influence FHABs

[22] A correlation or other association between measures or observations of two entities or processes, that occurs because of an underlying causal relationship.

[23] Causal assessment is the process of determining what factors may be responsible for an environmental condition (i.e., impairment).

[24] From the environmental causal assessment literature, abductive inference is the inference from data to the hypotheses that best accounts for the data.

Answers to “environmental driver” monitoring questions inform different types of actions, so the intended use of the information influences the spatial and temporal scale of monitoring and the approach required (Table 5.1). For example, a manager at the State Water Board may want to know what the top priorities should be for policies and programs (e.g., nutrient management), environmental flow criteria, healthy watersheds (e.g., restoration) that could effectively reduce the risk of HABs across a watershed, region, or statewide (see inset box: **Assessment of Drivers: SWAMP Bioassessment Program Example**). At a watershed scale, a Regional Board SWAMP coordinator may want to understand how certain sources or land uses may be associated with FHAB problems in order to do very targeted source tracking and catchment-specific interventions. A lake manager may want to know the specific environmental drivers of FHABs in a certain waterbody in order to decide what management actions would minimize the risk of their occurrence in the future.

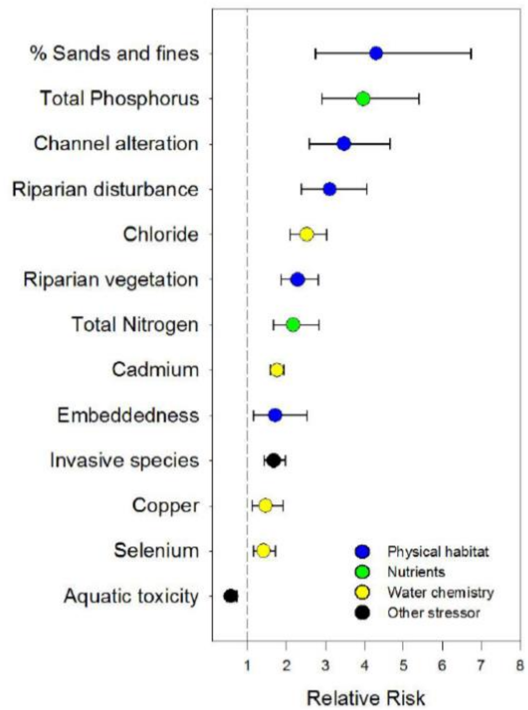

Figure 5.1. Relative ranking of stressors in southern California coastal streams based on their risk of biological impairment, as measured by benthic macroinvertebrate health index (Mazor et al. 2011).

Assessment of Drivers: SWAMP Bioassessment Program Example

The Wadeable Stream PSA and its regional partner, the Stormwater Monitoring Coalition (SMC), provide an example of information how survey data can be used to derive information on environmental drivers. Results of the PSA survey show the stream miles that are attributable to high and moderate levels of biogeochemical and physical habitat disturbance for the state. Ecoregion or by land use. This can direct priorities to prevent degradation or mitigate impacts. Organizing stressor information into relative risk can inform management priorities; in the SMC report, stressors were ranked by their relative risk (analogous to medical risk advisories), where stressors with a relative risk of 5 are 5X as likely to impact biology as those at or near one (Figure 5.1, Mazor et al. 2011). This information was transformative for the SMC stormwater agencies, who had previously been focused on stormwater heavy metals and associated toxicity (show here to have low risk); survey results highlighted the need to focus on low impact development, restoration and best management practices on physical habitat disturbance and hydromodification (channel alteration, riparian disturbance, % sands/fine) and nutrients (SCSMC 2017). The bioassessment survey data have ~90 percent overlap of FHAB responses and environmental drivers of interest, so similar analyses can be done for FHAB responses.

Table 5.1. Examples of management questions and information needs that are addressed by monitoring of environmental drivers at a statewide, regional or watershed scale and their complements that drive monitoring at the scale of an individual waterbody(ies).

Statewide, Regional or Watershed Scale (SWAMP)		Individual Waterbody (Partner Monitoring)	
Management Questions	**Examples of Decisions That Are Supported by Monitoring**	**Example Management Questions**	**Examples of Decisions That Are Supported by Monitoring**
What are the major drivers of FHABs across waterbodies or within a watershed?	Biostimulatory objectives and implementation policy Environmental flow policy State/regional NPS control strategies Irrigated Lands Program/Ag waiver requirements	What are the drivers of FHABs in the waterbody or watershed?	303(d) listing FHAB mitigation measures TMDL development TMDL implementation (e.g., BMPs) MS4, NPDES, and industrial permits Irrigated Lands Program/Ag Waiver Requirements

Assessments of drivers at the national, statewide, or regional scale have one common element: the sampling approaches reflect an attempt to characterize a broad gradient of environmental stressors and responses, from minimally disturbed (reference sites) to very disturbed. Assessment of sites with known HAB problems is important, but these sites represent the disturbed end of the stressor gradient, so inferences made about drivers based on that limited population could be spurious. For this reason, statewide and regional surveys often stratify their survey designs based on land use (agricultural, forest, urban, and open space) in order to capture a wide range of environmental stressors and diversity of responses.

At all statewide to regional scales, monitoring of environmental drivers and FHAB responses allows the development of screening level predictive tools that not only identify the key drivers but also can be used to predict the risk of FHABs in unmonitored waterbodies (Beck et al. 2019; Hill et al. 2018) or provide operation forecasts of future FHAB events. Examples of these types of models are further discussed in Chapter 7 in the context of FHAB risk and decision support.

Finally, while screening tools are helpful, there is no one-size-fits-all answer to the question of important environmental drivers across waterbody types. Despite the fact that the major environmental drivers influencing FHABs are fairly well-documented and their causal pathways understood, environmental drivers are highly variable over space and time (Paerl 2018); typically, the mix and relative importance of causal drivers is very specific to an individual waterbody or groups of waterbodies or regions and can vary over time. At a waterbody-specific scale, recurring monitoring of environmental drivers is needed to adaptively manage FHABs over time.

5.2 Basic Design Concepts

As reviewed in Section 2.5, the environmental drivers that favor the growth of FHAB species is an active and rich area of research (Chorus and Bartram 1999; Carmichael 2008; Paerl and Huisman 2009; Hudnell 2008, 2010; O'Neil et al. 2012; Paerl and Paul 2012). These conditions typically include favorable salinity, ample supply of nutrients, calm water and stratified conditions, plenty of irradiance, and warm water temperatures (Figure 2.3). While the general environmental conditions related to increased algal growth are well described, the specific factors influencing the specific FHAB species that will bloom, the exact timing, duration and location of a bloom, and the factors eliciting toxin production are still not well understood. The principal indicators and metrics of environmental drivers (Table 2.4) are those external and internal waterbody factors that link back to **nutrient loads and concentrations**, **temperature**, **irradiance and water clarity**, **stratification and residence time**, and **salinity regime**. Other intrinsic waterbody factors affect algal community composition (e.g., micronutrients, grazers, or herbicides) as well toxin production and degradation, but these factors need be characterized at a waterbody-specific scale since they tend to be quite site specific.

Spatial and temporal design considerations depend on the specific drivers being assessed, and as highlighted above, a one-size-fits-all approach is not appropriate. It is most appropriate to consider an assessment by driver type, as each has its own spatial and temporal design considerations. Some of the major drivers are discussed here, organized by those that are assessed “external” to the waterbody versus “internal” that occur within the waterbody.

5.2.1 FHAB Responses

Measurement of FHAB responses is required to assess environmental drivers. Monitoring of both drivers and FHAB responses at the same time is optimal and a thoughtful design that incorporates the appropriate spatial and temporal scales for both drivers and responses is essential. FHAB responses can be temporally or spatially decoupled from the source of their causal drivers. Responses can occur far afield of the original bloom event (in the case of toxins), the point of pollutant loading into the system, or the land use change; there can also be significant temporal lags of hours, weeks, or months, depending on the pathway of impact and the FHAB response. Not only can a temporal lag exist for drivers, but synergistic effects are also possible, for example, the loading of nutrient rich storm runoff in the winter season into a waterbody, followed by increased algal biomass in the summer only when water temperatures become optimal for growth.

Most monitoring programs assess FHAB status, then look for associations with drivers; Chapter 4 provides a full discussion of the basic design considerations, priority indicators and metrics, and spatial and temporal scales to be considered. A few major points are worth emphasizing, however. First, assessment of environmental drivers should choose designs that optimize the likelihood of detecting an association, i.e., by optimizing the ratio of “signal” (association with an environmental driver) to “noise” (environmental variability). Generally, this means choosing sampling approaches that are integrative (e.g., aquatic life, Section 4.4) versus just sampling shoreline or waterbody edges (e.g., swimmable, Section 4.1.1). Index sites can be chosen to be representative of a segment, but under characterize the segments, so care should be taken in making inferences to drivers based on a single index site.

Second, choice of FHAB indicators should reflect some degree of temporal integration, depending on the waterbody type and seasonality of external and internal drivers. For example, in lakes, total algal and cyanobacterial abundance measures are likely to integrate over time scales of weeks to a month, while species relative abundance (community composition) can vary over days to weeks. Water column toxin concentrations may vary over hours to days, while lake sediment cyanotoxins may integrate both water column and benthic algal toxin production on timescales of weeks (depending on degradation rates in sediments). In streams, winter storms can drive variability in benthic abundance and composition on timescales of days, while dry season conditions tend to integrate benthic FHAB measures over weeks. In coastal confluences, tidal variability can drive variations in water column properties on hourly time scales, while benthic or sediment FHAB measures can integrate over longer timescales.

In situ continuous data measured via probes are an important approach to collect high frequency data on some FHAB responses and drivers, typically used with waterbody- or watershed-scale programs. *In situ* probes can measure both can measure both FHAB responses and environmental drivers. Their advantages include: 1) capture FHAB responses that can vary on the order of hours, days, weeks to seasons, 2) these data streams can be compared against environmental drivers of variable frequency, 3) innovations have made their use fairly streamlined without requiring a high level expertise, 4) beyond the capital cost of purchasing and recurring costs of calibrating and maintaining the probe, costs for discrete sample analyses are not incurred. Disadvantages can include: 1) high capital costs, depending on the parameter of interest and the deployment environment and 2) instrument data can drift out of calibration, so frequent attention and maintenance is typically required.

5.2.2 External Drivers

Indicators and Example Metrics

External drivers consist of the combination of natural gradients (climate, geology, elevation/slope, soils, rainfall, groundwater, etc.), events (fires, extreme precipitation events and floods), and human activities (land use, water withdrawals and releases, fertilizer application, etc.) that are external to the waterbody and can influence FHABs (Table 2.4). Many of these indicators (and example metrics) can be assessed through a variety of geographic information system (GIS) office assessments and field observations (e.g., catchment flow, riparian cover).

For GIS-assessed indicators, public datasets are available to download and use; however, data processing is required to clip out the portion of the data that is applicable to the waterbodies/watersheds of interest. In light of this limitation, USEPA Office of Research and Development (EPA ORD) has made a concerted effort to assist states in this data processing step by assembling a comprehensive GIS dataset for convenient use in stream and lake assessments. The Stream-Catchment (StreamCat; Hill et al. 2016) and Lake-Catchment (LakeCat; Hill et al. 2018) dataset contains an extensive collection of ~580 landscape metrics for 2.6 million streams and ~270 metrics for 378,000 U.S. lakes and reservoirs and their associated catchments within the conterminous U.S. StreamCat and LakeCat includes both natural and human-related landscape features. The data are summarized both for individual lake catchments and for cumulative upslope watersheds. The datasets are derived by: 1) delineating the upstream catchments of the stream segments or lakes, 2) delineate lake catchments, 3) hydrologically connecting nested stream or lake catchments, and 4) generate several hundred watershed-level metrics that summarize both natural (e.g., soils, geology, climate, and land cover) and anthropogenic (e.g., urbanization, agriculture, and mines) features. These datasets greatly facilitate landscape assessment and are an asset for both research and management. In deciding what to use, a conceptual model of potential drivers is helpful to guide the expeditious use of resources decided to data analyses, but exploratory analyses can be used to identify a subset of variables that explain the greatest amount of variability in FHAB responses from a longer list.

As with any publicly available dataset, caveats are needed. The most important issues are vintage, data source, and resolution. GIS datasets can quickly become out of date, especially because some land use types (e.g., agriculture) and human activities (fertilizer application) can rapidly change (seasonal or annually), while national land use datasets are updated every 5 years (Homer et al. 2020). The second is resolution, whether for the raw data source or the aggregated product. Course resolution data for indicators such as precipitation can be particularly problematic for smaller watersheds or catchments with microclimates. Data source should be carefully considered; for example, while nationally sourced National Land Cover Data have a high level of quality assurance and metadata, they are typically developed through automated classification algorithms that have error rates of 20% or more. Locally sourced data (e.g., County land use) can be more accurate, but additional data processing would be required. Given these issues, perhaps the best approach, depending on the sophistication of the agency and the geographic scope of the assessment, is to conduct preliminary data analyses for the most important indicators/metrics through national datasets such as StreamCat or LakeCat, then refine the dataset with local data as needed or as resources allow to refine the answers to the FHAB assessment.

Spatial and Temporal Design Considerations

Spatially, approaches to assess external drivers should be nested, from the broadest (landscape) scale to the local scale (upland area adjacent to site). At the broadest scale, the upstream and/or local catchment is an important spatial unit for lakes and reservoirs (Figure 5.2), streams (Figure 5.3), and coastal confluence segments, which would include the upstream catchments of each of the major freshwater inputs to that segment (e.g., Figure 5.3), plus the local catchment. Size of the catchment relative to the waterbody is an important consideration; for example, spatial averaging of percent agricultural land use over a 1000 km^2 may be a less useful metric than what is within a 5 km buffered distance upstream. For that reason, it is helpful to consider measures of both the total and buffered distance in upstream catchment as well as in surrounding land use (Figure 5.3).

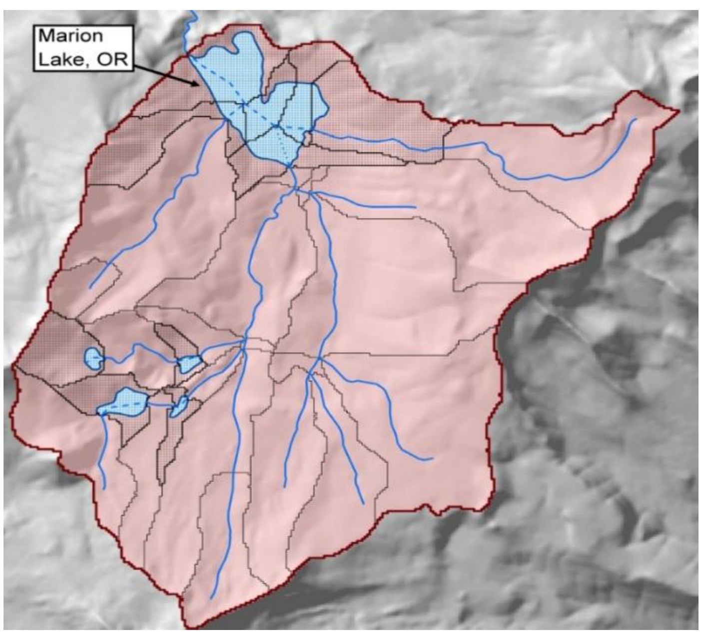

Figure 5.2. Example of on-network lakes and their associated catchments. On-network lakes intersect with stream lines and often have several tributaries with separate catchments (black stippled catchments of Marion Lake). LakeCat aggregates the local catchments that intersect with each lake polygon and reports combined catchment-level statistics. The set of hydrologically-linked catchments that feed to Marion Lake, OR are in pink. Figure from Hill et al. (2018).

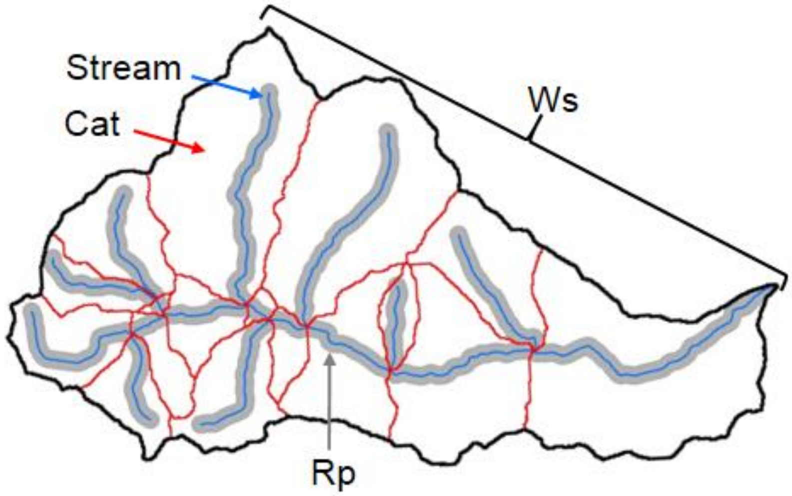

Figure 5.3. Geospatial framework of the StreamCat Datase showing buffered stream and riparian zone and upstream catchment and local (lateral to stream) catchment. Ws are watershed variables, Rp are riparian variables. Blue lines represent NHDplus version 2 streams. Figure from EPA.gov.

5.2.3 Internal Drivers

Indicators and Metrics

Internal environmental drivers can generally be grouped into categories of physical, biogeochemical, and biological, each of which have their own inherent spatial and temporal scales (Table 2.4). For <u>routine</u> ambient monitoring and assessment, indicators and specific metrics tend to be focused on the "state" of the waterbody (depth, TN, TP, light, dissolved oxygen) rather than the rates (e.g., benthic flux of nutrients, denitrification, grazing, primary production, etc.). Rate data can be incredibly useful and informative; however, their measures typically require expertise to design and interpret appropriately along with higher sampling resources. For this reason, we have chosen not to focus on them here, but note their importance for watershed- to waterbody-specific assessments and research special studies.

While SWAMP protocols exist for many of these indicators, they should be specifically reviewed for their efficacy to measure FHAB internal drivers (**SS25, Appendix 6**).

Spatial and Temporal Design Considerations

Options exist in how and where to assess internal drivers. Sampling of internal drivers are typically co-located with sampling of FHAB responses. In the status and trends (Chapter 4), we've discussed several types of spatial approaches that are particular to the core use being assessed: recreational use focuses on shoreline sampling while fishable, aquatic life, and raw drinking water would tend to use either index sites (e.g., middle of the lake) in which a depth-integrated sample is chosen, or integrative sampling that analyze or composite samples across multiple transects (e.g., stream bioassessment approach). Generally, approaches to assess the relationship between environmental drivers and FHAB responses rely on use of index sites or integrated sampling, as these approaches attempt to minimize environmental noise (variability) that might obscure a causal association that can occur by sampling in one location or at the edge. Trade off and exceptions to general rules of thumb always exist. Additionally, several basic water quality parameters (spectral reflectance etc.) can be measured via remote sensing approaches. These datasets can be useful alone or paired with *in situ* lake measurements. In recent years, approaches have been developed to streamline matching co-located *in situ* measurements with satellite observations (Ross et al. 2019), making this an accessible approach.

Physical Indicators. Among physical measures, **geomorphology** and **physical habitat** measures are typically assessed as an integrative measure (wetted channel dimensions, sediment grain size) at a waterbody or segment scale. In lakes, these measures may be slower to change; in streams and estuaries, morphological and physical measures can change radically from sampling period to sampling period due to erosion and depositional events that occur during storms and long-shore transport of sand (e.g., estuary sand bars).

Hydrological measures (e.g., water surface elevation, stratification, flow, velocity) are typically measured at index sites or as integrative measures over the segment. Temporal scales of variability range from minutes to interannual, so continuous monitoring via data sondes, moorings, or installed gauges is optimal when resources allow. Otherwise, instantaneous measures are essential and need to be repeated during each field visit but cannot be used to assess temporal lags in FHAB response measures or the effects of events (e.g., storms) that occurred in between site visits. Hydrodynamic monitoring at index sites are useful but not always representative of physical processes that impact FHABs at larger spatial scales. Integrative hydrologic or hydrodynamic measures can be developed from statistical (e.g., Statewide flow hydrologic alteration metrics) or waterbody-specific numerical models that can provide useful predictive measures.

Finally, spatial measures (vertical profiles, spatial maps, or transects) of **water temperature** and **ocean-derived salinity** (for coastal confluences) are useful to construct heat and salt budgets that ultimately can be used to trace the mixing and advection of water masses (tidal versus freshwater) or identify periods of stratification that are highly predictive of FHAB events. Temporal scales of variability range from minutes to interannual, so continuous monitoring via data sondes, moorings, or installed gauges is optimal when resources allow, co-located with hydrological observations.

Biogeochemical Indicators. Biogeochemical measures (Table 2.4) are typically measured at index sites in the riverine or estuarine channel thalweg or deepest part of the lake, moorings at fixed depth or as integrative measures over the segment (e.g., benthic % organic carbon, bottom photosynthetically active radiation; PAR) vertical profile of the water column. As with hydrodynamic indicators, temporal scales of variability range from minutes to interannual, so continuous monitoring via data sondes (i.e., dissolved oxygen, pH, nutrients, PAR sensors) mounted in tandem with moorings or installed hydrodynamic gauges is optimal when resources allow. Otherwise, discrete samples are typical and need to be repeated during each field visit but cannot be used to assess temporal lags in FHAB response measures or the effects of events (e.g., storms) that occurred in between site visits. Choice in specific metrics is key and should be guided by the conceptual model for the study. For example, dissolved inorganic nutrient concentrations are what is considered "bioavailable" to an FHAB bloom, but the total nitrogen (TN) and phosphorus (TP) concentrations are more representative of overall nutrient status and trophic state (oligotrophic to hypereutrophic) in lakes (Yuan et al. 2014). On the flip side, total water column nutrient concentrations can yield a false negative in streams or estuaries if most of the nutrients are locked up in macroalgal biomass, which is not typically sampled in a discrete water sample.

Biological Indicators. FHAB specific indicators related to FHAB biomass, community composition, and cyanotoxins are key response indicators and one or more of these metrics should be paired with driver metrics. Presumably, many or most of the FHAB response indicators will be measured to address status and trends questions or in waterbody-specific recreational health monitoring. Core principles related to spatial and temporal design principles of FHAB response indicators are discussed at length in Section 3 and Section 4.

Grazing by higher trophic levels is an important, albeit complex, control of algal blooms. Characterizing the grazer/zooplankton community can provide insights on the factors that might govern the phytoplankton community composition, overall biomass, as well as controls on bloom demise. This type of indicator, however, is uncommon in statewide monitoring programs because it is impossible to interpolate this type of information across many waterbodies. Top-down controls of algal growth tend to be waterbody-specific, and these factors are best assessed in a waterbody-specific monitoring. Additionally, characterization of the grazer community allows for an assessment of potential consumers of FHAB species and will yield informative information when paired with grazing rates. As noted above, rates are very useful measures but extend outside the scope of the resources available to most ambient monitoring programs.

5.2.4 Climate Change as a Driver of FHABs

There is ample evidence to support the claim that climate change has resulted in an increased frequency, extent, and magnitude of HABs (see inset; IPCC 2019; Griffith and Gobler 2020; Burford et al. 2020). Chapra et al. (2020) predicted that climate change will alter the occurrence of cyanobacterial blooms in U.S. lakes and reservoirs from about 7 days per year per waterbody under current conditions, to 16−23 days in 2050 and 18−39 days in 2090. The implications for California are clear and compelling; public health (drinking water, recreational use, commercial/recreational fishing, and aquaculture) and other core uses are at significant risk from FHABs under climate change. Significant increases in public health monitoring are warranted to protect Californians from adverse effects of FHABs. Environmental drivers should be managed to lower risk of FHABs wherever possible.

IPCC Statements on Linkage of Climate Change to HABS (September 2019)

The United Nations' Intergovernmental Panel on Climate Change's (IPCC) September 2019 Special Report was the first IPCC report to directly link HABs to climate change. In the Summary for Policy Makers, the report made the following declarations with "high confidence":

- Harmful algal blooms display range expansion and increased frequency in coastal areas [and other freshwater habitats] since the 1980s in response to both climatic and non-climatic drivers such as increased nutrient run-off.
- The observed trends in harmful algal blooms are attributed partly to the effects of warming, oxygen loss, eutrophication and pollution.
- Harmful algal blooms have had negative impacts on food security, tourism, local economy, and human health.

A number of recent reviews have synthesized the effects of climate change on FHABs (Burford et al. 2020; Cavicchioli et al. 2019; O'Neil et al. 2012; Paerl et al. 2014; Visser et al. 2016). These reviews have identified those features associated with climate change (increased temperature, atmospheric CO_2, irradiance, hydromodification, Figure 5.4), which can be linked back to specific external and internal environmental drivers of HABs (Table 5.2). Thus, monitoring of FHAB environmental drivers and responses can and should specifically incorporate climate change and the indicators proposed in Section 5.2.2 and 5.2.3 that encompass these forcings.

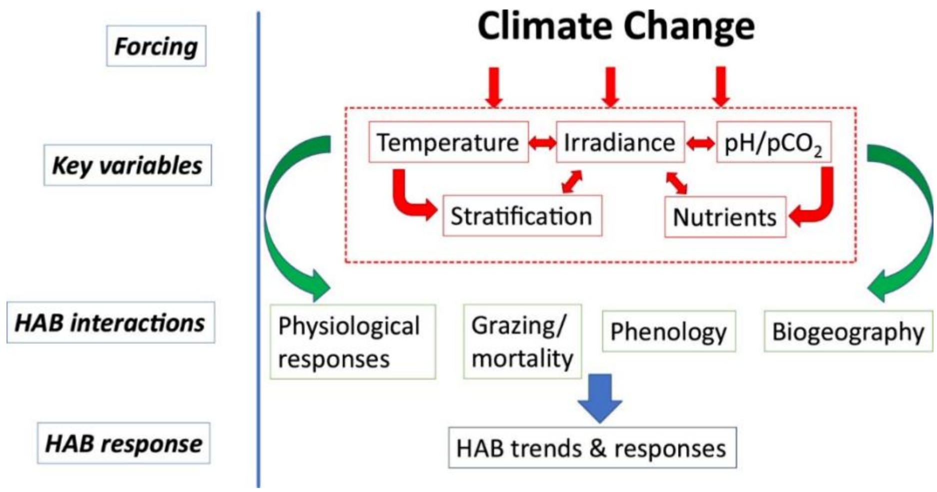

Figure 5.4. Schematic of the forcing, key drivers (variables), interactions and HAB responses associated with climate change. From Burford et al. (2020).

Specific design approaches are needed to quantify climate change impacts on FHABs (see Burford et al. 2020 for comprehensive review), many of which can be considered research special studies. However, California's FHAB monitoring programs can help to answer a key management question: "What is the contribution of global versus local anthropogenic activities on FHAB status, trends and drivers?" An appropriate design to answer this question would be to assess the status and trends in FHAB at minimally disturbed reference waterbodies throughout the state, by ecoregion and waterbody type. The design for this type of FHAB monitoring program component should be specifically developed through a special study (**SS29, Appendix 6**).

5.3 Survey Options and Leveraging Opportunities

Options for Integrated Field Survey Designs
Statewide Integrated Survey Designs – Remote sensing study of lakes and reservoirs – End of bloom season statewide survey – Decadal Trends in FHABs and drivers – **Leveraging options:** Wadeable Streams PSA and RCMP, SWAMP SPoTs (Large Rivers), and National Lakes Assessment
Regional and Watershed Integrated Survey Design – Regional status, trends and drivers – Watershed status, trends and drivers – **Leveraging option**: regional and watershed aquatic resource monitoring programs, TMDL studies

The TAC considered multiple approaches to integrated surveys to assess FHAB response indicators in conjunction with environmental factors. These were not detailed design discussions, but rather a higher-level discussion of options and tradeoffs. The key concepts of each approach are discussed below. As mentioned above, a one-size-fits-all approach for an environmental driver assessment is not possible, and several possibilities were developed by the TAC, each with inherent strengths and specific caveats in the spatial and temporal scale and applicability of the approach. Discussion of each is organized by scale (statewide, regional, watershed), as management actions and decisions are typically different at these different scales.

5.3.1 Statewide Integrated Survey Designs and Leveraging Opportunities

Survey Design Options

Three basic integrated survey design options were discussed by the TAC for statewide status and driver assessments: 1) remote sensing study, 2) "end of bloom season" sediment survey, and 3) decadal FHAB trends and drivers. Noteworthy among these designs is that they don't speak to a particular beneficial use (e.g., swimmable, fishable, aquatic life), though one could argue that they provide a reasonable analog for FHAB risks to these uses.

Remote Sensing Study of Lakes and Reservoirs. Chapter 4 discussed the utility of remote sensing to assess lake and reservoir status and trends. Previous studies have demonstrated the linkage of remotely sensed phycocyanin or chlorophyll-a with environmental drivers, either for individual waterbodies or across waterbody types. The TAC recommends analyses of environmental drivers with remotely sensed phycocyanin and chlorophyll-a in order to increase the utility of this type of survey to inform management action. Currently, processed imagery is readily available from Sentinel-3 OLCI for 255 large California lakes and reservoirs. Indicators of duration, intensity, and severity could be analyzed relative to LakeCAT indicators, most external drivers (Table 2.4) and selected internal drivers (geomorphology, hydrologic alteration in catchment) could be used in the analysis (**SS11, Appendix 6).** The TAC recommended a special study (**SS13, Appendix 6**) to pilot the use of Sentinel-2 for status and trends, which has higher resolution, and therefore could extend the majority of the California's 14,000 lakes and reservoirs (> 1 ha). Such a study could be expanded to include environmental drivers as well. TAC members noted the opportunity to pair remote sensing with *in situ* sensors to get more detailed information on FHAB bloom evolution.

"End of Bloom Season" Lakes Sediment Survey. Statewide surveys that require multiple sampling events during the bloom season will be cost prohibitive. Recreational assessments conducted at the shoreline do not produce information that can link FHABs with environmental drivers. One integrated survey concept that the TAC considered for lakes and reservoirs was a one-time sampling event of sediment toxins, sediment total OC, N and P, and cyanobacterial community composition via genetic barcoding. This design is essentially a screening level study that could be paired with both external drivers (GIS-based) and internal environmental drivers (e.g., water column trophic status indicators such as Chl-a, TN, TP). This survey would be conducted at the end of a recreational season and could address questions such as "What is the percent of recreational lakes and reservoirs that experienced a toxic bloom event?" and "How does sediment cyanotoxins and cyanobacterial relative abundance relate to lake trophic state?" Conducting a statewide survey of lakes and reservoirs at the same time (end of season) would requires a collaboration between state and partners (voluntary agencies and community science groups). The TAC considered the viability of sediment cyanotoxins as an integrative measure of FHAB events over time. There is conflicting evidence about the residence time of cyanotoxins and DNA in the sediments following blooms. Ultimately, a special study is needed to determine the feasibility of this study design for statewide implementation (**SS28, Appendix 6**).

Decadal Trends in FHABs. The TAC recognized the challenge of assessing FHAB trends, given their inherent interannual variability and that high frequency sampling (throughout each year) is needed in order to appropriately characterize FHABs trends. A key limitation of assessing the magnitude of FHABs is the "natural background" frequency and extent of occurrence. Analysis of trends would require a longer timescale (multidecadal to centennial) than is currently available with remote sensing imagery (> 2000). Paleoecology studies in lakes have establish linkages between human activities and lake acidification (Whitehead et al. 1990), cyanobacteria (Zastepa et al. 2017; Taranu et al. 2015), eutrophication (Bennion et al. 2014), climate change (Saros et al. 2012; Booth et al. 2002), and other ecological changes (Anderson

1993; Wingard et al. 2017). Deep sediment cores are taken from lakes. The sedimentary layers are dated using radioisotopes and biogeochemical markers are used to identify how the ecosystem has evolved over time in response to land use change, changes in atmospheric deposition, or climate. A special study might look at changes in lake sediment cores to identify how the phytoplankton composition in general and the dominance of cyanobacteria in particular has changed over time (**SS30, Appendix 6**). This could be done at a subset of lakes around the state, with strata reflecting key differences in catchment land use (ag, timber, urban) as well as potential influence of atmospheric deposition of nitrogen and acidifying constituents.

Leveraging Opportunities

SWAMP PSA/RCMP and National Lakes Assessments represent tremendous leveraging opportunities for FHAB status and drivers, as they contain the majority of desirable response and driver indicators (Table 5.2); the notable exception is toxins (benthic or water column). Statewide causal associative analyses of the wadeable streams (Mazor et al. 2018) and national lakes assessment data have been conducted (Hill et al. 2018); while more refinements to these analyses are needed to improve FHAB-specific management relevance, these data can already be summarized to report out (with appropriate caveats) FHAB status, trends, and drivers. Hill et al. (2018) has gone further to predict the probability of eutrophication in lakes and reservoirs nationwide not sampled by NLA (see Figure 7.9 and discussion in Chapter 7), based on LakeCAT parameters. Such predictive models should be refined, given the paucity of NLA data in California, but point to the utility of a combination of remote sensing and sampled lake data to inform prioritization of FHAB intensive sampling. Finally, the RCMP is an appropriate program to assess climate change effects on FHABs and should be the focus of a pilot study (**SS29, Appendix 6**).

Leveraging opportunities exist for the SPoTs survey (sediment contaminants in large rivers) and the BOG "bass lake" mercury bioaccumulation assessment, but the lift is much larger to comprehensively sample both FHAB responses and internal environmental drivers in these surveys, since only a handful of indicators listed in Table 5.2 are collected. Since a large portion of the costs is field data collection, the opportunity to leverage should not be neglected, but as with the PSA/RCMP and NLA surveys, the emphasis should be on collecting screening level data (to be defined) since these surveys are also conducted as a single sample event per season.

As previously noted (Chapter 4), the major drawback of both of these surveys is the lack of repeated seasonal sampling, such that analyses of environmental drivers and their influence on FHABs may not capture peak responses. Given the problem of lack of high frequency seasonal sampling, the TAC did not specifically suggest investing in additional sampling sites or adding toxins to the analyte list (PSA/RCMP/SMC); instead, the recommendation is to use these survey data as screening level information that can drive where more intensive assessments of FHABs (and their environmental drivers) may be focused. In this sense, these survey types, in addition to the remote sensing survey, could provide a good complement to a regional or watershed intensive and integrative survey of FHAB responses and drivers.

Table 5.2. Potential leveraging opportunities presented by national and statewide ambient surveys that contain either status and/or field- internal environmental driver data. NLA = National Lakes Assessment. PSA/RCMP/SMC = Perennial Wadeable Stream Survey/Reference Condition Monitoring Program/Stormwater Monitoring Coalition. Type indicates response indicator (R) or environmental driver (D). Metric reference no. links discussion of conceptual models in Section 2.5 to discussions of responses and drivers in Chapters 4 and 5.

Indicator Group	Metric	Metric Ref. No. (R#)	Type	NLA	PSA/RCMP/SMC
Water Clarity and/or Quality	Secchi Depth, Turbidity or total suspended solids, or remotely sensed water clarity	R1-3	R, D	X	X
	Dissolved oxygen, pH	R4, R5, D27, D29	R, D	X	X
	DOC	R6	R	X	
Sediment organic matter and physical characteristics	Sediment TN and OC	R7, D25	R, D	X	N/A
	Sediment or substrate grain size	D19	D	X	X
Algal and cyanobacterial abundance	Planktonic, benthic, or drift algal Chl-a (discrete samples)	R10, D26	R, D	X	X
	Macrophyte Percent Cover	R12	R, D	X	X
Cyanobacterial Abundance	Toxigenic cyanobacterial cell density (microscopy or qPCR)	R17, R18	R	X	X
Algal/cyanobacterial community composition	Species composition via microscopy or molecular barcoding	R19, R20, D30	R, D	X	X
Primary consumer	Benthic or pelagic invertebrate community composition	R21, D32	R, D	X	X
Toxins/Taste& Odor Compounds	Discrete total toxin samples	R22	R	X	
	Via passive sampler	R23	R		
	Toxin gene counts	R24	R		
	Tissue toxins, MIB, geosimn	R25	R		
	MIB, Geosimn, Sulfur	R26	R		
	Sediment toxins	R27	R		
Hydrology/Hydrodynamics	Waterbody hydrodynamic measures (flow, stratification, etc.)	D14	D	X	X
Geomorphology	Shoreline or floodplain morphology	D15	D	X	X
	Lake or channel morphology (wetted channel dimension, depth, volume)	D16	D	X	X
Water Temperature	Instantaneous or daily mean water temperature	D17	D	X	X
Nutrients	Nitrogen forms such as Nitrate + nitrite, ammonium, DON, total nitrogen	D22	D	X	X
	Phosphorus forms such as PO4, DOP, Total Phosphorus	D23	D	X	X
	Silica	D24	D	X	
Carbonate Chemistry	DIC, PCO_2, alkalinity	D27	D	X	X
Ionic Composition	Major Ions, conductivity, TDS, Hardness	D28	D	X	X

5.3.2 Regional-Scale and Watershed Scale Designs and Leveraging Opportunities

Survey Design Options

Regional-Scale Integrated Survey of Status, Trends and Drivers. The TAC discussed the inherent tradeoffs between increasing the spatial extent (to achieve statewide coverage) versus frequency of sampling at fewer locations (to produce high quality characterizations of risk and actionable information, i.e., 303(d) listing). For this reason, some TAC members favored a regional-scale environmental driver survey of targeted locations with known FHAB problems (previous incident responses required). The sampling design would consist of monthly shoreline (recreational) and index or integrative sites, the latter of which would be used to link FHAB problems with specific internal environmental drivers. This type of information would be used to make waterbody-specific 305(b) reports and 303(d) listings and guide early management decisions (source tracking, hydromodification assessments, permits, agricultural and urban BMPs). The TAC recognized clear tradeoffs exist in producing data that is more "actionable," particularly a higher cost.

Watershed Scale Integrated Survey of Status, Trends and Drivers. The TAC offered an alternative to the regional-scale integrated survey design (above), in which a holistic assessment of status, trends, and drivers would be carried out by watershed, surveying over multiple waterbody types (lakes, rivers and streams, and coastal confluence (if applicable)). With the regional design, this survey design would also feature high frequency FHAB sampling at monthly shoreline (recreational) and index or integrative sites, the latter of which would be used to link FHAB problems with specific internal environmental drivers. However, because FHABs upstream can impacted downstream uses, an integrated watershed approach can be used to link FHAB responses with both driver and sources of those drivers (source tracking), in a way that increases amount of the actionable information (e.g., not only that nutrients or hydromodification is responsible, but which catchments are responsible and the timing of those drivers). The concept of a watershed approach to FHAB monitoring is a core recommendation of a recent MERHAB "land to sea transfer" study. As with the regional survey, the tradeoff is the high cost. Such an approach could only be reasonably implemented with a statewide or regional screening level study that has identified the watersheds that are at high risk for eutrophication and/or FHABs. We note that this is a consistent theme of FHAB ambient monitoring recommendations (tiered sampling) that could be used in tandem with a risk prediction tool and decision support system (Chapter 7).

Leveraging Opportunities

Regional, watershed or waterbody specific FHAB partner (voluntary) ambient monitoring can contribute to a statewide picture by identifying a common core of indicators (with specific SOPs) that can be included in ambient FHAB assessments (see Section 3.2.3). Detailed discussion of those core indicators is beyond the scope of this document but should be the focus of a special study (**SS0, Appendix 6**).

5.4 Summary and Recommendations: Integrated Surveys of FHAB Responses and Drivers

Waterbody, watershed, or regional-scale integrated assessments of FHAB drivers and responses are time and resource intensive but produce information that is the most likely to result in a management action. Given this, we recommend use of existing bioassessment data (PSA/RCMP, regional monitoring programs, and national aquatic resource surveys) to screen for FHAB risk, then intensify FHAB assessments with temporally intensive designs at these high priority and higher risk watersheds or waterbodies, consistent with the recommendation for aquatic life (see discussion on Decision Support, Chapter 7).

Table 5.3. Overview of field survey and remote sensing options to assess FHAB responses and drivers.

Key Indicators	FHAB responses (FHAB toxins in ambient water samples, FHAB species composition, FHAB biomass (Chl-a) and organic matter indicators, remotely sensed CiCyano, Chl-a and water clarity) and internal and external drivers (see Tables 5.3 and 5.4 for comprehensive list)
Target Population	All lakes and reservoirs, rivers and streams, and coastal confluences
Spatial Design	Index areas targeting an integrative sample (deepest part of lake, river or stream segment targeting multihabitat riffles and pools)
Temporal design	Question dependent
Challenges	Expensive to implement; remote sensing option is the most likely to produce trends cost-effectively Need to consider both benthic and pelagic habitats/species Logistically more difficult, because involves the use of a water craft to sample deepest part of the lake
Major Survey Options to Consider	**Statewide** • Remote sensing status, trends and drivers assessment of large lakes • End of bloom season statewide survey • Decadal trends in FHABs and drivers **Regional or watershed intensive, integrated surveys** • Regional status, trends and drivers • Watershed status, trends and drivers
Recommended leveraging opportunities to consider	• Wadeable streams PSA and RCMP • SWAMP SPoT program (large rivers) • National lakes and rivers assessments • Regional monitoring programs (Stormwater monitoring program, SF Bay RMP, Delta RMP or IEP) • TMDL studies and partner monitoring
Relevant Special Studies	Build the capacity to conduct landscape FHAB screening assessments (SS24, see chapter 6 for details); Review SWAMP protocols for adequacy in measuring internal FHAB drivers (SS25); Determine the feasibility of sediment cyanotoxin surveys for assessment of FHAB trends and drivers (SS28); Develop ambient monitoring approach to assess climate change impact (SS29); Sediment core analysis of historical phytoplankton community shifts (SS30)

6. Californian FHAB Incident Response Protocols

This chapter provides an overview of the FHAB incident response protocols (response protocol) that OIMA established in 2016[25]. The response protocol provides a coordinated and standardized approach to response, assessment, and public notification statewide in close collaboration with the Regional Boards and some partner state agencies. Limited resources were allocated to incident response that prioritizes short-term response activities to reports submitted by the public to the Water Boards. This chapter also provides recommendations to strengthen response protocols. Participation by local agencies, tribes, and water managers is voluntary as are the health advisories, which poses a challenge to meet the goals of incident response.

6.1 Protocol Overview

From 2010 to 2016, due to the absence of federal or state recreational water criteria, the CCHAB Network developed a voluntary guidance document to address the process of HAB occurrence, monitoring, and public notification in recreational waterbodies. The CCHAB voluntary guidance provided a set of instructions to guide local health departments and water managers for decisions to post recreational health advisories. Statewide response to occurrence of FHABs lacked leadership, resources, and infrastructure to track and effectively respond to the increasing occurrence of FHABs associated with the extended drought. In 2016, the CCHAB Network updated the voluntary guidance document to provide tiered approach for advisories to protect human and animal health that included a decision tree to inform posting and de-posting decisions and standardized advisory signs. The 2016 update was developed by an interagency committee including Dept. of Public Health, CalEPA OEHHA, and Water Boards, and underwent peer review by CCHAB Network members. The 2016 update was adopted by the CCHAB Network and CWQMC.

Incident response protocols were established in 2016 and implemented the CCHAB Network 2016 update, with support by the publication of the Phase 1 - California HABs Assessment and Support Strategy (SWAMP, 2016) and redirected SWAMP resources to support implementation of the strategic vision. Shortly thereafter, a directive from the state government established the leadership role of the Water Boards to address response to FHABs in collaboration with other environmental protection and natural resource agencies. The SWAMP 2016 Strategy described a coordinated and standardized approach to incident response, assessment, and notification to protect public health and the environment from FHAB events. Key to the strategy was building the infrastructure required to effectively respond to FHABs. Ultimately, the participation in incident response efforts is voluntary, as are the health advisories developed by CCHAB Network.

6.1.1 Current Protocol Elements

OIMA and SWAMP established the incident response infrastructure recommended in the SWAMP 2016 Strategy, including the following components: a centralized website, a reporting and database system, incident response guidance for recreational waters, standardized field and laboratory procedures, the development of a web-based satellite imagery analysis tool (See Section 3.1 for more details), and limited outreach, education, and applied research to support

[25] Incident response protocols were not reviewed by the TAC so the information provided here reflects the thoughts and opinions of the co-authors of this report.

incident response efforts. The centralized website became the CA HABs Portal and hosts an Incident Reports Map to publish data from incident response investigations and some waterbody-specific monitoring by CCHAB members. The implementation of these components was conducted in close collaboration with the Regional Water Quality Control Boards and the CCHAB Network.

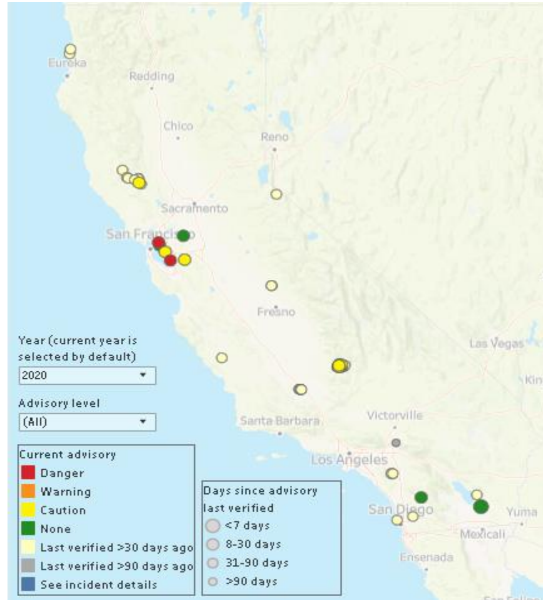

Figure 6.1. View of HAB incident reports website.

Due to the increasing number of reports and the occurrence of year-round blooms, the infrastructure and tools for response has undergone continued development and refinement. The communication resources and satellite imagery tool were prioritized for improvements to support response efforts. The centralized website was augmented to provide quick reference fact sheets and pages focused to answers to frequently asked questions for a broad audience (public, medical professionals, animal veterinarians and stakeholders), as well as improved web layout. Recently, comprehensive answers to frequently asked questions are provided for many subjects including general FHABs, human health impacts, dogs and livestock impacts, toxic algal mats, and clarifying the recommendations on FHAB advisory and general awareness signs. The web-based satellite imagery analysis tool underwent beta testing prior to release to the public in 2019.

Short-term incident response has been the priority by supporting initial response with staff, supplies, and lab analysis to inform initial health advisories due to limited resources since incident response efforts began. Currently, the Regional Boards are provided with sampling supplies and equipment to support field investigations, as well as sampling kits for partner organizations. Following initial short-term incident response, local agencies and water managers are encouraged to continue monitoring efforts to collect data to inform public health advisories throughout the recreation season. However, as with many voluntary efforts, full participation is lacking. For example, a portion of Water Boards recommended advisories are not physically posted at local waterbodies due to the lack of willingness or resources by the local agencies and water manager to post signs.

The Governor's approval of AB 834 in 2019 mandates comprehensive short-term and long-term incident response and potentially the staff and resources to fulfill the mandate. Current and future data collected from comprehensive incident response can be used to inform partner-based (Section 3.2) and state-led monitoring approached (Section 3.3) as well as decision support systems (Section 7).

6.1.2 Incident response

Bloom Reports and database system

A foundational component of incident response is the FHABs reports and database system. The database stores two classes of data: a) bloom incident reports that are sent voluntarily to the Water Boards from the public or other entities; and b) ambient monitoring data from partner entities who share their HABs monitoring data with the Water Boards voluntarily. The location, advisory level, and brief description of each sampling location (depicted by a colored dot, see Figure 6.1) is posted on the reports web map. This is the primary tool used to communicate to the public about the status of HABs in waterbodies across the state. The map is updated daily to publish available data.

Any member of the public or agency employee can submit a bloom report, which will initiate Water Boards and Regional Boards response. Reports can be submitted through an online form, by calling the HABs hotline or emailing cyanoHAB.reports@waterboards.ca.gov. This information is made available through signage at some waterbodies but such signage is not required. Once a report is received, State Water Board and Regional Board staff will collect information from the reporting party and waterbody managers to confirm the type of bloom and assess the potential health risks.

Waterbody managers are responsible for assessing the impact of blooms to their waterbodies. In addition, the recreation manager (e.g., regional and state parks) associated with the impacted waterbody can take responsibility for the assessment to inform public access to their parks. Water sample collection is strongly recommended in the response procedures. However, not all managers have the financial resources, expertise, or inclination to collect samples. In these cases, the Water Boards may assist in collecting samples and provide funding for analyses. Incident response policy prioritizes funding initial incident response sample collection; therefore, State Water Board or Regional Board staff rarely fund, or conduct follow up sampling. Waterbody managers are responsible for assessing the bloom status of their waterbodies throughout the recreation season that can be a few months or year-round. When continued sample collection is not conducted to inform continued advisories, the report is not updated on the report's web map and the last advisory sign often remains until the bloom visual indicators dissipate or by the cooler Fall season. When this occurs, the lack of continued sample collection does not inform appropriate public health advisories and can also result in confusion from the public.

Incident Response Growth and Capacity

Since formal tracking of reports submitted to the Water Boards began, the number of reports has increased annually. The number of reports doubled between the first and second year of incident response efforts, which caused strain on the limited staff and resources. During the first couple years of report tracking, the increasing report numbers was somewhat influenced by increasing public awareness of blooms and of the reporting webpage. Water Boards staff observed increasing occurrence and duration of blooms statewide during the drought (2013-2016); however, inadequate data collection infrastructure resulted in a loss of data for analysis.

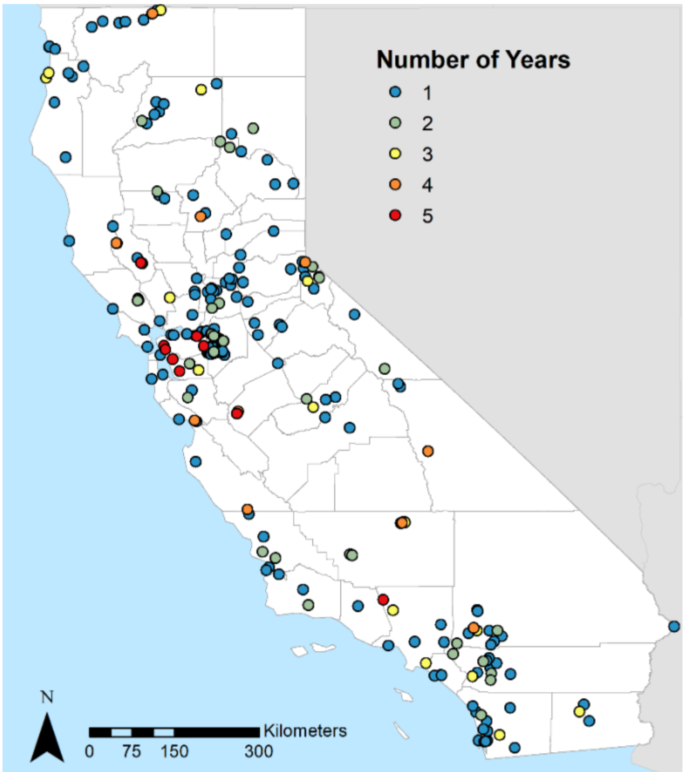

Figure 6.2. Locations of voluntary reports received between 2016 and July 2020. Locations are colored based on repeat reports over time at that location.

Geographically, reports span the entire state with many waterbodies being reported repeatedly for FHAB events over multiple years (Figure 6.2). In addition, numerous HAB-related illness are submitted as part of bloom reports impacting humans, animals, and wildlife. Additional expertise was sought to support health investigations and data collection resulting in the formation of the Interagency Illness Workgroup consisting of staff volunteers from OEHHA, CDPH, and CDFW. With the current funding and staffing levels, responses can be initiated for roughly 150-180 reports, depending on how many reports co-occur at a given period of time. In 2018, the response efforts surpassed capacity and the Water Boards needed to collaborate with the Illness Workgroup who aided in responding to events with associated illnesses as well as some reports without reported illness.

During 2019, staff responded to approximately 241 reports of suspected FHABs in drinking water and recreational waterbodies. These reports resulted in posting recommendations of recreational health advisories, corresponding to the tiered advisory thresholds, at approximately 65% of the locations reported. The Water Boards spent approximately $78,000 to respond directly to 58 of the reported waterbodies in 2019. To keep up with the increasing number of reports each year, resources are prioritized for short-term incident response to public waterbodies that provide recreation, raw drinking water, and/or a reported HAB-related illness. The second priority are waterbodies with only non-contact recreation. Long-term response and other beneficial uses are currently deprioritized due to funding and staffing constraints.

Table 6.1. Number of voluntary reports submitted year-round to the online bloom reporting tool between 2016 and 2019.

Total reported FHAB incidences by year			
2016	**2017**	**2018**	**2019**
91	181	190	241

Field Investigation and Sampling

Reports of suspected blooms trigger a suite of responses from the Water Boards. A field investigation occurs, which includes survey for visible indicators of bloom, sample collection, and collection of photographs. The field investigation is coordinated with local agencies and the waterbody manager. If they are unable, then the Water Boards may conduct the investigation.

SOPs and forms for incident response have been developed by SWAMP to standardize visual field observations and water sample collection to ensure that data are collected in an effective and uniform manner to inform public health decisions. The SOPs and forms were designed for individuals with minimal scientific training to conduct field assessments and include guidance for health and safety, site reconnaissance, and visual observations of aquatic plants, algae, and cyanobacteria.

During the field investigation, staff usually collect 1-2 samples per location and may visit several (usually 1-5) locations depending on the size of the waterbody and bloom. Samples are primarily shore-based surface grab samples, though surface scums or mat samples may also be collected depending on the characteristics of the bloom. Also, general water chemistry (temperature, pH, turbidity) is measured at majority of the sites when investigations are conducted by Water Boards. Collected samples are then analyzed for some or all of the following metrics: microscopic identification of dominant cyanobacterial species, cyanotoxin biosynthesis genes (qPCR), and cyanotoxins (microcystins, anatoxin-a, cylindrospermopsin, and saxitoxin). All analyses of samples collected by Water Boards have been conducted by contracted state or commercial laboratories; however, Water Boards staff with appropriate training may conduct microscopic identification at Regional Board onsite labs. Animal illnesses can be associated with a bloom report, and the treating veterinarian may collect biospecimen samples within the animal to test for cyanotoxins.

Table 6.2. Current indicators and metrics used in incident response protocols.

Indicator Group	Metric	Core	Optional	Metric Ref. No.
Water Clarity and/or Quality	Secchi Depth or light penetration		X	R2
	Turbidity or total suspended solids		X	R3
	Dissolved oxygen		X	R4
	pH		X	R5
	Temperature		X	D16
	DOC		X	R6
	Planktonic, benthic, or drift algal Chl-a (discrete samples)		X	R10
	In Situ Chl-a Fluorescence		X	R11
Cyanobacterial Abundance	Remotely Sensed CIcyano (if available)	X		R13
	Visual scum/mats	X		R14
	In Situ CIcyano Fluorescence		X	R16
Algal/cyanobacterial Community Composition	Species composition via microscopy	X		R19
Toxins/Taste& Odor Compounds	Total planktonic/benthic toxin samples	X		R22
	Via passive sampler		X	R23
	Toxin gene counts (qPCR)		X	R24

Response Coordination

Response to bloom reports involves many entities, an overview of the interagency response coordination is shown in Figure 6.3. An initial report of suspected or confirmed bloom is submitted to the report and database system and published to the web reports map. The Water Boards' role is to lead coordination of the local response and communicate with the local entities such as local health, water and land managers, and tribes and other local partners. When a potential FHAB may impact source water, the Division of Drinking Water leads response and communication with the water purveyors, both of the impacted waterbody and downstream users. If a human or animal illness is related to the report, then the Interagency Illness Workgroup, leads the health investigation. All illness data are collected per the CDC's procedures for submitting illness reports to the One Health Harmful Algal Bloom System (OHHABS). Local responding entities are requested to provide updates regarding continued monitoring and posting decisions.

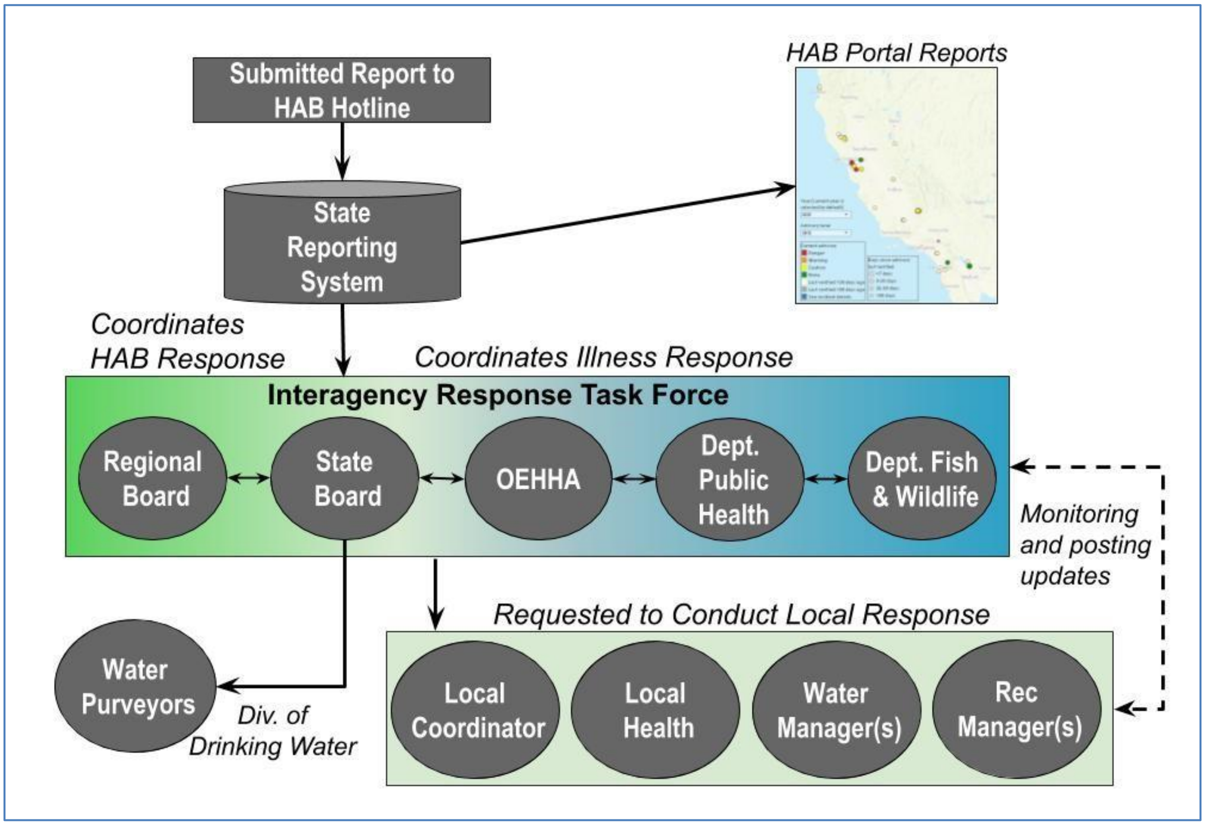

Figure 6.3. Interagency Response Coordination.

The CCHAB guidance for recreational waters is implemented as part of the response procedures and has been supplemented with additional tools; the comprehensive California Voluntary Guidance for Response to HABs in Recreational Inland Waters (Guidance for Response) is published on the CA HABs Portal for use by responding entities. The results of the field investigation and cyanotoxins concentrations in water are used to determine the appropriate voluntary health advisory. The advisories are tiered ranging from Caution (lowest severity), Warning, and Danger that are triggered by increasing cyanotoxin concentration levels (see Table 3.2.1). Non-toxin based triggers of Caution advisory includes presence of visible indicators of a bloom and related illness. The health advisories are developed to provide recommendations to protect recreation (particularly children and dogs), fishing and shellfish consumption. A separate health advisory process is provided for proliferations of benthic cyanobacteria (toxic algal mats).

After a harmful bloom is confirmed, continued monitoring by waterbody managers is recommended to track the changing bloom status and update health advisories. The Water Boards does not have sufficient resources to support continued monitoring at all waterbodies, therefore, continued monitoring is the responsibility of local entities and waterbody managers.

As such, some blooms are not monitored to inform appropriate health advisories during the recreation season. In addition, the Water Boards recommendations to local agencies and water managers for posting health advisories are sometimes not implemented resulting in a portion of un-posted waterbodies. The latest recommended status is displayed on the web reports map. Data and information related to incident response is stored in the report and database system and eventually uploaded to CEDEN.

6.1.3 Communication

Data Sharing from Partners

To better document FHABs across the state, the FHABs Program accepts HABs data from other entities willing to share their results with the Water Boards. This increases the spatial scope of the FHABs database and incident map, providing the public with more thorough information about the status of waterbodies in California. The partner entities do not uniformly follow the SWAMP SOPs for sample collection and there is some variation in the sampling methods among the groups. The FHABs Program continues to invite additional partners to contribute their data to the database, so that the database provides a more comprehensive collection of HABs related data in California.

Data Management and Visualization

The report and database system consists of the following components:

- An **online report form** that automatically notifies the applicable State Water Board and the centralized FHAB inbox with a summary of the report. Any photos or supplemental documents are emailed separately. All information is forwarded to the Regional Board. If a report does not include a Regional Board, then the notification is manually forwarded to the Regional Board.

- A **database** that stores all data and displays the data using an user interface. Due to agency security protocols, other environmental and resource agencies cannot read or write to the database.

- A **review and validation process** by Water Boards staff prior to publishing to the online reports map. All updates to published reports are pushed to be displayed on the map daily on all weekdays except holidays.

Published data are visualized on an interactive map and dashboard and supported by R-script queries for additional functionality. Individual reports are displayed as colored dots that provide pop-up windows to display additional details. The dashboard also presents tabular data to sort reports by county and other parameters. In 2020, additional features were added to the reports map to display color coded advisory levels corresponding to each report and allow for updates to advisory levels during a calendar year. Prior to these new features, the report map displayed a single color for all reports that faded in color intensity based on the length of time passed since the last record update. All published data are available for download from the state's open data portal (https://data.ca.gov/dataset/surface-water-freshwater-harmful-algal-blooms).

6.1.4 Outreach and Education

Using a voluntary approach, the FHABs Program has used different strategies to encourage participation in incident response efforts and engage with partner entities. Outreach is conducted though the CCHAB Network and entities involved during incident response. The Program coordinates and conducts workshops with the Regional Boards to engage with and train entities such as local environmental health, waterbody managers, recreation managers, community monitoring groups, tribal governments, and non-governmental organizations. The workshops provide networking opportunities to build effective communication plans, training on the response and advisory process, as well as hands on demonstrations of field investigations and microscope identification. During 2017 to early 2020 the Program conducted approximately 35 outreach events statewide (Figure 6.4) and presented similar information at industry led conferences, workshops, and webinars. During the peak bloom season, often a new or less engaged local agency or water manager is provided with web-based education that focuses on field investigation and advisory processes to support immediate needs.

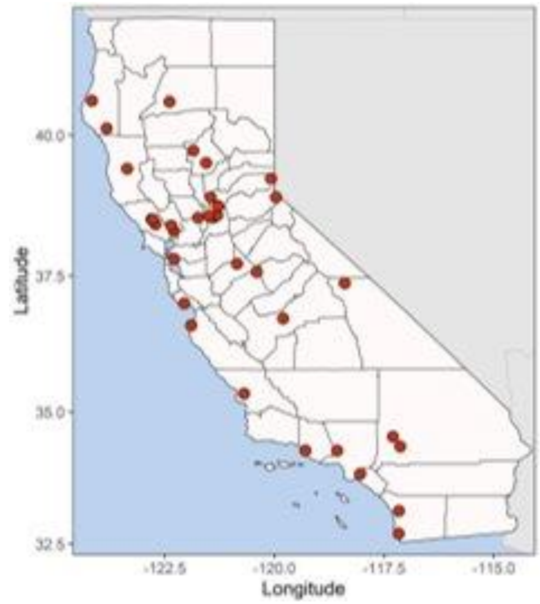

Figure 6.4. Locations of outreach events conducted between 2017 and 2020.

6.2 Current Management Applications

Incident response primarily informs the posting of health advisories related to recreational exposures to cyanotoxins. When reports are received Water Boards staff works with Regional Boards, local health agencies, tribal partners and waterbody managers to determine the risk to the public and post appropriate signage and recommended restrictions for that waterbody until the bloom subsides.

Beyond public health advisories, the Division of Water Quality is developing standardized procedures for using cyanotoxin data in the 2020 integrated report cycle, consistent with the Water Boards listing policy. If the Division adopts these listing procedures, then cyanotoxin data in CEDEN would be considered when developing Integrated Reports and assessing impairments. The proposed listing procedures considers thresholds for municipal, recreation, and fishing beneficial uses. Currently, only a few waterbodies have a state or federal impairment listings for cyanobacteria or cyanotoxins, including the Klamath River Reservoirs and Pinto Lake (Santa Cruz County). The ability for the Water Boards to assess waterbodies for FHABs impairment is credited to the increased amount of available cyanotoxin data from the incident response and partner entities.

In addition, the data collected from incident response has further strengthened the case for state regulatory standards to require reporting, assessment, and advisory postings. The Division of Water Quality is considering the development of water quality objectives for FHABs and cyanotoxins; as proposed, it would be incorporated specifically into the Biostimulatory and Biological Integrity amendment of the Inland Surface Waters Plan. The amendment would address biostimulatory conditions, such as nutrients impacts, that can cause FHAB response in waterbodies. These planned regulations may also apply cyanotoxin thresholds to lakes, reservoirs, and streams.

To support future regulatory standards, the laboratory analysis methods used to measure FHABs and cyanotoxins will require validation per the Environmental Lab Accreditation Program (ELAP) standards to meet laboratory accreditation requirements.

6.3 Considerations to strengthen FHAB Incident Response Protocols

The FHAB incident response continues to expand and develop, and the approval of AB 834 in September 2019 has the potential to bring additional financial and staff resources to improve response efforts. With the mandate to monitor FHABs, the timing is appropriate to evaluate the effectiveness of the incident response protocols in the following sections and identify the priority programmatic elements to strengthen the critical role that incident response serves.

6.3.1 Evaluation of Strengths and Weaknesses

The key strength of incident response lies in its ability to provide a mechanism to receive, respond and communicate public and agency reports of FHAB events. The results of these efforts provide daily updated information to the public and collaborating agencies on where known HABs are occurring in the state. A majority of reports of suspected blooms come in from the public, so they are not dependent on agency staff and reports may address waterbodies that otherwise would not receive much attention from an agency. With increasing impacts of climate change, FHABs are anticipated to increase, so the ability to respond to public reports will continue to increase. Currently, only a small number of waterbodies are routinely monitored, so incident response is the primary means of determining and communicating in near-real time of confirmed bloom events and associated postings throughout the state.

Through the implementation and development of these protocols, a network of trained agency staff now exists who can conduct FHAB field investigation and sample collection. Additionally, incident response efforts allowed for the organic development of many connections to local health agencies and waterbody managers, as well as recruited numerous partners for recreational use monitoring. The recreational monitoring triggered by reports provides source water surveillance which has been used by Division of Drinking Water and water purveyors.

Although the types of analyses that can be conducted with incident response data are somewhat limited, the collected data can show percentage of samples or waterbodies that have been repeatedly recommended for posting (e.g., Figure 6.1) or exceeded certain advisory levels over time. Incident response data currently provides the most comprehensive information on waterbodies with chronic issues statewide. As described above, these data are also being considered for use in integrated reports to provide more information about waterbodies with chronic FHABs to be considered for future management actions.

Although the incident response protocols have several important strengths, there are some key weaknesses in the current program. The incidence response efforts have had difficulty satisfying the procedures laid out in the CCHAB response guidance, because of limited staff time, limited financial resources to fund analyses, and no mechanism to require waterbody managers or local agencies to perform the initial and continued sampling or post recommended advisories at waterbodies. Reports are not standardized (temporally and spatially) and voluntary, so trend analysis is difficult. A relevant question is whether the current level of incident response monitoring is adequate to protect and address recreational use impairments. Discussion along these lines is also addressed in Section 4.1.1 (Recreational Use Surveys). Continued monitoring is often insufficient or may not occur at all, so minimal data on duration and severity of blooms is collected. Incident Response data are collected following a report, therefore, provides limited information on temporal and spatial dynamics of blooms. For sites that do have continued monitoring, the current database is not well structured for storing data on changing bloom conditions over time.

Since many of the reports are submitted by members of the public, not all reports are for cyanobacterial blooms, some include nuisance algae blooms and commonly non-toxin producing algal blooms. Although these reports are less useful from a public health perspective, overgrowth of nuisance algae is useful information for understanding waterbody status and waterbodies which may be more prone to toxin producing blooms. Currently, due to the limited resources allocated for incident response efforts, this information is not able to be captured efficiently since the main priority is public health protection.

6.3.2 Recommendations to Strengthen Incident Response Protocols

Five priority elements are recommended to strengthen and support effective incident response:

1. *Improve data management and visualization of incident response data to improve public communication and agency staff use of FHABs data. Specific actions include:*
   - Modernized database for managing bloom incidents and storing bloom related data.
   - Improved ability and ease for partners to contribute their data into the database.
   - Modernized webpage and interactive maps to better communicate to the public the HABs condition at waterbodies.
2. *Assurance that incident response data are used in Water Boards programs, actions and policies. Specifically, this includes:*
   - Incorporate incident response data into decision support tools designed for Water Boards staff.
   - Closer linkage with Inland Beaches Workgroup and Safe to Swim Network to develop comprehensive data visualization on swimming safety.
   - Support laboratory method validation and accreditation per the Environmental Lab Accreditation Program (ELAP) standards, this will be a requirement for development of regulatory standards for recreation and maximum contaminant levels for drinking water.
3. *Continue to fund incident response efforts, including need for staff to field adequate response and follow-up to better protect recreational uses.*

- AB 834 calls for long-term incident response to ensure that data are collected to inform continued advisory postings and ensure posting is done on the ground to notify the public. Current funding is limited to initial assessment and infrequent 1-2 times additional assessments. Therefore, a need exists to continue data collection when water managers are not able or willing to participate in the Partner Monitoring program.
- Follow-up to provide adequate staffing support (field work, long-term monitoring, follow with reporting parties) and analytical support for samples collected.
- Standardized guidelines for assessing spatial area and advisory extent (lake-wide vs single/coves).
- Assure timely monitoring data submitted to Water Boards to inform posting.
- Posting of education and outreach information on FHABs at recreational sites across the states.

4. *Strengthen collaboration with other agencies to respond to bloom reports:*

- Strengthen collaboration with other state agencies identified in AB 834 to meet the mandates described in that legislation.
- Build collaborations with tribes, local agencies, and scientific NGOs.

5. *Integrate incident response with other program elements described in this Monitoring Strategy:*

- Revise SOPs to develop a seamless and unified approach between incident response and the Partner Monitoring Program.
- Incident response data shows known at risk waterbodies to prioritize for partner-based or state-led monitoring.

6.4 Summary and Recommendations

Incident response is a core component of the FHABs Program. Even as ambient monitoring increases, the Water Boards will still need to respond to the public reports of blooms. Public observations of conditions at waterbodies statewide occur more frequently than that of Water Boards staff and partner agencies. In this sense, the public is a partner of the Water Boards who can ultimately provide more surveillance than ambient monitoring can feasibly provide. We recommend that incident response efforts should continue and expand to efficiently respond to FHAB reports from the public, per the recommendations listed above. As ambient monitoring increases, we anticipate that more public reports can be responded to with data from ambient monitoring and reduce the overall workload needed for incident response efforts.

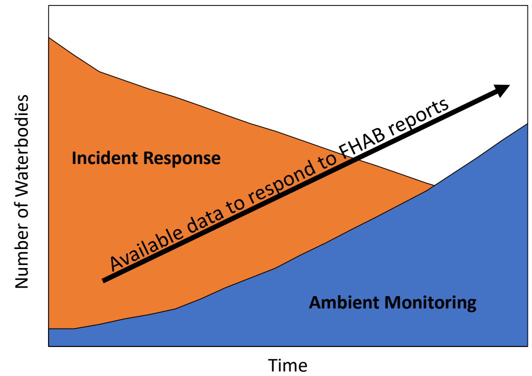

Figure 6.5. Conceptual model of reduced need for staff to launch a field response to FHAB reports from the public with increasing amounts of ambient monitoring data.

7. FHAB Decision Support

7.1 Introduction to FHAB Decision Support

A core principle of California's FHAB monitoring program is the focus on management decision-making (Table 2.1). In Chapters 4 and 5, management questions and information needs were explicitly stated and considered in discussing the indicators, spatial, and temporal design and options for implementation to assess FHAB status, trends, and environmental drivers. However, Chapters 4 and 5 do not specifically speak to important implementation components that facilitate use of FHAB monitoring data to support decision-making. This is especially relevant as FHAB monitoring is expensive and the significant data gaps exist for many parts of the State. FHAB prediction and visualization tools that can begin to expand to waterbodies for which little data are currently available will be an important near-term strategy to prioritize limited field monitoring resources. In fact, managers interviewed to discuss how the FHAB monitoring program could support their needs explicitly called out the difficulty in the use of current data management systems to make management decisions on individual waterbodies or groups of waterbodies.

Investments in data visualization tools and functionality that allow FHAB monitoring program partners to streamline their own reporting and visualize the results of their data in the context of other waterbodies in their region may incentivize partners to submit their data to the State (**SS4, Appendix 6**).

This chapter establishes the vision and basic principles for FHAB public health protection and water quality management decision support and identifies some of the early tools that can enhance decision support across partners and agency programs. We review the types of decisions that need to be made, then describe in general detail the types of tools and their functionality that would facilitate making those decisions.

> **Open Data Core Principles**
> **(SWRCB Resolution N. 2018-0032)**
>
> - Make data accessible in machine readable datasets with metadata and data dictionaries
> - Understand data quality and integrity
> - Improve data literacy with robust data science capacity
> - Use data to govern
> - Govern our data with proactive steps to develop effective data and information technology management practices

Any decision support tool must embrace the Water Boards' open data policies and core principles. In 2018, the State Water Boards committed to generating open data within the agency (see inset box: Open Data Core Principles, State Water Board Resolution No. 2018-0032). This initiative from the Water Boards builds upon the multi-agency mandate in AB 1755 Open Water Data Act[26], which directs all water data in the state to be accessible and available to the public. California is not alone in this effort and other states, such as New Mexico (https://newmexicowaterdata.org/), are also mandating open data be provided by state agencies. OIMA was tasked with developing an open data strategy to implement these principles throughout the Water Boards. Any data collected for and used by an FHAB decision support tool should be managed according to the guidelines in the CA Open Data Handbook (https://handbook.data.ca.gov/). Central to the open data initiative in the waterboards is making

[26] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB1755

data freely accessible, usable, and shareable for any purpose[27]. Effective data management considers the entire data life cycle[28] and requires developing systems to address each life cycle stage – collecting, processing, storing, analyzing, interpreting, and making data accessible. These data and information systems are part of the critical infrastructure needed to address the State's current and future FHAB priorities (**SS5, Appendix 6**). We note that some disadvantaged communities may have poor access to electronic information, and thus multiple dissemination modes for FHAB information will be required.

7.2 FHAB Decision Support: What Are the Decisions and What is Needed?

Decisions supported by FHAB monitoring data can be broadly grouped into two categories that have similar decision support needs: 1) public health protection and response and 2) FHAB water quality management decision support, which can more generally encompass decisions on prioritizing ambient monitoring, Water Boards regulation, FHAB causal assessment, and mitigation and actions to conserve or prevent degradation of habitat (Table 7.1).

Table 7.1. Categories of management decisions, example decisions, and their use of basic types of data or model output to inform decisions.

Category	Example of Decisions	Types of Data or Model Output				
		FHAB Event Data	Ambient Recreational or Fishable Use Data	Remote Sensing	All Other Ambient Field Data (Responses/ Drivers)	Predicted FHAB Risk Models
FHAB Public Health Decision Support Tool						
Public Health Response	Public decisions whether or how to use a waterbody (recreation, fishing, drinking)	X	X			
	Decision whether to sample or timing to sample a waterbody	X	X	X		
	Decision to post/unpost a public health advisory	X	X			
FHAB Water Quality Management Decision Support Tool						
Ambient Monitoring	Prioritize waterbodies or watersheds for intensive FHAB risk characterization	X	X	X	X	X
Regulatory	Waterbody assessment and 303(d) listing	X	X	X	X	
	Issue permit requirements, monitoring or special studies (NPDES, MS4, etc.)	X	X	X	X	X
	Waste discharge requirements, waivers, permit conditions	X	X	X	X	X
Causal Assessment and Mitigation	Investigations & causal assessment	X	X	X	X	X
	Prioritize sites or catchments for non-point source control strategies	X	X	X	X	X
	Identify restoration or mitigation sites in water quality improvement plans/TMDL implementation plans	X	X	X	X	X
	Communication to land users and dischargers	X	X	X	X	X

[27] http://opendefinition.org/

[28] Data life cycle management involves managing the flow of information from the initial identification of data needs through the stages of data collection, data storage, data accessibility, and the final process of turning data into information and knowledge.

We envision two distinctly different tools that share and draw from data and model output, including 1) FHAB event monitoring data, 2) satellite remote sensing data, 3) ambient field monitoring data, and 4) FHAB predictive models. Recreational or fishable use data have stringent temporal requirements (near real time) and thus they are distinguished from other types of ambient field data (including both responses and drivers).

In this section, we consider the functions that decision support tools would need in order to facilitate different decisions. The concepts described here are meant to be illustrative rather than prescriptive. A dedicated task in FHAB monitoring program implementation is to develop the detailed designs for these decision support systems by querying their intended user groups about key components and detailed functionality of the tools (**SS5, Appendix 6**).

7.2.1 FHAB Public Health Information System

FHAB Public Health Information System Key Features

- Focused on recreational and fishable waterbodies
- Publicly viewable "Nowcast" of conditions and FHAB advisories and historical views of FHAB grades
- Public-facing web interface requires no formal training to use.
- Updated continuously.
- "Back-end" of the portal with Water Board and partner permissions to upload data and automatically post to information system
- Automatic notifications to responsible parties when CIcyano (lakes) or public bloom reports are submitted

The existing incident response program is comprehensively defined in Chapter 6. Here, we pick up the thread of discussion, focusing specifically on decision support tools to facilitate incident response (posting and un-posting) and the interface needed to inform the public of FHAB risk (beyond incident response). These decisions of the public or agencies vis-à-vis general waterbody safety and FHAB incident response are quite distinct from other FHAB functions and decisions (Table 7.1). Generally, three types of decisions are involved in FHAB incident response: 1) Water Boards decisions on whether to initiate sampling or resampling (partner and/or state-led) or complete toxin analyses of a waterbody for an FHAB event, particularly if an event has not been reported but is suspected due to exceedance of a CIcyano trigger through a satellite remote sensing tool, 2) decisions on whether to post or un-post a waterbody, and 3) decisions by members of the public on whether or how to use a waterbody (for fishing, swimming), based on their review of historic or current conditions. The decision support tools need to provide: 1) data sharing and automated notification capabilities to facilitate strong local agency or partner and state coordination, 2) full public access to the information support, and 3) timeliness, in which the recreational or fishable use field survey monitoring data must be made available immediately upon completion of laboratory analyses.

Water Boards or Regional Board FHAB decisions to initiate sampling and analyses of toxins should be supported by desktop notifications of relevant state and regional agency staff that a bloom trigger has occurred. These bloom triggers could be generated by exceedance of remotely sensed CIcyano value for a given waterbody or partner submission of an event report. Currently, the FHAB satellite tool already provides an automatic notification to relevant Regional Board HAB coordinators when the modified CIcyano value exceeds a specified threshold. Thus, the tool as it currently exists could provide an early warning for managers to mobilize field crews to conduct a field assessment to track the potential increase of cyanotoxins. Additional features could make a waterbody satellite bloom report more effective for Water Boards HAB coordinators and local managers, including: 1) monthly, seasonal, or yearly historical trends, 2) statistics on the extent and magnitude for a defined time period (e.g., percent probability for a given month), and 3) statistics on its rank or trophic status within the universal set of remotely sensed lakes.

Distinct from agency decisions, members of the public should be able to make informed decisions whether or not to go to recreational or fishing areas in specific waterbodies. This requires a combination of educational outreach to inform the public of the risks FHABs pose, as well as providing the public with a combination of historical and/or current conditions in order to make decisions about recreation within a specific waterbody. More advanced webpages and

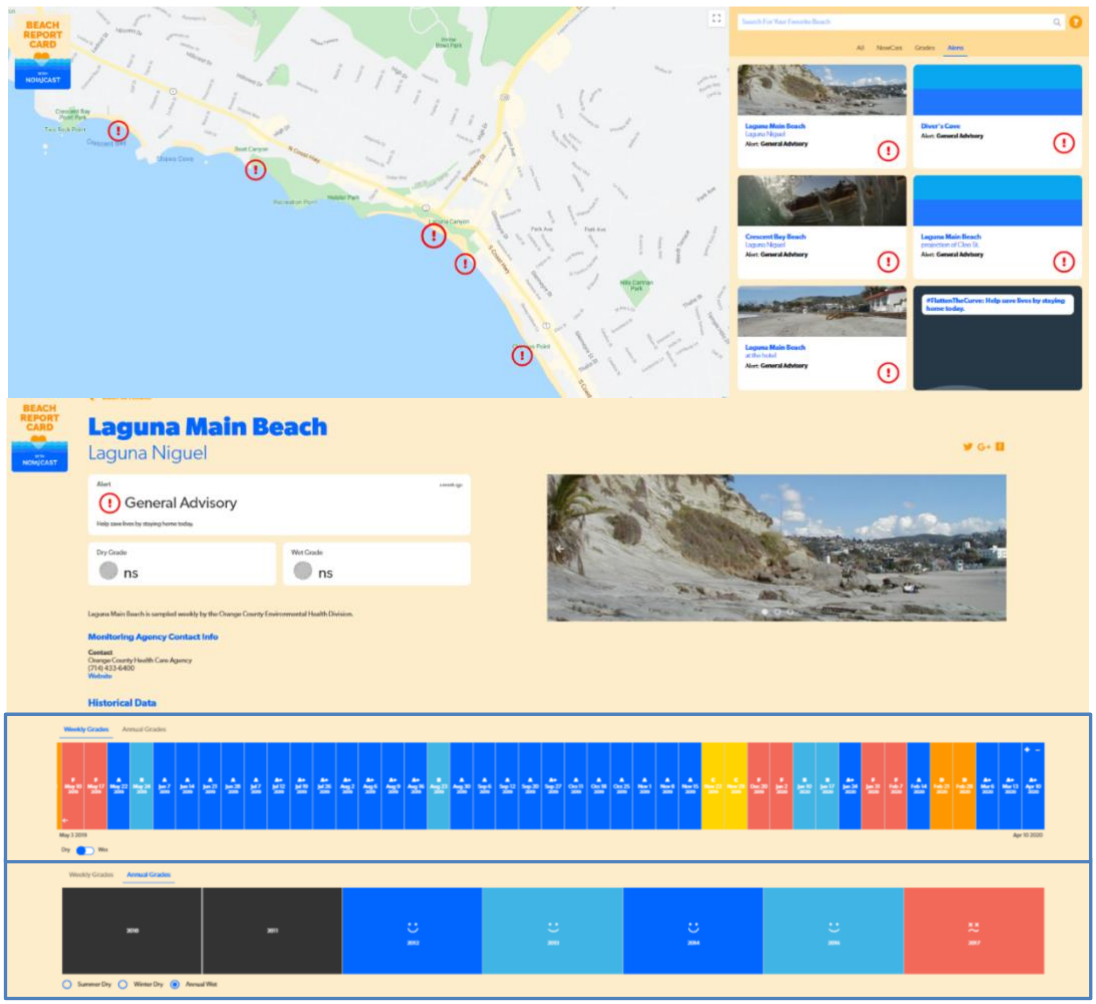

Figure 7.1. Example of recent data (top panel) and historical beach recreational use grades (lower panels) in the beachreportcard.org.

interactive maps are needed to better communicate to the public status of FHABs at waterbodies. Communication of risk should be transparent and unequivocal. There are FHAB communication tools and examples based on advisory level and/or cyanotoxin concentrations available from USEPA and from other states (for example, see USEPA's summary of state monitoring program pages, https://www.epa.gov/cyanohabs/state-habs-monitoring-programs-and-resources). Health grades such as is used with the BSMP (AB 411) data and Heal the Bay's Nowcast accomplishes this well. The public should have the ability to toggle between the most recent results (within the last week) or the historical grades by week or annual (see example from Nowcast portal, Figure 7.1).

Decisions to post or remove a post on a waterbody are a key component of the health information system. Currently, CCHAB guidelines recommend posting/un-posting be done by public health agencies and so these decisions are usually made via email correspondence with Regional Water Boards and local health agencies. These partners need to be able to input their event monitoring data and whether a decision to post has been made. Automatic data quality checkers and upload capabilities are key to assure seamless data quality and integrity. Daily decisions on posting or removal of postings should be made immediately available to the public via a "nowcast" interactive website.

7.2.2. FHAB Water Quality Management Decision Support Tool

FHAB Water Quality Management Decision Support Tool Key Features

- Publicly accessible but focused on a set of water quality protection and watershed/land management functions, so target audience is more constrained to "managers;"
- Draws from publicly available datasets, published models and their outputs;
- Visualize standardized set of spatial and temporal "views" of FHAB response indicators and environmental drivers;
- Does not presume a standardized way to combine multiple indicators (i.e., an index). Rather it would allow the juxtaposition of multiple lines of evidence in order to allow for maximum flexibility in decision support.
- FHAB outcomes can be categorized into standardized and user-defined triggers;
- A publicly available version would have standard features for use by partners, while a customized version can be used for State and Regional Water Board explicit regulatory and non-regulatory functions.

Beyond public health protection (Section 7.2.1), state, regional, and local managers make a range of decisions on FHAB water quality management, including prioritization of ambient monitoring, regulatory decisions (permits, 303(d) listing), causal assessments and mitigation (TMDL implementation, NPS, and PS control strategies) and conservation, anti-degradation or drinking water source protection. Inherent to all these types of decisions is the use of available information to: 1) Identify locations, 2) rank waterbodies/ catchments/watersheds to prioritize actions, 3) look for spatial and temporal linkages between human actions, natural events (e.g., fires, storms, etc.), and FHAB responses, and 4) evaluate appropriate management decisions based on some categorical evaluation of information. Managers interviewed to discuss how the FHAB monitoring program could support their needs explicitly called out the difficulty in the use of current data management systems to make management decisions on individual waterbodies or groups of waterbodies because data are in disparate places or require expertise to use (e.g., remote sensing).

An example of this decision support is the prioritization of ambient monitoring resources – a common challenge among state, regional, and local agencies and organizations. As noted earlier, a recurrent theme of status and trends (Chapter 4) assessments of FHAB impacts to swimmable, fishable, aquatic life, tribal and cultural uses, and raw water uses that is adequate characterization of FHAB risk requires <u>repeated sampling</u>, an expensive endeavor. A key recommendation of this strategy is to use available resources to prioritize this more intensive FHAB monitoring, based on a combination of measured risk (e.g., toxins, CICyano values), predicted FHAB responses or environmental drivers and other contextual information (e.g., intensity of waterbody use, environmental justice issues, etc.). A decision support tool that could support prioritization of ambient monitoring or other water quality decisions (Table 7.1) would consist of a desktop tool that pools available ambient monitoring and incident response data (remotely sensed and field) and shows predicted FHAB risks where data are lacking (e.g., Table 7.2). Additional watershed or waterbody contextual information could be included to drive decision support. Standard and user defined thresholds or triggers could be used to evaluate the monitoring data, predicted FHAB model responses, and other contextual information. The outcomes could be visualized as a map or as a ranked list of waterbodies or riverine segments for each of the factors of interest. Determining what factors should be considered needs to be user defined, rather than some standardized index, because of significant differences in what is valued as ranking factors among the potential user groups.

Table 7.2. Examples of data sources that could be used to prioritize monitoring.

Category	Example data types
Monitored Toxic FHAB risk	Toxic FHAB events Remotely sensed CICyano Dominance of toxigenic FHAB species FHAB toxins in fish or shellfish tissues or passively sampled
Monitored Eutrophication Response	Wadeable stream benthic Chl-a, AFDM, macroalgal percent cover Lake Chl-a, hypoxic volume, secchi depth Estuarine Chl-a, macroalgal biomass, percent of time below DO WQO
External drivers	Catchment nutrient loading, atmospheric nutrient deposition, catchment land use, et al.
Internal drivers	Ambient TN, TP, channel substrate alterations (e.g., hardscaping), hydromodification
Models of predicted FHAB responses	Predicted risk of eutrophication (benthic Chl-a) in wadeable streams Predicted risk of remotely sensed CICyano or Chl-a in lakes and reservoirs
Waterbody or watershed context	GIS layers designating recreational use or fishing sites Population density Waterbody use statistics Ease of access (distance from major road) Median income

The SFEI FHAB satellite tool has several "building block" components of this FHAB water quality management decision support tool. It features an interactive map. It has a graphical interface from which a user can choose views of both satellite and CEDEN (ambient) monitoring data (Figure 7.2). However, this platform could be augmented to support FHAB management in several ways. First, data visualization features could be expanded beyond that of a single lake[29] to include streams, lakes and reservoirs, and the coastal confluence within a watershed. The advantages of including multiple waterbodies are several-fold: 1) within a watershed, aquatic ecosystems (lakes, rivers, streams, and coastal confluences) are hydrologically connected; FHAB drivers or problems detected upstream are an important consideration to prioritize downstream monitoring, and 2) at a landscape scale, lack of data for certain waterbody types (e.g., lakes and reservoirs, a statewide problem), can be addressed to a limited extent by plotting more abundant data for other waterbody types (for some regions, wadeable streams) that are hydrologically connected and therefore may have similar patterns in eutrophication in general or FHABs in particular.

Second, the data visualization could be expanded to include a time-integrated spatial view that shows relative FHAB risk and linkage on a broader spatial scale. An example of this landscape view and categorization is the output of the Stream Classification and Prioritization Explorer (SCAPE) tool for biointegrity (Beck et al. 2019). The SCAPE tool, programmed into R shiny

[29] The focus on a single lake is logical, since remote sensing data are only available for large lakes.

apps, allows the user to: 1) view maps of measured biointegrity data versus predicted biointegrity at the watershed scale, 2) slide the scale on the condition threshold and confidence range required to understand sensitivity of output to trigger value, 3) view a stream reach ranking of scores, 4) and set priorities for different actions (e.g., investigate, protect, or restore with targeted action for causal assessment and mitigation). Comparable to biointegrity, categorical triggers could be applied to the data in order to "grade" FHAB risk that could be visualized on a landscape scale. Those could be regulatory thresholds or advisory guidelines as a standard default, or user defined. Geographic scale of decision support is an important consideration. While some Regional Boards may wish to prioritize among watersheds, a watershed group may want to prioritize among waterbodies found in different catchments, and a lake manager may want to focus on a single waterbody. We recommend the use of the watershed as an appropriate unifying geographic assessment unit, with the note that functionality to zoom in on a single waterbody or to compare outputs among watersheds will be important.

More advanced functionality would be required for "causal assessment" of environmental drivers that are supporting FHABs (see Chapter 5), though there is no need to "reinvent the wheel." EPA's Causal Analysis/Diagnosis Decision Information System (CADDIS), designed to help scientists with causal assessment, is a good foundation for consideration of the type of functionality that one could offer. Towards this end, EPA offers CADStat, which is a menu-driven package of several data visualization and statistical methods to conduct causal assessment. Given that these causal assessment statistical methods are tuned to identify stressors impacting biological communities, the analytical approaches and paradigms will be similar. It would be helpful to have specific demonstrations of FHAB causal assessments in streams, lakes and reservoirs, and coastal confluences that point to appropriate comparisons and decisions on spatial or temporal aggregation of data.

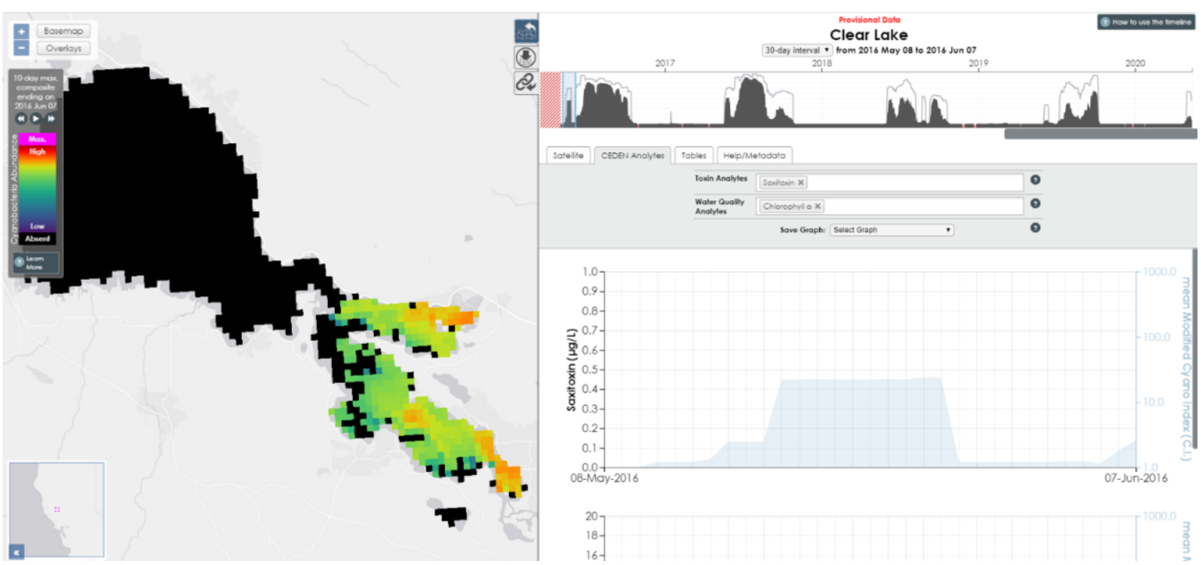

Figure 7.2. Snapshot view of the FHAB satellite tool, which shows a map view of Clear Lake with time-averaged CIcyano (left panel) with the CIcyano (top right panel) time series and the ability to plot ambient field monitoring data from CEDEN (bottom right panel), if is available in CEDEN.

7.3 Foundational Data Useful to Drive Decision Support and Role of Predictive FHAB Models

Section 7.1 laid out the premise that two different user interfaces (public health and water quality management) that could serve as decision support would share and draw from five basic types of data and model output: 1) Satellite remote sensing, 2) FHAB event monitoring data, 3) Ambient recreational or fishable use field monitoring data, 4) All other ambient field monitoring data (including both responses and drivers) and 5) FHAB predictive models.

With the exception of FHAB predictive models, these data sources and the needs for improved data visualization have been comprehensively discussed in Chapters 3-6 and in Section 7.2. Beyond modernization of databases, automation of quality assurance, and quality control data checkers, discussion of specific improvements or visualizations of existing data that are needed to facilitate building these decision support systems should be scoped with the intended user audience and as such is beyond the scope of this document.

In the near term, we face considerable data gaps on the extent and drivers of FHABs in all surface waters. Available resources to address this have not been identified. In the interim, we propose using existing data to develop early-stage predictive models, based on relationships between drivers and FHAB response, of the probability that FHABs would occur in all the State's inland waterbodies. Such models would provide a line of evidence to support prioritizing more intensive monitoring and to formulate regional control strategies (e.g., NPS and PS controls, WDR, environmental flows, etc.). **Appendix 5** describes the scope, development, and potential uses for predictive FHAB models, which could be the target of a set of special studies **(SS24, Appendix 6).**

7.4 Summary and Recommendations

This chapter establishes the vision and basic principles for FHAB public health protection and water quality management decision support and identifies some of the early tools that can enhance decision support across partners and agency program. We review the types of decisions that need to be made, then describe in general detail the types of tools and their functionality that would facilitate making those decisions. Over the long-term, two major types of decision support tools are recommended for development: 1) a public health information system, targeted at providing near real time data on recreational and fishable use impacts from FHABs and 2) an FHAB water quality management tool, intended to support decisions on prioritization of ambient monitoring, regulatory decisions (permits, 303(d) listing), causal assessments and mitigation (TMDL implementation, NPS and PS control strategies) and drinking water source protection. To accomplish this long-term vision, several recommended actions can be taken incrementally to build towards these decision tools.

Table 7.3. Summary of specific recommended actions and special studies that could be implemented for FHAB public health protection and water quality management decision support.

Specific Recommended Actions	Special studies
Modernize and incrementally build databases that houses FHAB incident response and recreational and fishable use	
Develop the vision, including key data sources, data visualizations and GUI interface functionality, for each type of decision support, through interactions with intended user groups (targeted FHAB monitoring program partners)	Determine user needs for FHAB decision support systems (SS5)
Incrementally build FHAB response models and data visualization tools, using an open source approach such as R shiny apps to encourage community development of such functionality	Build the capacity to conduct landscape FHAB screening assessments (SS24). Models for coastal confluences and non-wadeable rivers would be site-specific.
Build data systems and decisions support incrementally even at moderate FHAB monitoring program funding levels to encourage strong partnerships and rapid dissemination of FHAB monitoring data	Develop partner program open data systems (SS4)

8. Strategy to Develop an FHAB Monitoring Program

8.1 Introduction

The elements described in the previous chapters need to be synthesized into a strategic implementation plan to build an FHAB monitoring program. Chapters 3-7 identified the elements, options, and recommendations that could form the foundation of a comprehensive FHAB monitoring program that protects the core beneficial uses. Together, these options can synergistically address the multiple management questions and objectives identified at the onset of strategy development (Figure 8.1). However, the resources and staff required to implement all the recommendations promoted in Chapters 3-7 have not yet been identified.

This chapter recommends *a strategy* to incrementally build and implement an FHAB monitoring program. Priority building blocks are identified to ensure an early return on state investments in monitoring. Because available resources were not specified, this strategy must be flexible to scale with future available resources and identify the incremental timelines for development (immediate, near-term, and long-term).

Water Boards staff considered TAC recommendations for prioritized monitoring program components for each of the elements and actions examined in the previous chapters. They then formulated a set of six recommended actions (and associated special studies) that represent the strategic implementation of a subset of these approaches, implemented with appropriate data systems and decision support tools in accordance with open data policies (see inset box: Open Data and Decision Support as a Core Principle). The following recommendations should be implemented, along with a strong program for public education and outreach to communicate risks and impacts of FHABs:

1. Develop and implement an FHAB partner monitoring program;
2. Strengthen incorporation of remote sensing in FHAB monitoring program;
3. Implement field surveys focused on protecting human health;
4. Conduct focused assessments of FHAB environmental drivers;
5. Synergize incident response with ambient monitoring;
6. Work to integrate FHAB monitoring elements into all relevant water boards programs, permits, and policies.

Open Data and Decision Support as a Core Principle

- A core principle of California's FHAB monitoring program is the focus on management decision-making.
- Open data are a foundational principle for all current and future elements of the FHAB monitoring program and congruent with SWAMP data policies.
- Managers interviewed to discuss how the FHAB monitoring program could support their needs explicitly called out the difficulty in the use of current data systems to make management decisions on individual waterbodies or groups of waterbodies.
- Investments are needed in data visualization tools and functionality to enhance decision support for both public health protection and water quality management.
- FHAB partners recruited to monitor and submit their data will find greater incentive to participate if their data visualization and reporting can be addressed through FHAB decision support tools.

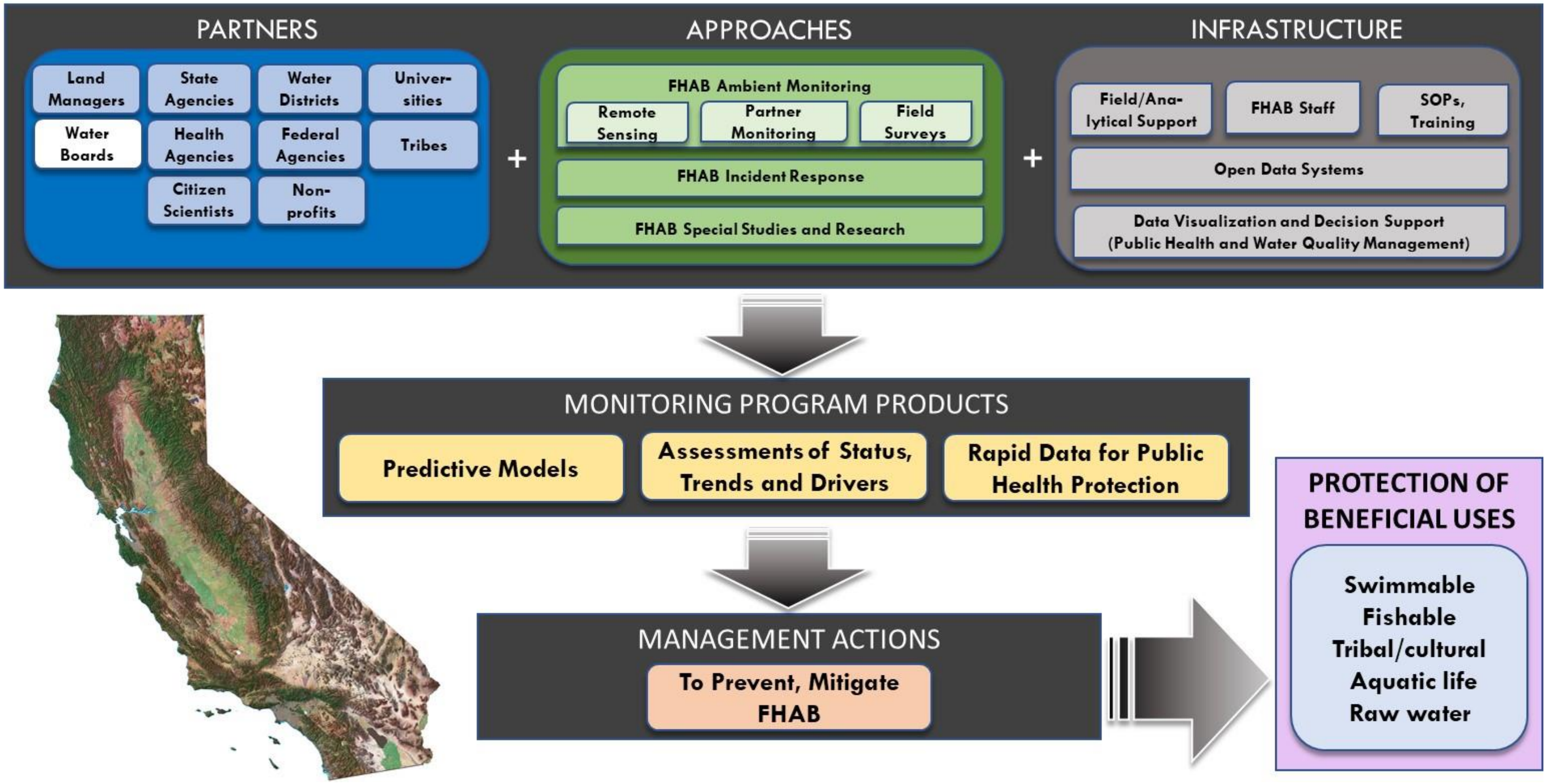

Figure 8.1. Components of the current and proposed Californian FHABs monitoring program. This schematic shows the major elements of the program including the ambient, incident response, and special (research) studies (shown in green). These approaches are implemented by FHAB monitoring partners (shown in blue). Infrastructure to support the monitoring program are shown in gray. Collectively, these components produce assessments of FHAB status, trends and drivers, and predictive models of FHAB occurrence and drivers. This information is used in coordination with Water Board policies and programs to implement actions to prevent and mitigate FHABs. These actions will ultimately protect core beneficial uses.

The suite of special studies identified in the subsequent tables represent high priorities for early implementation of the program. However, many special studies identified by the TAC represent key information gaps (SS26-SS32) and we strongly encourage our partners to consider supporting this research.

In making these investments, we stress that funding monitoring doesn't mitigate HABs, but provides data to inform it, and allows us to track the progress resulting from implementation actions.

8.2 Develop and implement an FHAB partner monitoring program

Development and implementation of an FHAB partner monitoring program is among the highest priority recommendations of this Monitoring Strategy. By partnering with other entities, this component can collect monitoring data on relevant spatial and temporal scales to assess risks to public health from FHABs. The TAC agreed that recreational health should be the immediate priority for this FHAB partner monitoring program. The details of the proposed FHABs partner program are described in Section 3.2.5.

The first step in program development is to decide on the scale and scope of the partner program (Table 8.1). A key decision is the level of support to provide to partners. At least three options are available: 1) Provide training and SOPs, but no capital investments in equipment or analytical support; 2) provide training, some capital equipment, and/or limited support for laboratory analytical costs; or 3) provide training, capital equipment, and laboratory analytical support. The success of the partner program will depend on effective data management, dissemination, and visualization, as partners who contribute their data will want rapid accessibility and relevant visualizations to analyze FHABs conditions in their watershed, region, or state.

Once the program scale and scope are determined, investments in the core partner program infrastructure are the next step: standardized methods, partner training, documentation, quality assurance and control procedures, and open data systems. This infrastructure will also benefit state-led FHAB field surveys and incident response by providing a common set of protocols across the entire FHAB monitoring program. These protocols and training programs can immediately be put to use by engaging with current state and regional monitoring programs to incorporate FHAB indicators, where feasible.

As the infrastructure develops, dedicated staff at the State and Regional Water Boards will be necessary to coordinate the program and work with partners (among other duties). Resources will also be required to fund the equipment and laboratory costs associated with the scope and scale of the partner program.

In the long-term, the FHAB partner program can be expanded to assess the status and trends of FHABs for additional beneficial uses and incorporate FHAB environmental drivers. Assessment tools (e.g., thresholds and/or guidance levels) for other beneficial uses, in particular for fishable and aquatic life, are less well-developed. Therefore, these other beneficial uses were identified by the TAC as a longer-term priority but should be developed as more risk indicators and thresholds are developed.

Table 8.1. Partner program development recommended actions, special studies, associated level of resource investment and timing. Low resources: < $200,000, medium: $200,000-$1,000,000, high: > $1,000,000.

Timing	Resources Required	Specific Recommended Actions	Special Studies or Implementation Options
Immediate	Low	Identify scope, scale, and budget of FHABs partner program focused initially on recreational and fishable uses. Decide what level of resource investment to support partner efforts is sustainable.	Proactively identify partners, focusing on tribes, communities of color and economically disadvantaged groups (SS2).
	Low	Develop infrastructure to support the program, e.g., write SOPs and sample design documents for partners, develop training modules. Engage with existing state/regional programs to pursue opportunities to incorporate FHAB indicators.	Develop FHAB recreational use monitoring protocols for shorelines, beaches, and/or wadeable rivers (SS0). Develop an algal condition index for lakes, reservoirs and estuaries and an FHAB specific component for routine application in waterbody assessment. (SS19-21). Develop visual FHAB advisory trigger that fits into cyanotoxin based triggers, so Tier 1 groups can inform advisories (SS1).
	Low	Inventory recreational and fishable use sites and identify where monitoring partners and interest already exist.	
	Low	Create data management and visualization infrastructure, including means for partners to rapidly visualize their data.	Determine user needs for FHAB decision support systems (SS4). Develop partner program open data systems (SS5).
Near-term	Low	Recruit and train partners.	
	Medium	Dedicate staff at SB and RB to coordinate program.	
	Low-Medium-High	Continued funding of supplies and data management identified above.	
Long-term	Medium	Expand infrastructure for partner program to address other beneficial uses and incorporate environmental drivers.	Develop FHAB use monitoring protocols for other core uses and environmental drivers (SS0).

8.3 Strengthen the incorporation of remote sensing into FHAB monitoring program

> **Why Strengthen Remote Sensing Approaches?**
>
> - Remote sensing approaches are powerful since they provide a high level of spatial and temporal coverage with minimal staff investment.
> - Remote sensing of FHAB can be used as a screening tool for event response and ambient monitoring
> - It is the most powerful approach to assess FHAB status, trends and drivers in lakes and reservoirs, albeit with some limitations in management applications.
> - Particularly when paired with partner monitoring data and/or event response data, this strategy element can support management actions in the immediate or near-term future with minimal financial investments.

Remote sensing is a cost-effective and complementary approach to field-based sampling of FHAB status, trends, and drivers. The State Water Boards has already made strategic investments to capitalize on federally curated FHAB remote sensing products for large lakes and provides these data through a Californian FHAB satellite portal (fhab.sfei.org). However, these initial investments have not yet resulted in extensive use to address FHAB management questions or actions. **We recommend making strategic investments to strengthen California's partnership on remote sensing to capitalize on the cost-effective and complementary information that it provides to field-based assessments of FHAB status, trends, and drivers.** These investments are described in Table 8.2.

An immediate priority is to use satellite data more broadly within the Water Boards. For this to occur, more data quality and assurance documentation for remote-sensed products are necessary. The Water Boards have already begun field validation to ground-truth satellite data and improve data quality characterization. This work should continue and be expanded so that partners can help participate in field verification data collection and submit those data to a common database.

Once Water Boards staff has identified the quality and uncertainty associated with satellite data, then they can use the data to inform water policy and program decisions. To help in this process, data visualization and decision support tools should be created to efficiently provide Water Boards staff with relevant satellite data for their duties (see Chapter 3.1 and Chapter 7 for specific details). These immediate investments will allow for routine use in monitoring and management decisions, including 305(b) reporting and as a supporting line of evidence in 303(d) listing.

Satellites provide one of the most consistent and longest time series of any type of water quality data. Water Boards staff has a pressing need to fill information gaps related to the status and trends of FHABs and to use these data to support management decisions. An immediate recommendation is to analyze the existing remote sensing data for large lakes and reservoirs to determine trends and environmental drivers of satellite metrics over the last 20 years.

Once the current data are more fully used and analyzed by the Water Boards, new data can be included to increase the number of remote sensed metrics calculated (e.g., chlorophyll-a) and the number of waterbodies imaged by satellites. For example, data from the Sentinel-2 satellite could cover much smaller waterbodies than the current Sentinel-3 data. We recommend partnership with the federal CyAN Project to pilot and onboard new remote sensing products, such as Sentinel-2 data, that can expand the scope of lakes and reservoirs currently assessed (255) to most of California lakes and reservoirs (~14,000). All satellite data, both current and proposed, will need to be open and available to Water Boards staff and the public. It is imperative to allocate resources to create functional data management and visualization systems to meet the goals laid out in the Water Boards Open Data Policy.

Table 8.2. Remote sensing program recommended actions, special studies, and associated levels of resource investment and timing. Low resources: < $200,000, medium: $200,000-$1,000,000, high: > $1,000,000.

Timing	Resources Required	Specific Recommended Actions	Special Studies or Implementation Options
Immediate	Low	Write report about data quality of remote sensed satellite algorithms for HAB detection.	Develop QA documentation on remotely sensed data products (SS9). Develop a routine workflow to use satellite imagery data in reports and listing decisions (SS12).
	Low	Establish standardized protocols for routine analytical metrics for use in satellite analysis.	Develop standardized analytical metrics for imagery data (SS8).
	Low	Conduct a status, trends and drivers assessment with current Sentinel-3 and MERIS satellite data (limited to lakes > 160 ha).	Develop remotely sensed chlorophyll triggers (SS11).
	Low	Add existing metrics (e.g., CI_noncyano and Chla) to current database and increase accessibility of data to the public.	Add available satellite derived FHAB response and driver metrics (SS7).
	Low	Enhance data management and data visualization platforms to ensure open and easy access to data for staff and public.	
	Low	Continue and expand collection of data to ground-truth satellite data and improve data quality characterization.	Develop CIcyano field verification protocols (SS10).
Near-term	Medium	Incorporate Sentinel-2 data into routine use for lake and reservoir status, trends and drivers assessments.	Conduct a pilot project to use Sentinel-2 data in a regional or statewide status and trends assessment (SS13).

8.4 Implement field surveys focused on protecting human health

A state-coordinated SWAMP field survey would meet the mandate in AB 834 to monitor FHAB conditions in California and would complement the data provided by the FHAB partner program (section 8.1). Monitoring at spatial and temporal scales to protect human health will require many resources, therefore, leveraging pre-existing monitoring programs is recommended to help reduce costs. **The TAC recommends starting with recreational and fishable beneficial use surveys, with potential future expansion to address additional beneficial uses.** The steps to accomplish this are highlighted in Table 8.3.

Why Implement Field Surveys Focused on Human Health?

- Climate change and local human activities are combining to create an unprecedented risk of FHAB to human health through recreation, fish/shellfish consumption and drinking water.
- Due to dynamic FHAB conditions, high frequency sampling is needed to adequately characterize risk to recreational uses.
- Fish and shellfish tissue sampling are needed where FHAB are a chronic risk to inform fish consumption advisories.
- Field survey data support actions such as: 1) public health advisories, 2) briefings for Legislature and State Water Board, and 3) 305(b) report and decisions on 303(d) listing.

To develop a recreational use field survey, the Water Boards need to first determine the key management needs from the survey, then the scale and scope of the survey, as ambient monitoring on relevant timescales on a statewide level is impractical due to logistical and financial constraints. Resources can be maximized by leveraging pre-existing programs, such as the BSMP (AB 411), Inland Beaches Workgroup, and Safe-to-Swim Network. Inclusion of FHABs monitoring in these programs would create a more holistic assessment of recreational safety by incorporating more indicators into water quality risk assessments. If frequent monitoring is not possible, then monitoring prior to major holiday weekends (e.g., Memorial Day, Independence Day, and Labor Day) is recommended, so that recent data are available to assess recreational risk for these high-use weekends.

A fishable field survey and associated risk assessments would fill many data gaps about the exposure risks to cyanotoxins from fish and shellfish consumption in California. The Bioaccumulation Oversight Group (BOG) performs statewide fish tissue sampling and adding FHABs indicators to the sampling could be considered. Because cyanotoxins have been detected in coastal shellfish but are not routinely monitored by the CDPH Marine Biotoxin program, we recommend working with CDPH to develop cyanotoxin indicators for marine monitoring. A fishable field survey will also require special studies to create consumption advisory thresholds and trigger levels.

The TAC prioritized recreational and fishable beneficial uses, though in some watersheds or regions additional beneficial uses could be prioritized, Tribal Beneficial Uses for example. Additionally, Regional Boards could implement regional or watershed-scale surveys for high-priority waterbodies. For each survey, multiple special studies will be required to determine the optimal leveraging opportunities and arrangements to protect public health. Due to the investments required to conduct state-led surveys, the management needs must be carefully considered before pursuing leveraging options and designing the spatial and temporal elements of the FHABs field survey (see **Example of cost estimate for two monitoring scenarios**).

Table 8.3. Field survey implementation recommendation actions, special studies, associated level of resource investment and timing. Low resources: < $200,000, medium: $200,000-$1,000,000, high: > $1,000,000.

Timing	Resources Required	Specific Recommended Actions	Leveraging Opportunities	Special Studies or Implementation Options
Immediate	Low	Modernize and incrementally build databases that house FHAB "public health" incident response and recreational and fishable use		Determine user needs for FHAB decision support systems (SS4).
	High	Implement a recreational use survey in collaboration with FHAB partners	BSMP (AB 411): monitoring enclosed coastal beaches (partnership with local health agencies). Inland Beaches Workgroup and Safe to Swim Network assessing FIB and HABs.	Create the design for a state-led recreational use survey (S14), including how to incorporate or modify the current FHAB pre-holiday assessment as part of the field-survey. Assess FHAB impacts on enclosed beaches in partnership with BSMP (AB 411) (SS15).
	Low-medium	Conduct FHAB fishable assessments where existing data point to chronic blooms.	Bioaccumulation Oversight Group (BOG) partnership to conduct FHAB tissue analyses in "Bass Lakes."	Assess toxin bioaccumulation and depuration rates in recreational fish in California lake and rivers and create new protocol for FHAB cyanotoxin fish advisories based on FHAB data (SS18).
	Medium	Conduct coastal confluence FHAB tissue monitoring (commercial aquaculture and other partner sites)	CDPH partnership to add cyanotoxins to marine shellfish biotoxin analytical suite.	Conduct a pilot project to routinely monitor shellfish cyanotoxins in coastal zones (SS17), after determining the cost-effectiveness of such a partnership. Develop a standardized cyanotoxin tissue analysis protocol (SS16) (partially funded through MERHAB study).

EXAMPLE OF COST ESTIMATE FOR TWO MONITORING SCENARIOS

To quantify the costs of different monitoring options presented in this strategy, we selected two monitoring scenarios and estimated some of the cost of these programs.

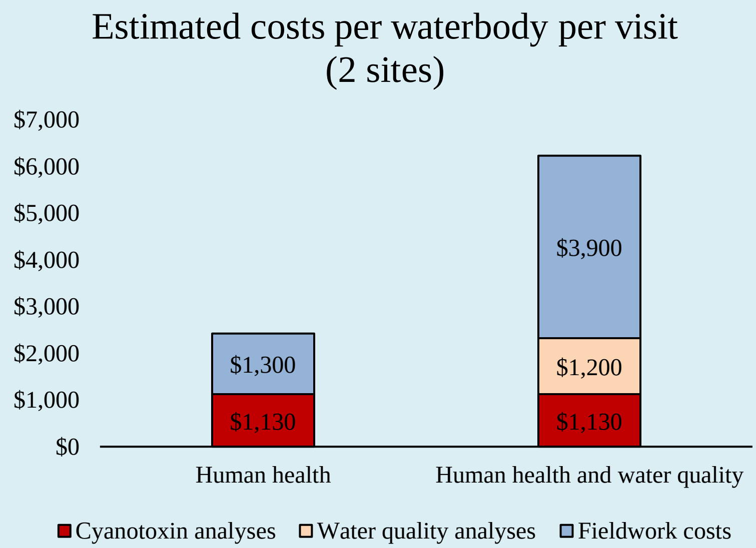

Figure 8.2. Estimates costs to sample the first site per waterbody for human health and water quality sampling. Larger waterbodies may require sampling at more than 2 sites.

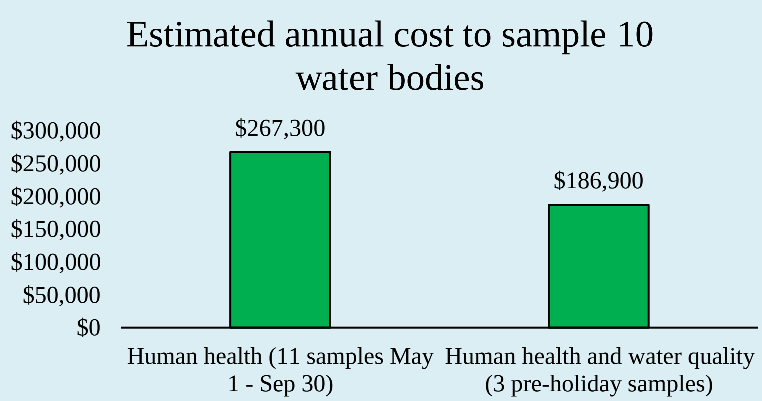

Figure 8.3. Cost to monitor two sites at 10 waterbodies. Adding additional monitoring sites at a waterbody would be necessary for larger waterbodies or waterbodies with many recreational beaches.

Scenario 1: The human health scenario focuses on human health indicators and involves higher-frequency sampling every 2 weeks for 5 months of the year (similar to the design BSMP (AB 411)).

Scenario 2: The human health and water quality scenario collects data to inform environmental driver's assessments as well as human health risks. This scenario involves sampling 3 times per year, prior to the major summer holidays (Memorial, Independence, and Labor Days).

Field sampling costs are a substantial percentage of the total cost to sample a site, ranging from 40-70% of the total per site cost for the BOG program and 56-65% for the PSA program. We estimate that fieldwork costs could account for about 50% of FHAB monitoring costs. Any field-work partnerships to reduce the cost of field sampling to the Water Boards would expand the number of sites that the FHABs monitoring program could survey. More details on estimated costs are in **Appendix 7** or here.

8.5 Conduct focused assessments of FHAB drivers

> **Why Conduct Focused Assessments of FHAB Drivers?**
>
> - Regional Board staff frequently receive calls about FHAB blooms and questions about what the Water Boards are doing to deal with them.
> - Status and trends monitoring can assess the magnitude and extent of the FHAB problem across California waterbodies, but only assessments of drivers provide information about what policies, programs and waterbody-specific actions are needed to mitigate HABS.
> - The most important landscape and waterbody scale drivers of FHABs will vary from watershed to watershed, so solutions must be customized.
> - Waterbody, watershed, or regional scale integrated assessments of FHAB drivers and responses and are time and resource intensive but produce information that are the most likely to result in a management action.

Answers to FHAB monitoring questions inform different types of actions, so the intended use of the information influences the spatial and temporal scale of the monitoring approach. For example, a manager at the State Water Board may want to know what the top priorities should be for policies and programs that could effectively reduce the risk of HABs across a region or state. To answer these types of questions, assessments of drivers at the statewide or regional scale are used to characterize a broad gradient of FHAB environmental drivers and responses. Because of expense inherent in a broad spatial scale, low frequency sampling is integral to these designs, but mischaracterize toxic FHAB risk. At a watershed scale, a SWAMP coordinator may want to understand how certain sources or land uses may be associated with FHAB problems in order to do very targeted source tracking and catchment- specific interventions. A lake manager may want to know the specific environmental drivers of FHABs in a certain waterbody in order to decide what management actions would minimize the risk of FHAB occurrence in the future. These waterbody-, watershed-, or regional-scale integrated assessments of FHAB drivers and responses and are time and resource intensive but produce information that are the most likely to result in a corrective management action.

To address the management information needs at all scales, **we recommend use of existing field survey and remote sensing data to conduct a statewide status and drivers assessment and to screen watersheds for FHAB risk** (see recommendation #6 on decision support)**, then fund intensive FHAB assessments at these high priority and higher risk watersheds or waterbodies**. Existing remote sensing of large lakes and reservoirs and existing SWAMP programs such as the Perennial Stream Assessment (PSA), the Reference Condition Monitoring Program (RCMP), and the National Lakes Assessment (NLA) measure the majority of recommended FHAB responses and drivers. They represent an important leveraging opportunity that can be used to assess the status and trends of FHABs statewide. These same data can be used to develop statistical models to predict risk of FHAB occurrence in unmonitored watersheds and waterbodies. Intensive FHAB assessments are needed at these high priority and higher risk watersheds or waterbodies. All existing FHAB data and predictive models can be used to inform, along with other considerations, where to conduct these more intensive assessments. Collectively, our understanding of FHAB risk environmental drivers will improve over time as data gaps are addressed.

Table 8.4. Field survey leveraging opportunities and recommended actions, required special studies, associated level of resource investment and timing. Low resources: < $200,000, medium: $200,000-$1,000,000, high: > $1,000,000.

Timing	Resources Required	Specific Recommended Actions	Leveraging Opportunities	Special Studies or Implementation Options
Immediate	Low	Use remote sensing, PSA, RCMP, and NLA data (and other partner data) to generate an FHAB status and driver assessments of wadeable streams, lakes, and reservoirs.	Augment type of FHAB data generated through other SWAMP surveys (PSA, RCMP and regional partners) or NARS assessments.	Adapt existing algal bioassessment protocols to improve quantitative measure of abundance and extend protocols to assess lentic systems (SS22). Develop standardized molecular methods for FHAB monitoring (SS23).
	Low	Conduct FHAB landscape screening assessments to identify watersheds where more intensive FHAB assessments should be conducted	PSA, RCMP, NLA, other data	Build the capacity to conduct landscape FHAB screening assessments (SS24).
Near-Term	Medium-High	At high priority locations, conduct intensive FHAB status and driver assessments at regional, watershed or waterbody scales.	Consider cost-sharing for FHAB intensification of regional board SWAMP “rotating basin” or “rotating waterbody” assessments.	

8.6 Strengthen incident response program

Incident response is a core component of the FHAB Monitoring Program. Even as ambient monitoring increases, the Water Boards will still need to respond to the public reports of blooms. Public observations of conditions at waterbodies statewide occur more frequently than that of Water Boards staff and partner agencies. In this sense, the public is a partner of the Water Boards who can ultimately provide more surveillance than ambient monitoring can feasibly provide.

Why Incident Response?

- Incident response efforts serve a distinct purpose of being able to respond to public reports of FHAB events.
- California has some 198,000 miles of rivers and streams, ~14,000 lakes and reservoirs, and 400 coastal confluences that are not routinely monitored. Incident response is a key component to protect public health while funding of FHAB monitoring is not yet sustained.
- Public reports are more likely to occur in economically disadvantaged and communities of color, so neglecting this program introduces inherent environmental justice issues.
- Climate change will exacerbate FHABs, so need for incident response is greater than ever.

We recommend that incident response efforts should continue and expand to efficiently respond to FHAB reports from the public (Table 8.5). Fortunately, the mandates of AB 834 provide opportunities to strengthen incident response collaborations with other state agencies and improve response. With the implementation of the monitoring strategy, incident response SOPs should be revised to remain consistent with the FHAB partner program and field surveys to ensure that data are all comparable. As FHAB incident response expands, the current data life cycle of incident response data needs to be modernized. New databases, data management infrastructure, and data visualization tools must be developed to improve timely and informative communication to the public and for data use by other Water Boards programs.

Table 8.5. Incident response recommended actions, leveraging opportunities, associated level of resource investment and timing. Low resources: < $200,000, medium: $200,000-$1,000,000, high: > $1,000,000.

Timing	Resources Required	Specific Recommended Actions	Leveraging Opportunities
Immediate	Medium	Continue to fund incident response, including need for staff to field adequate response and follow-up.	Strengthen collaboration with other state agencies identified in AB 834
	Low	Review incident response SOPs and harmonize with those developed for the FHAB Partner Program.	
	Low	Improve data management and visualization of incident response data to improve public communication and agency staff use of FHABs data.	
	Low	Modernized webpage and interactive maps to better communicate to the public the HABs condition at waterbodies.	
	Low	Assurance that incident response data are used in Water Boards programs, actions and policies.	

8.7 Work to integrate HAB monitoring elements into all relevant Water Boards programs, permits, and policies

FHABs are interconnected with other water quality issues and stressors. In particular, FHABs are strongly linked to eutrophication, climate change, hydromodification, and land use change that can alter physical habitat, temperature and light regimes. Thus, FHAB issues crosscut a number of Water Boards policies and programs (Section 1.4). **We recommend that a specific and concerted effort should be made by FHAB and other Water Boards program staff to link FHAB monitoring program elements to all applicable Water Boards programs wherever possible for a more holistic approach to assessing, managing and preventing FHAB issues.** This includes decision support to facilitate use of FHAB data for management decisions (Table 8.6). For example, FHABs are fundamentally a eutrophication problem that has a strong linkage to biostimulatory objectives through a shared set of indicators; ultimately biostimulatory numeric targets or objectives can serve as evaluation criteria for FHAB monitoring program data. Data from the FHAB monitoring program can serve as the basis to evaluate biostimulatory impairments of beneficial uses. Table 8.7 provides a partial list of categories of actions that could be considered by different Water Boards programs.

Table 8.6. Examples of Decision Support Implementation Recommendation Actions, Required Special Studies, Associated Level of Resource Investment and Timing to Support Water Boards Programs. Low resources: < $200,000, medium: $200,000-$1,000, 000, high: >$1,000,000.

Timing	Resources Required	Specific Recommended Actions	Special Studies or Implementation Options
Immediate	Low	Create tools for data analysis and visualization for Water Boards staff and local community partners to use HABs data in water quality data, drinking water, water rights program and policies, and in local land use permitting and planning decisions.	
Near-term	Medium	Incrementally build publicly available data visualization tools, using an open source approach such as R shiny apps to encourage community development of such functionality.	Develop partner program open data systems (SS5).

Table 8.7. Examples of potential actions that Water Boards can do to incorporate FHAB monitoring and assessment more fully into Water Boards policies and programs.

Water Boards Program	Adopt FHAB Triggers	Employ FHAB SOPs, QA in routine monitoring	Train Partners	Apply Triggers	Submit data to FHAB open data system	Prioritize grant funding for FHABs??	Evaluate actions to control and mitigate FHABs	Conduct special studies
Climate Change		X				X	X	
Drinking Water	X			X				X
Water Rights	X	X	X	X		X		X
Water Quality Standards	X							
Water Quality Assessment				X				
Beach Safety		X	X	X	X			
Point Source Control		X	X	X	X		X	X
Non-Point Source Control		X	X	X	X	X	X	X
Stormwater		X	X	X	X	X	X	X
Irrigated Lands		X	X	X	X			X
Cannabis		X	X	X	X	X		X
Total Maximum Daily Loads		X	X	X	X	X	X	X
401 WQ Certification/ Wetlands		X	X	X	X		X	X
Recycled Water								X
Healthy Watershed Program		X	X	X	X	X	X	X

9. SUMMARY

In California, toxic FHABs have been a recurring and escalating threat to public health, dogs and other domestic pets, and other treasured beneficial uses. Climate change is already exacerbating these threats. With projected increases in temperature, FHABs will worsen significantly over the next several decades. California is currently ill-poised to respond to these threats because FHABs are not routinely monitored and concrete management actions are hampered by lack of data. FHAB monitoring is challenging because of multiple morphologies, species and toxins, and impacts to uses occur through many pathways that require unique approaches, FHAB events are highly variable in space and time, and beneficial use impacts occur far afield from their point of origin.

Monitoring is a key element of California's 2016 FHAB Assessment and Support Strategy. Here, we describe California's strategy to develop and implement Freshwater Harmful Algal Bloom (FHAB) Monitoring Program. The Monitoring Strategy articulates the vision, programmatic elements and recommends the priority options for how FHAB monitoring and assessment can be used to inform management decisions to protect public health and the environment and improve water quality. It provides a roadmap for the tools and guidance needed to support agencies and organizations as they are informed of and seek to address FHABs in a coordinated way.

An Executive Synthesis document was produced to provide an overview of the Strategy for any audience. This document is available at: https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1141_FHABStrategy_Synthesis.pdf.

The main document, comprised of one introductory and seven technical chapters, is intended to provide a comprehensive vision and detailed rationale for the programmatic elements, options and recommendations that could form the foundation of a comprehensive FHAB monitoring program.

The resources and staff required to implement all the recommendations have not yet been identified. Therefore, *a strategy* to incrementally build and implement an FHAB monitoring program has been developed by Water Boards staff. Priority building blocks are identified, to ensure an early return on state investments in monitoring. Because available resources were not specified, this strategy is flexible to scale with future available resources and identified the incremental timelines for development. Six recommendations were proposed to cost-effectively characterize FHABs and confront these challenges. Taken together, multiple monitoring approaches provide complementary, cost-effective, and actionable information to protect public health and mitigate FHABs (Figure 9.1). Investments must be made across all approaches for California to achieve its goal of public health and beneficial use protection. Our proposed strategy is scalable to available resources and can be used to incrementally fill these data gaps on FHABs over time.

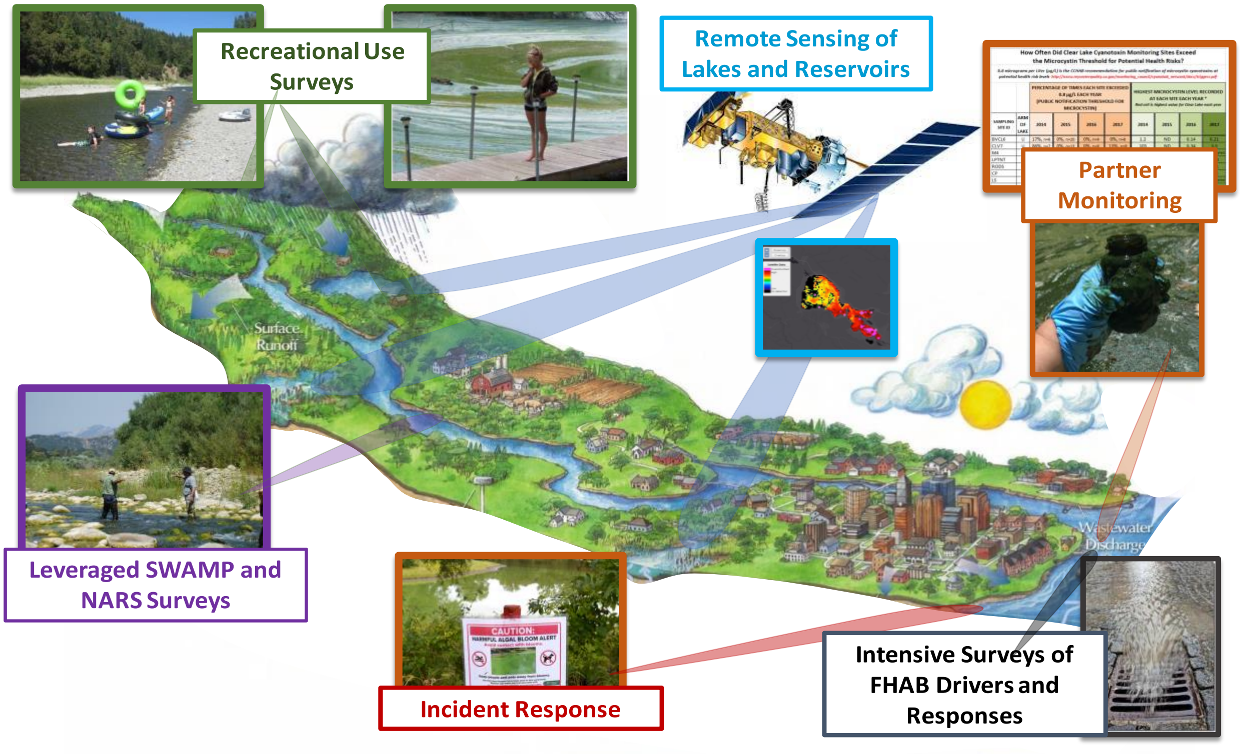

Figure 9.1. Different FHAB monitoring approaches provide complementary, cost-effective and actionable data to protect public health and mitigate FHABs. For example, partner monitoring and recreational use surveys are done frequently enough to protect public health, but don't provide data on drivers. Remote sensing, SWAMP and National Aquatic Resource Surveys (NARS) provide data on broad environmental drivers but do not inform what is driving a problem in a waterbody. For that, intensive FHAB driver assessments are needed. No single approach is a silver bullet, but employed together can provide powerful information to protect public health and mitigate FHABs.

The anticipated outcomes of this proposed FHAB monitoring program are several-fold (Fig. 9.2):

1. Strong collaborative partnerships adopt a shared set of standard practices and information through open data systems,
2. Data visualization tools that enhanced decision support,
3. Science products such as improved thresholds to diagnose impairments of beneficial uses and FHAB predictive models that can fill in data gaps,
4. Partner and Water Boards tools (e.g., biostimulatory objectives), actions (waterbody-specific mitigation projects, 303(d) listing, adoption of total maximum daily loads), and policies (e.g., climate change, recycled water, cannabis).

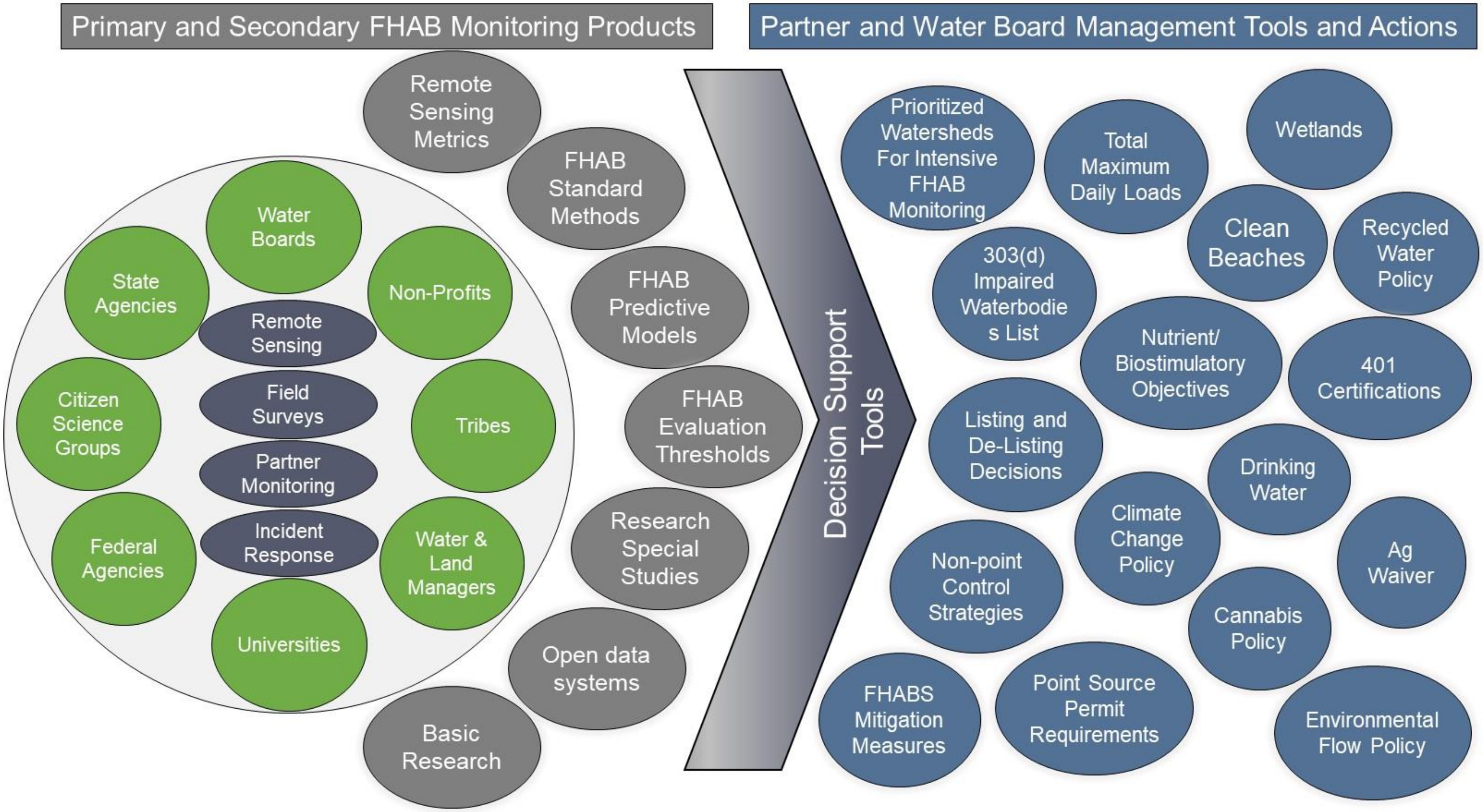

Figure 9.2. Illustration of relationship between FHAB core monitoring approaches (remote sensing, ambient field surveys and incident response), and how these are applied by the Water Boards and their partners to yield the technical tools and products (featured in blue). These data and products are served through decision support tools to a variety of audiences including the public, land owners and management agencies. Their use of this information can result in a number of different programmatic tools, actions and policies. Adapted from P. Ode (Bioassessment Program Products and Related Tools, Action and Policies).

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APPENDIX 1. TABLE OF CYANOBACTERIAL GENERA AND KNOWN TOXINS

Table A1.1. Summary of known toxins produced by cyanobacterial genera. Table references and updates can be found at https://mywaterquality.ca.gov/habs/resources/field.html#cyanobacteria

Cyanobacteria Genus	Cyanotoxin Class										References
	CYL	MC	NOD	ATX	SAX	NEO	LYN	BMAA	DAT	APL	
Anabaenopsis		✓									Lanaras and Cook 1994; Graham et al. 2010
Aphanizomenon	✓	✓	✓	✓	✓	✓		✓			Graham et al. 2010; Jacoby and Kann 2007; Pilotto et al. 1997; Vezie et al. 1998; Graham et al. 2008
Aphanocapsa		✓									Graham et al. 2010
Calothrix		✓						✓			Mohamed et al. 2006; Paerl and Otten 2013
Coelomoron		✓									Dos S Vieira et al. 2005
Coelosphaerium		✓									Graham et al. 2010; Jacoby and Kann 2007
Cylindrospermopsis	✓	✓		✓	✓			✓			Graham et al. 2010; Griffiths and Saker 2002; Woods and Sterling 2003; Graham et al. 2008; Paerl and Otten 2013
Cylindrospermum		✓		✓	✓						Borges et al. 2015; Pandey and Tiwari 2010; Sivonen et al. 1989
Dolichospermum (Anabaena)	✓	✓		✓	✓	✓		✓			Bruno et al. 1994; Graham et al. 2010; Harada et al. 1991; Jacoby and Kann 2007; Mohamed et al. 2006; Pilotto et al. 1997; Sivonen et al. 1989; Spoof et al. 2006; Vezie et al. 1998; Graham et al. 2008
Fischerella		✓									Otten and Paerl 2015
Geitlerinema		✓			✓						Aboal et al. 2005; Borges et al. 2015; Myers et al. 2007

Gloeotrichia		✓									Carey et al. 2007; Graham et al. 2010; Jacoby and Kann, 2007
Hapalosiphon		✓									Prinsep et al. 1992
Limnothrix		✓									Graham et al. 2010
Lyngbya	✓			✓	✓	✓	✓	✓	✓	✓	Berry et al. 2004; Dos S Vieira et al. 2005; Foss et al. 2012; Harr et al. 2008; Onodera et al. 1997; Stewart and Falconer, 2008; Paerl and Otten, 2013
Microcystis		✓						✓			Botes et al. 1982; Graham et al. 2010; Jacoby and Kann, 2007; Miller et al. 2010; Oberholster et al. 2006; Pilotto et al. 1997; Ueno et al. 1996; Vezie et al. 1998; Graham et al. 2008
Nodularia		✓	✓					✓			Carmichael et al. 1988; McGregor et al. 2012; Pilotto et al. 1997; Graham et al. 2008
Nostoc		✓						✓			Mohamed et al. 2006; Sivonen and Carmichael, 1990; Sivonen et al. 1992; Paerl and Otten, 2013
Oscillatoria (Planktothrix)	✓	✓		✓	✓		✓	✓		✓	Brittain et al. 2000; Carmichael and Li 2006; Graham et al. 2010; Jacoby and Kann 2007; Luukkainen et al.1993; Mazmouz et al. 2010; Mez et al. 1997; Sivonen et al. 1989; Graham et al. 2008
Phormidium	✓	✓		✓	✓			✓			Borges et al. 2015; Gugger et al. 2005; Harland et al. 2013; Izaguirre et al. 2007; Mez et al. 1997; Mohamed et al. 2006; Skulberg et al. 1992; Smith, 2012
Planktolyngbya					✓		✓				Graham et al. 2010
Prochlorococcus								✓			Paerl and Otten 2013

Pseudanabaena		✓		✓							Graham et al. 2010
Raphidiopsis	✓			✓	✓						Graham et al. 2008; Otten and Paerl 2015
Rivularia		✓									Aboal et al. 2005
Schizothrix				✓						✓	Sivonen and Jones 1999; Paerl and Otten 2013
Scytonema					✓			✓			Smith et al. 2011; Otten and Paerl 2013
Synechococcus		✓						✓			Carmichael and Li 2006; Graham et al. 2008
Synechocystis		✓						✓			Graham et al. 2008
Trichodesmium								✓			Paerl and Otten 2013
Tychonema				✓							Shams et al. 2015
Umezakia	✓										Paerl and Otten 2013
Woronichinia		✓		✓							Oberholster et al. 2006; Paerl and Otten 2013

CYL = cylindrospermopsin **MC** = microcystin **NOD** = nodularin **ATX** = anatoxin-a and homoanatoxin **SAX** = saxitoxin and decarbamoylsaxitoxin **NEO** = neosaxitoxins **BMAA** = β-N-methylamino-L-alanine **LYN** = lyngbyatoxin-a **DAT** = debromoaplysiatoxin **APL** = aplysiatoxin

Appendix 2. Detailed Description of Conceptual Models of Impacts on Beneficial Uses and Environmental Drivers of FHABs

FHABs can impair waterbodies in several ways that can ultimately result in failure to adequately support human and aquatic life beneficial uses. Conceptual models of these pathways are useful in showing how FHABs, their drivers, and beneficial uses are linked, and they point to informative and representative indicators[30] and metrics[31] that can be used to address management information needs (USEPA 1998; Suter 1999). Four conceptual models representing aquatic life, swimmable, fishable, and drinkable were developed to characterize the pathways by which FHABs impact each beneficial use (Figure 2.2, Table 2.4). A fifth conceptual model of impacts to tribal uses was developed by the Yurok and Clear Lake tribal representatives (Figure 2.3). Finally, a conceptual model of environmental drivers of FHABs was adapted from Paerl (2018; Figure 2.4). Collectively, these conceptual models were vetted by the TAC and used as the basis to identify indicators and metrics of FHAB "response" associated with specific pathways of effect (Table 2.3) and environmental drivers (Table 2.4).

A2.1 Impact of FHABs on Beneficial Uses

FHABs can cause impacts on multiple beneficial uses of surface waters via multiple pathways (Figure 2.2). This section summarizes those pathways by core and tribal beneficial uses (Table 2.2), which can be further linked to groups of FHAB response indicators that provide the rationale for incorporation into the FHAB monitoring program (Table 2.3).

Aquatic and (Terrestrial) Wildlife Uses. Effects of FHAB on aquatic life, terrestrial wildlife and livestock occur through multiple pathways. As the extent, frequency, and magnitude of algal blooms begin to increase, marked changes to primary producer biomass and community structure fundamentally restructure food webs that support invertebrates, fish, birds, amphibians, and other wildlife. The biomass of nutrient tolerant, opportunistic epiphytic and drift micro- and macroalgae and phytoplankton can increase under these scenarios and these species can dominate the microalgae and macrophyte communities. Toxic FHABs can become more prevalent and can directly affect aquatic life at all trophic levels. At the extreme end of the eutrophication gradient, benthic and planktonic algae and cyanobacteria blooms dominate at extremely high biomass causing negative effects. Poor habitat quality caused by alterations in primary producer community structure and degradation in water and sediment chemistry can cause shifts in the community structure of primary (benthic infauna, epifauna, and pelagic invertebrates) and secondary consumers. Higher level consumers, such as fish, birds, amphibians, mammals, and other wildlife that prey upon these secondary consumers (referred to here as tertiary consumers), experience reduced food availability and quality, decreased growth rates, reduce reproductive success, increased stress and disease, and increased larval and adult mortality (Glibert 2012; Glibert et al. 2011).

As a waterbody becomes increasing eutrophic, organic matter deposited from upstream or upslope sources, as well as elevated live and dead aquatic primary producer (APP) biomass

[30] An *indicator* is a characteristic of an ecosystem that is related to, or derived from, a measure of biotic or abiotic variable, that can provide quantitative information on ecological condition, structure and/or function or a physical, chemical or biological stressor. Relative to the term "metric," an indicator may be used to define a category of specific measures (e.g., algal biomass)

[31] A *metric* refers to very specific type of measurement (chlorophyll-a fluorescence, ash-free dry mass, etc.) for which a protocol could be cited for its use in a monitoring program.

produced *in situ* from available nutrients provide an elevated supply of labile organic matter. This organic matter accumulation alters microbial and biogeochemical cycling in the sediments and surface waters and transforms physical habitats. These effects include, but are not limited to: 1) change in physical habitat through altered water clarity (Dennison et al. 1993), dampening of velocity, reducing reoxygenation at the surface and causing anoxic conditions at depth (Dodds and Biggs 2002), or changes in physical habitat from increased organic matter sedimentation or legacy organic matter that fundamentally alters benthic habitat for invertebrates and fish (Welch et al. 1989, Chessman et al. 1992; Hawkins et al. 1982); 2) increased photosynthesis and respiration by live biomass and increased respiration of dead organic matter in the sediments and surface waters causes increased extent, frequency, and duration of low DO and pH and/or high carbonate concentrations, as well as large diurnal swings in DO and pH (Gray et al. 2002; Cloern 2001; Meyer-Reil and Koster 2000; Harper 2012; Mallin et al. 2006; Dodds 2007); 3) increased concentrations of water column sediment pore water ammonium or other toxic metabolites, increasing the potential for toxicity to benthic organisms (Figure 2.6, D'Avanzo and Kremer 1994; Nixon 1995; Diaz 2001; Howarth et al. 2002); 4) altered nutrient cycling due to fluctuating oxygen concentrations, fueling increased organic matter accumulation and retention of nitrogen and phosphorus within the waterbody, both in the water column as well as in the sediments (Pearson and Rosenberg 1978; Sutula et al. 2006; Middelburg and Levin 2009); and 5) increased heterotrophic bacteria populations enhance the survival and regrowth of pathogenic bacteria and can result in clogging of gills, increased frequency of disease, poor feeding behavior, etc.

Swimmable Uses. Recreational uses (REC1 and REC2) are impacted by both planktonic and benthic FHABs through a variety of pathways, whether those blooms are found within the water column or stranded and decaying mats on the banks of the waterbody. Contact (REC1) and non-contact (REC2) recreation are included in the swimmable "core beneficial use." Non-contact recreation includes activities such as boating, fishing, shoreline recreation with pets, or walks and picnics along the shore of a waterbody. First, visual scums and filamentous mats, poor water clarity, the "pea green soup" of high biomass blooms all impair waterbody aesthetics. Non-contact recreation is also impaired by odors resulting from decaying algal biomass or stranded mats, or from specific compounds (e.g., taste and odor compounds) produced directly by certain species of cyanobacteria (Appendix 1) (Graham et al. 2010; Watson et al. 2016). Second, increased organic matter accumulation associated with high biomass blooms, coupled with low dissolved oxygen concentration can cause a proliferation of heterotrophic bacteria, some of which may be pathogenic to aquatic organisms and humans (NRC 2000). Third, high biomass blooms and aquatic vegetation can impede boating and small watercraft (e.g., kayaks, etc.). Finally, direct impacts to human health and domestic animal health from toxin exposure are significant concerns; direct contact, respiration of aerosols, or direct ingestion may result in skin, eye, respiratory irritation, gastrointestinal issues, hepatic system harm, and neurological damage (Puschner et al. 2008; Stewart et al. 2008; Backer et al. 2013). Recreational exposure to these toxins can occur through multiple pathways; toxins can be freely dissolved (released from cells), in a particulate form (sometimes forming surface scum or benthic mats), accumulated in shellfish or fish tissue, or aerosolized with spray from boats, or on plant stems or sticks, etc. (Chorus et al. 2000; Codd et al. 1999, 2005; Stewart et al. 2006).

Fishable Uses. Fishable beneficial uses are impacted through several pathways. First, human health is a significant concern with respect to ingestion of toxins accumulated in tissue in cultured, harvested and commercially fished species of shellfish and fish (AQUA, SHELL and

COMM; Chen et al. 2009; Hardy et al. 2015; Drobac et al. 2016). FHABs can result in hypoxia, shellfish disease, fish kills, and the mortality of other aquatic species (Glibert et al. 2002) that ultimately reduces abundance and biodiversity of aquatic and terrestrial wildlife (e.g., salmonids, crabs, bivalves, et al. sportfish) associated with AQUA, SHELL, and COMM. Toxins can bioaccumulate and have far reaching effects downstream, resulting in impacts far from the source (Miller et al. 2010; Kudela 2011). Taste and odor compounds from cyanobacterial blooms can also be accumulated in fish tissue, causing fish to be off flavor (Burr et al. 2012; Howgate 2004; Robin et al. 2006).

Drinkable Uses: Raw Water Source Protection. Nationally, the various “do not drink” orders issued due to contamination of drinking water supplies by cyanotoxins in U.S. cities such as Toledo, Ohio and Salem, Oregon clearly point to the threat to “drinkable uses” (Steffen et al. 2017; Davis et al. 2019). A less visible but more pervasive threat is the health risks and associated costs of poor protection of raw source water. Both FHAB toxins in particular and high biomass blooms in general are problematic, for several reasons. First, chronic or recurring toxic bloom events in raw water sources require improved high-cost treatment to remove these toxins from potable water products; water withdrawals from streams and lakes outside municipal or county water systems pose an unquantified high risk, because of the lack of monitoring and prescribed treatment for such systems (Westrick et al. 2010). Second, some FHAB species directly contribute to taste and odor problems in raw drinking water sources (Watson et al. 2016). Third, increased dissolved organic carbon (DOC) results from “leaky” algal blooms; higher DOC levels increase the amount and costs of disinfectants required to achieve disinfection goals. DOC, algal metabolites, and other decomposition products, when present in raw water and chlorinated or brominated by treatment processes, can produce trihalomethanes (THM), which include several known and suspected carcinogens. (USEPA 2000b; Graham et al. 1998; Plummer and Edzwald 2001). Finally, high biomass blooms and aquatic vegetation impede municipal or industrial water intakes.

Tribal and Cultural Uses. Tribal beneficial uses were first adopted in 2004 as a distinct beneficial use designation by the North Coast Regional Water Board. From 2008-2017, a coalition of tribes and NGOs worked to develop Statewide beneficial use designations related to tribal and cultural uses. Two use designations related to tribal tradition, cultural uses and subsistence fishing were adopted in California in 2017. The language associated with these uses was carefully designed to be broad enough to encompass the diversity of tribal uses of waterbodies. These designations are Tribal Tradition and Culture (CUL) and Tribal Subsistence Fishing (TSUB). The development of CUL and TSUB on the Statewide scale represented a significant milestone in insuring that tribal and cultural uses of waterbodies were appropriately represented in waterbody use designations and in waterbody management. Since the development of CUL and TSUB, the state formed a Tribal Beneficial Uses Working group and most Regional Boards have tribal liaisons.

Tribal uses of waterbodies are impacted by FHABs through a variety of pathways. Tribal and cultural uses of waterbodies is very specific to each tribe and it is difficult to summarize the diversity of uses simply. Each tribe in the State is a sovereign nation with distinctive cultural practices and traditional uses of waterways. These uses of the water are often extensive and involve significantly more and different types of exposure than recreational uses. Depending on the specific tribe and tradition, exposure pathways can vary and can occur through multiple routes. A conceptual model of FHAB impacts on tribal uses of water highlights the diverse pathways with which a given tribal practice might be impacted (Figure 2.3). Tribal activities can involve multiple routes of exposure, often a tradition will involve one or more route of exposure. Exposure pathways can involve direct ingestion of water or ingestion of particles or aerosols. Exposure can also occur via the ingestion or handling of plants or consumption of contaminated food items. Uses can be repetitive, gender assigned and long-term. The effects of aerosol exposure as a pathway are not well understood.

Tribal uses have site and time specific uses of water related to the specific tribes and tribal tradition for which the waterbody is being used. Multiple tribes can use a given waterbody, each of which have unique cultural practices and uses of the water. Variations in how water is used exist within a tribe since members do not all observe a given tradition or practice in a uniform way. Tribal activities can be gender-assigned, therefore depending on the use and tradition, men and women can have large differences in the route and duration of exposure. Traditions and practices can be very seasonal, with extensive activity in or near a waterbody in particular seasons on an annual basis. These uses proceed even if an FHAB is present and therefore tribal uses can result in chronic exposure to cyanotoxins that far exceed those of recreation. Assessment thresholds currently only exist for recreational uses, therefore the true impact of FHABs on tribal members is not fully understood. Tribes experience a myriad of other public health concerns and comorbidities such as increased rates of diabetes and higher rates of mental health disorders. It is unknown if tribes may therefore experience higher sensitivities to cyanotoxins.

A2.2 Environmental Drivers of FHABs

The worldwide increase in the incidence of FHABs has prompted a great deal of research into the conditions that favor the growth of these species (Chorus and Bartram 1999; Carmichael 2008; Paerl and Huisman 2009; Hudnell 2008, 2010; O'Neill et al. 2012; Paerl and Paul 2012). Conditions typically favorable to the formation of planktonic blooms include salinity, ample supply of nutrients, calm water and stratified conditions, plenty of irradiance, and warm water temperatures (Figure 2.4). The formation of benthic blooms is less well studied but conditions such as warm temperatures, light, and moderate flow rates appear to be favorable in many systems (Wood et al. 2020). Several of the factors favorable to FHAB formation are expected to be exacerbated by the impacts of climate change (Burford et al. 2020; Griffith and Gobler 2020). While the general environmental conditions related to increased algal growth are well described (Berg and Sutula 2015), the factors influencing the specific FHAB taxa that will bloom, the exact timing, duration and location of a bloom, and the factors eliciting toxin production are still not well understood. The principal indicators and metrics of environmental drivers (Table 2.4) are discussed at length below.

Temperature. Temperature is one of the most important factors in controlling the growth rate and seasonal succession of cyanobacteria in aquatic systems (Sommer et al. 1986; Robarts and Zohary 1987; Butterwick et al. 2005; Reynolds 2006; Paerl and Huisman 2008). Cyanobacteria isolated from temperate latitudes (i.e., excluding polar regions) typically have temperature growth optima between 25 and 35°C (Reynolds 2006; Lürling et al. 2013). For example, in a survey of eight cyanobacteria, the growth optima of two *Microcystis aeruginosa* strains were 30-32.5°C and that of *Aphanizomenon gracile* was 32.5°C. Lower growth temperature optima were observed in *Cylindrospermopsis raciborskii* and *Planktothrix agardhii*, both at 27.5°C while

Anabaena spp. had an optimum of 25°C (Lurling et al. 2013). Compared with other phytoplankton taxa, cyanobacteria typically demonstrate higher growth rates at higher temperatures. For example, diatoms typically have a 6-fold higher growth rate at 15°C, 3-fold higher growth rate at 20°C, and a similar growth rate at 25°C, compared with cyanobacteria (Butterwick et al. 2005; Lürling et al. 2013; Yamamoto and Nakahara 2005). Above 25°C, both chlorophytes and cyanobacteria have faster growth rates than diatoms and dinoflagellates. In a mixed phytoplankton assemblage, all else being equal, cyanobacteria will be able to grow faster and outcompete other phytoplankton taxa as the temperature increases (Lehman et al. 2005; Paerl and Huisman 2009). With continued climate change and global warming, there's an increased risk that cyanobacterial blooms will outgrow diatoms which often dominate community composition in temperate regions (Paerl and Otten 2013; Reynolds 2006).

Irradiance and Water Clarity. Some cyanobacterial genera can be exposed to high irradiances without experiencing photoinhibition due to the abundance of photo-protective carotenoid pigments (Paerl et al. 1983, 1985). Many toxigenic cyanobacteria species are not strong competitors for light in a well-mixed environment due to their poor light absorption efficiency (Huisman et al. 1999; Reynolds 2006). Thus, these cyanobacteria grow ineffectively in low and mixed light, but very effectively when exposed to high light, particularly the toxic peptide-producing varieties (Huisman et al. 2004; Reynolds 2006; Carey et al. 2012). Cyanobacteria such as *Microcystis* are aided by their positive buoyancy and can grow very close to the surface by tolerating, or even benefiting at irradiance levels that are inhibitory to other members of the phytoplankton community providing a competive advantage for the cyanobacteria (Carey et al. 2012). These cyanobacteria can increase their cell densities past the point where they would ordinarily become light-limited by self-shading, forming high density surface scums. Growing close to the surface can also help cyanobacteria avoid light limitation if there is a high concentration of suspended sediment matter in the water. This also allows for cyanobacteria to shade out other organisms, such as benthic plants. Other FHAB species such as *Cylindrospermopsis raciborskii* and *Planktothrix* spp. are good competitors at low light (Briand et al. 2004; Dyble et al. 2006). *C. raciborskii* can cause issues, particularly in source waters since it can bloom several meters below the surface, making blooms more difficult to detect and monitor (Saker and Griffiths 2001). Not only is the rate of photosynthesis in *C. raciborskii* efficient at low irradiances, it's also efficient at high irradiances, making this a very versatile FHAB species (Wu et al. 2009). In benthic cyanobacteria, light intensity plays a role in the establishment and morphology of colonies and mats (Wood et al. 2020).

Nutrient Loads, Concentrations and Ratios. The biomass of all photosynthetic phytoplankton, benthic algae, and cyanobacteria, given optimal temperatures and irradiance, is influenced by the concentration and ratios of macronutrients (total N and P) available in the water column (Paerl 2008). Increased nutrient loading in aquatic systems has been linked with increases in algal biomass and the apparent global rise in FHAB events (O'Neil et al. 2012; Paerl and Otten 2013). With respect to nutrient status, algal and cyanobacterial growth in freshwater systems (rivers and lakes) that have historically been phosphorus-limited are frequently linked to excessive P loading (Paerl 2008; Schindler et al. 2008), while in algal blooms in historically nitrogen-limited estuarine and marine systems are frequently linked with excessive N loading (Paerl 2008; Conley et al. 2009; Ahn et al. 2011). At low and intermediate nutrient loads, reduction in only N or P may be sufficient to control cyanobacterial blooms. But with elevated loadings of both N and P, reduction of only one type of nutrient can lead to an imbalance in the N:P ratio of the water column, generally resulting in increased algal biomass (cyanobacterial or other types of algae) (Smith 1983; Paerl 2008; Paerl et al. 2011, 2014). Although increased nutrient concentrations are linked to increased algal biomass, the N:P ratio has little predictable effect on the community composition of the phytoplankton taxa present in the water column (Paerl 2008; Davidson et al. 2012; Downing et al. 2001; Glibert et al. 2011). Investigations that separate the effect of changes in absolute concentrations from ratios find that changes in absolute concentrations of nutrients, or changes in total Chl-a biomass, are more strongly related to changes in cyanobacterial biomass than changes in the ratio of N:P (Trimbee and Prepas 1987; Downing et al. 2001; Dolman et al. 2012). Ultimately, nutrient concentrations and N:P ratios are not reliable indicators of FHAB blooms. These dynamics are the result of complex interactions (e.g., both bottom-up and top-down controls) that govern community composition and biomass accumulation.

Stratification and Residence Time. In general, planktonic algal blooms, and FHAB blooms in particular, tend to occur in calm, stratified water columns through increased temperatures and irradiance (Elliott 2010; Huber et al. 2012). Growth rates will increase as a result of the increasing temperature in the top layer of a stratified water column. With the ability to regulate buoyancy, many cyanobacteria will remain in the top layer of the water column with greater irradiance and not sink or become mixed down to the bottom and into lower light, allowing them to maintain higher growth rates. Stratification may be a sign of increased residence times (reduced flushing rates), which allows cyanobacteria additional time to use all the nutrients available in the water column (Jeppesen et al. 2009). Because residence time is determined by the flushing rate, increased residence time may also result in a decreased loss rate of cyanobacteria (Elliott 2010; Romo et al. 2013).

Salinity. Most harmful algal-bloom-forming and toxin-producing cyanobacteria are freshwater species, while most marine cyanobacteria do not form HABs (Paerl and Fulton 2006). However, salinity may not be the strongest "barrier" in terms of restricting the occurrence and geographical distribution of toxic FHABs. Laboratory investigations of freshwater cyanobacteria species such as *Anabaenopsis* and *Nodularia* spp. thrive at salinities from 5-20 ppt (Moisander et al. 2002), while some strains of *Microcystis aeruginosa* tolerates up to 10 ppt salinity without a change in its growth rate (Tonk et al. 2007). Given optimal growth conditions, these species can also bloom in brackish-water regions of California coastal confluences (Lehman et al. 2013). Similarly, *P. parvum* blooms appear to be favored in freshwater systems that have slightly elevated salinity (> 1 to < 12). Increased occurrences of *P. parvum* blooms were reported in many waterbodies through the south-central areas of the United States that experience slight increases in salinity (Roelke et al. 2016)

Factors Impacting Toxin Production and Degradation. There is substantial discussion surrounding the purpose of toxin production in cyanobacteria and the conditions under which toxin production is stimulated are still poorly understood and are an active area of research (Horst et al. 2014; Heath et al. 2016). Roles as allelopathic compounds (substances that are inhibitory towards competing cyanobacteria and algae) and as predator-deterrent factors have been proposed. First of all, to complicate matters, not only does toxin concentration per cell vary in strains that produce toxins (i.e., are toxigenic), but natural populations are typically comprised of a mix of toxigenic and non-toxigenic strains of the same species (Davis et al. 2010; Vézie et al. 2002; Wood and Puddick 2017). Additionally, toxin molecules are chemically diverse and may perform different (unknown) functions for different species or strains. Therefore, competitive advantage(s) conferred by these compounds are hard to define at this time (Holland and Kinnear 2013). For this reason, disentangling drivers regulating toxin production require further study.

Cyanotoxin degradation depends on biological, chemical, and physical processes and dynamics might vary between planktonic and benthic forms of cyanobacteria (Jones and Orr 1994; Gibble and Kudela 2014). Together with labile dissolved organic carbon, toxins are thought to be rapidly degraded by the natural microbial community following sedimentation (and subsequent release of cellular material) of a cyanobacterial bloom (Jones et al. 1994, Rapala et al. 2005). The predominance of specialized bacteria in the microbial community may determine the length of time it takes (i.e., lag period) before bacterial degradation of toxins takes place (Rapala et al. 1994). Other degradation processes include UV degradation (Tsuji et al. 1995; Kaminski et al. 2013), and adsorption onto clay particles (Morris et al. 2000).

Top Down Controls. In addition to the above-mentioned factors, grazing by higher trophic levels play an important role in shaping community composition and controlling FHAB events. Cyanobacteria have generally been considered poor quality prey for most common zooplankton grazer species and may explain cyanobacterial dominance in many systems. However, some studies suggest that the grazing community can shift to organisms better suited for grazing cyanobacteria over time, introducing the potential for top-down controls in systems with chronic blooms (Ger et al. 2016). Overall, top-down controls on FHABs are less well studied and less well understood than many of the previously described factors.

Other Factors. A number of others may influence cyanobacterial blooms including exposure of cyanobacteria to herbicides and pesticides. These compounds are commonly used in an attempt to control and mitigate the impacts of FHABs. Investigations demonstrate substantial variability in sensitivity to herbicides of cyanobacteria compared with other phytoplankton such as green algae and diatoms (Peterson et al. 1997; Lürling and Roessink 2006). The long-term effects of these control measures are not well known and require future study.

APPENDIX 3. DESCRIPTION OF INDICATORS

Chapter 2 of the main body of the report reviews important background information relevant to the ambient monitoring approaches and monitoring strategies described in the subsequent chapters. A central element of Chapter 2 included the FHAB management questions and information needs, priority waterbody types and their definitions, targeted beneficial uses, conceptual pathways of impacts of FHAB and environmental drivers. The conceptual models of impacts and drivers of HABs were developed in conjunction with the TAC and from these models, the key indicators that represent measures of those impacts as well as potential drivers or environmental context for FHABs were derived. The key indicators for assessing the impacts of FHABs are found in Table 2.3 and the key indicators for assessing potential drivers or environmental context can be found in Table 2.4.

As a review from Chapter 2, ***Indicators*** and ***metrics*** describe what information the monitoring program will collect to address management questions (described in detail in Section 2.5). An ***indicator*** is the type of measurements, while ***metric*** is the precise measurement and value resulting from multiple locations and temporal measurements. The details of each indicator and metric were not covered within the main body of the report. Here, the basic description of each indicator will be discussed. The metrics are numbered according to the reference number found in Tables 2.3 and 2.4.

Water Clarity and/or Quality Indicators

Water quality refers to physical, chemical and biological condition of the water within a waterbody or watershed. Most often, water quality is considered in relation to the quality of the water for a given beneficial use such as recreation or source water. FHABs can degrade overall water quality and result in altered trophic structure or lower fishery yields.

Water clarity, in particular, can be severely impaired by FHABs. Water clarity is a measure of how deep light can penetrate through the water column[32]. The amount of algae, organic matter and suspended particles are the main factors that control the depth of light penetration. The amount of light that can penetrate into water is an important factor for the overall productivity and ecology of a waterbody. Severe attenuation of light penetration into the water can limit the productivity of photosynthetic organisms such as aquatic plants and result in an overall alteration of trophic structure as well as potential lower yields of fishable species. Reduced water clarity also results in poor waterbody aesthetics and potential impacts on recreation.

R1: Remotely sensed water clarity

Remote sensing, at its core, is able to measure the optical qualities of water through the observation of light reflected off of a waterbody. Depending on sensor packages deployed on a satellite, the data products can provide indicators of waterbody properties such as water transparency, biological properties, or other optically based properties (Dörnhöfer et al. 2016). Currently these capabilities are best developed in lentic waterbodies such as lakes and reservoirs. As basic background, the optically active water parameters that contribute to the total water-leaving signal are phytoplankton, organic and inorganic suspended solids, and colored dissolved organic matter (CDOM); the sum of these three individual constituents, in combination, attribute

[32] EPA. (2016). Indicators: Water Clarity. https://www.epa.gov/national-aquatic-resource-surveys/indicators-water-clarity

to differences in overall water clarity, which is frequently used as a proxy for water quality (Topp et al. 2020).

R2/D19/D20: Secchi Depth or light penetration

The light penetration depth of water can be measured in multiple ways. The most common measure of light penetration is a Secchi depth. This a very simple and inexpensive measurement and is determined by measuring the depth at which a Secchi disk is no longer visible in a water to the observer. The basic principle is that with a Secchi disk will be visible at a greater depth with greater light penetration. Since light penetration is related to the concentration of suspended solids and algae in the water, the Secchi depth will provide a repeatable estimate of water clarity, and in many cases, the density of an algal bloom. Secchi depth measurements can be semi-quantitative since factors such as variations in the analyst's vision and the sun's glare can create variation in measurements.

More sophisticated and expensive measures of light penetration can be obtained using a quantum meter or photosynthetically active radiation (PAR) meter which can quantitatively measure the light intensity in water[33]. These sensors can be used to measure a light profile in a waterbody, which can determine the portion of the water column suitable for the growth of photosynthetic organisms such as algae and macrophytes.

R3: Turbidity or total suspended solids

Turbidity is an optical property and is based on the amount of light scattered by the water sample. Turbidity is a measure of the clarity of water. Light scattering components in the water can include sediments, dissolved colored organic matter, inorganic and organic particulate matter and algae and microbes. Turbidity is standardly reported as nephelometric turbidity units (NTU). Turbidity is commonly measured using a nephelometer or turbidimeter that measures the intensity of light reflected from the water sample. The intensity of the reflected light is indicative of the amount of light scattering material in the sample.

Turbidity is often used to estimate the total suspended solids (TSS) concentration of a sample. TSS is the primary factor causing turbidity, and simpler to measure than the TSS concentration directly. TSS can be measured directly by filtering water onto a filter, drying the filter and then weighing the filter[34].

R4/D28: Dissolved oxygen

Dissolved oxygen (DO) is important indicator for both chemical and biological processes in waterbodies. All higher aquatic organisms depend on the presence of DO to survive. Similarly, aerobic geochemical processes require oxygen to occur. After the decline of an FHAB event, the microbial degradation of the biomass can cause hypoxic (low oxygen) or anoxic conditions (no oxygen) can impair habitat for aquatic life. DO can also be reduced by the algae via respiration at

[33]USGS. Light Penetration Profile. Retrieved from https://sfbay.wr.usgs.gov/access/wqdata/overview/measure/ctd/profiles/lite_prof.html

[34] EPA. (2012). 5.8 Total Solids. In Water: Monitoring and Assessment. Retrieved from https://archive.epa.gov/water/archive/web/html/vms58.html

night when photosynthesis does not occur. This is most common in lentic waterbodies such as lakes, ponds, reservoirs and lagoons but can also occur in tidally influenced estuaries.

DO can be measured in the field or in the laboratory. The most common approach to measure dissolved oxygen is the use of field probe. Field probes are available in a variety of configurations from a single probe or sonde, to a multiparameter field probe. The accurate measurement of DO using a sensor requires the concurrent measurement of temperature and conductance. Regular maintenance and calibrations are required for a DO sensor to work properly. DO probes can be sensitive and are easily destroyed through deterioration of the membrane without proper care. DO can also be measured in the laboratory using a technique known as a Winkler Titration or Winkler Method. This is a sensitive and intensive process that requires training, and as a result, many agencies are discontinuing the use of this technique.

The approach for measuring DO is waterbody dependent. In highly dynamic systems like estuaries, a 24-hour timeseries of DO measurements is most appropriate. In other systems, like lakes and rivers, a discrete measure or profile of DO can be conducted. The measurement location is an important consideration when for DO and should be clearly noted.

R5/D26: pH & Carbonate Chemistry

pH and other carbonate chemistry metrics (alkalinity, dissolved inorganic carbon, pCO_2) provide an indication of the acidity and buffering capacity of a waterbody. These metrics, particularly pH, are important water quality parameters that provide a measure of the suitability of a waterbody to support different types of life. Most aquatic life has an optimal pH range of 7 to 8.5, and conditions outside of this range are not suitable for survival.[35] Larval stages of estuarine organisms are sensitive to pH< 7.9.

pH is most commonly measured using a pH meter. These measurements can be conducted in the field using a field sonde or in the lab using benchtop pH meter. In both cases, pH sondes and meters are sensitive instruments that require frequent calibration.

Other measures of carbonate chemistry are generally measured in the laboratory. Alkalinity, which is the capacity of water to neutralize acids, is measured by titration. Alkalinity titrations can be performed manually using a buret, or with manual or digital titrators.

R6: DOC

Dissolved organic carbon (DOC) is a measure of the organic material that is dissolved in water and is an important regulator of the biogeochemistry and ecology of aquatic ecosystems. The dissolved fraction is nominally defined as that which passes through a 0.7 micron filter. DOC can be derived within the waterbody from aquatic plants and algae or from external sources such as soils or terrestrial plant matter. Carbon is an essential molecule to heterotrophic microbes and therefore high levels of DOC can contribute to low oxygen in a system. DOC can also influence the pH and water clarity in freshwater systems. DOC can also be an indicator of the trophic status of a waterbody and the properties of the DOC can indicate whether the DOC is more

[35] EPA (2016). Indicators: Acidification. Retrieved from https://www.epa.gov/national-aquatic-resource-surveys/indicators-acidification

terrestrially or microbially derived. DOC with a low nitrogen content is generally terrestrially derived, while DOC high in nitrogen is microbially derived.

DOC concentrations are generally measured in the laboratory and is quantified using either a high temperature combustion approach or a UV/Persulfate oxidation approach. In both approaches, the DOC is typically quantified using a nondispersive infrared sensor. The general composition of DOC can be determined by looking at the UV or fluorescens spectra of the DOC sample.

Sediment Quality

Sediment quality is an important consideration in overall ecosystem health. Sediments provide a key habitat for many aquatic organisms and therefore, are an important consideration for assessing the impacts of FHABs in freshwater systems. Sediments serve as reservoirs of nutrients and other materials (e.g., cyanotoxins and other environmental contaminants), as well as a potential source of these compounds to the water column. The assessment of changes in sediment quality are used in assessing ambient environmental quality, particularly for aquatic life beneficial uses. FHABs may contribute large amounts of nutrients, as well as potentially cyanotoxins, to sediments following the demise of a bloom, which in turn could alter the trophic structure, reduce overall sediment quality and reduce the aesthetics of a waterbody.

R7: Sediment TN/TP and OC

Sediment concentrations of organic carbon and nitrogen provide an indicator of eutrophication, sedimentation rates and type of matter dominating sediments. The concentration of organic carbon in the sediments is an indicator of the types of water column matter reaching the sediment surface. Just as in water column DOC, the amount of nitrogen associated with organic carbon in the sediments provides an indication of the sources of the organic matter present in the sediments (e.g., terrestrially or microbially derived). Total phosphorus concentrations in sediments can be used to estimate the overall sediment nutrient load. Additionally, TOC is a common measurement by which other contaminant measures in sediment are normalized.

Photosynthetic (Algal and Cyanobacterial) Benthic or Planktonic abundance

Bulk measures of photosynthetic abundance and biomass provide an understanding of the trophic status of a waterbody. Indicators of photosynthetic algal abundance include bulk estimates of microscopic algal biomass via chlorophyll a and visual estimates of macrophyte (aquatic plant) biomass.

R8: Remotely Sensed Chlorophyll a

Chlorophyll a (Chl-a) can be optically determined via satellite imagery in surface water. The amount of Chl-a in water changes the waterbody’s adsorption and reflection of light which is sensed by satellite spectrometers. An algorithm is used to estimate the near-surface Chl-a concentration from the spectral data. Multiple current and past satellite products provide Chl-a information including the OLCI (Ocean and Land Colour Instrument) onboard Sentinel-3 A/B, the MSI (Multispectral Instrument) onboard the Sentinel-2 A/B, MODIS (Moderate Resolution Imaging Spectroradiometer) onboard Aqua and Terra, MERIS (MEdium Resolution Imaging Spectrometer) onboard the Envisat platform.

R9: Water column/benthic particulate OC, nitrogen, phosphorus and nutrient ratios

Particulate organic carbon (OC) and nitrogen (N) is a measure of the organic material that is in particles in water. Particulate OC and N is functionally defined as material that is retained on a filter (nominally > 0.7 microns). The concentration of nitrogen associated with organic carbon is an indicator of the type of OC, terrestrially or microbially derived. OC with a high associated nitrogen content is derived of microbial life, therefore the OC:N ratio can provide an indication of the relative contribution of microbial biomass (both phototrophic and heterotrophic) in water. Total phosphorus concentrations in water can be used to estimate the overall trophic status of a waterbody. Nutrient ratios, particularly N:P ratios, can be used to determine if a system might be limited by one of these major macronutrients.

R10: Discrete planktonic, benthic, or drift algal Chlorophyll a

Discrete samples can be collected of Chl-a to directly measure the concentration of Chl-a in the water, benthos or in detached floating mats of algae (drift algae). Chl-a can be quantified either by absorbance via spectrometry or fluorescence via fluorometry. Chl-a (along with other photosynthetic pigments) can be separated via HPLC and measured via an absorbance or fluorescence detector. The most common measurement is of water column Chl-a, where a sample is filtered and extracted for analysis.

R11: In Situ Chlorophyll a Fluorescence

Discrete or continuous measurements of Chl-a can be made using optical sensors that measures Chl-a fluorescence. *In situ* fluorescence measure provide the advantage of instantaneous measurements, but in situ approaches are less accurate than extraction approaches. *In situ* fluorescence should be complemented with discrete measurements periodically to ground truth sensor data.

R12: Macrophyte or macroalgal % cover

Macrophytes (aquatic plants) and macroalgae are an indicator of waterbody health. Submerged macrophytes provide important habitat for aquatic organisms. The absence or overabundance of macrophytes are an indication of imbalance in a waterbody. FHABs can decrease the water clarity with may reduce the presence of macrophytes and macroalgae. Conversely, eutrophic waterbodies can have an overgrowth of macrophytes and macroalgae.

Cyanobacterial Abundance

The bulk abundance of cyanobacteria in a waterbody can provide a relative estimation of the risk that a waterbody may experience impacts related to FHAB events. Cyanobacteria have unique taxonomy and pigments that allow for the estimation of cyanobacterial abundance and biomass that is distinct from bulk estimations of photosynthetic biomass. Cyanobacteria have chlorophyll-a but also have phycocyanin which is a unique accessory pigment. Phycocyanin can be used as an indicator of cyanobacterial biomass. In many cases, assessment of bulk cyanobacterial abundance is useful as an initial assessment of hazard. It can also be advantageous to differentiate the genera present, as a more precise estimation of potential risks to impairing beneficial uses.

R13: Remotely Sensed CIcyano

Satellite imagery can estimate the abundance of cyanobacteria based on the spectral characteristics of the waterbody, similar to estimations of Chl-a. Estimating the abundance of cyanobacteria requires the spectral differentiation from bulk Chl-a estimates. Cyanobacterial biomass can be differentiated using a distinct wavelength signature that allows for the differentiation of cyanobacterial biomass from other algae and optically active matter. CIcyano is a spectral shape algorithm used by the CyAN program (not routinely used in scientific literature) and is based on phycocyanin and chlorophyll-a reflectance.

R14: Visual scum

Visual assessments of scum can provide a quick indication of the spatial extent of an FHAB with a surface manifestation. Scums formed by cyanobacteria have distinct characteristics from aquatic plants and algae. This is a qualitative indicator that is limited by several factors. Visual scum assessments can only assess surface manifestations of FHABs and also cannot differentiate between toxigenic and non-toxigenic blooms. Visual scum assessments can be used as a trigger for the collection of additional FHAB indicators and are also useful in assessing the frequency of aesthetic impairments.

R15: Discrete planktonic or benthic phycocyanin

Discrete measurements of phycocyanin in the water column or benthos provide an indicator of bulk cyanobacterial biomass. Phycocyanin can be measured using the same approaches to measure chlorophyll a, spectrometry and fluorometry. When both chlorophyll a and phycocyanin are measured, the ratio of the concentrations of both pigments can provide an indication of the dominance of cyanobacteria within the overall algal biomass.

R16: In Situ Phycocyanin Fluorescence

Just as with the photosynthetic Chl-a, discrete or continuous measurements of phycocyanin can be made using optical sensors that measure phycocyanin fluorescence. The same principles apply to phycocyanin optical sensors that were discussed in R11. *In situ* approaches are less accurate than extraction approaches and *in situ* fluorescence should be complemented with discrete measurements periodically.

R17: Cyanobacterial Cell density

Cyanobacterial cell density can be determined via microscopy, which can yield an estimate of cells per unit volume. Counting approaches can vary depending on the specific type of information needed and counts can be conducted focused on a few key genera or by all cyanobacteria.

R18: Toxigenic species abundance (qPCR)

The abundances of specific target genera can be estimated using molecular approaches. Quantitative polymerase chain reaction (qPCR) is a method that can estimate the quantity of specific DNA sequences within a sample. The DNA sequences of specific cyanobacterial genera can be enumerated and then can be estimated back to an abundance of cells per unit volume.

Algal/cyanobacterial Community Composition

Algal and cyanobacterial community composition analyses allow for the specific assessment of the members within a community and the specific toxigenic and harmful species. Assessing the dominance of potentially harmful species is an important indicator of risk of impairment of beneficial uses. In waterbody-specific monitoring species composition data, particularly paired with driver metrics, is useful in developing an understanding of how and why communities shift over time. This type of data also may also provide an early indicator of emerging taxa of concern.

R19/D30: Species composition via microscopy

Cyanobacterial community composition can be accessed via microscopy by differentiating different cyanobacterial genera and species taxonomically. Identifying cyanobacterial species requires specific taxonomic training and a disadvantage of this approach is that data quality can be impacted by the analysts experience and training. Microscopy can be used to quantitatively or qualitatively assess species composition, although quantitative counts of filamentous and colonial cyanobacterial can be extremely challenging and time consuming. Microscopy is most commonly used to assess the most dominant genera or to conduct a relative abundance assessment of the members of the community. Depending on the analyst’s training, the relative composition of other algal groups can also be assessed. Relative abundance data best paired with an indicator of algal or cyanobacterial biomass.

R20/D30: Species relative abundance via molecular barcoding

Community composition can be accessed via molecular barcoding approaches which provides the relative abundance of cyanobacteria genera and species within a sample. Community composition can be assessed from genomic DNA extracted from samples. Generic 16S rRNA barcoding or cyanobacterial specific primers can be used, although this approach may miss any emerging taxa of concern that are eukaryotic. Additional sequencing of the 18S rRNA gene can also be conducted to assess the eukaryotic algae present in the community. An advantage of molecular approaches is that variation across samples can be reduced by standardizing the primers and bioinformatic pipelines. Molecular approaches are also higher throughput than microscopy-based analyses for a large number of samples, making larger sample sizes more feasible.

Primary consumers

Grazing by higher trophic levels is an important control of algal blooms. Characterizing the grazer/zooplankton community can provide insights on the factors might govern the phytoplankton community composition, overall biomass as well as controls on bloom demise.

R21/D32: Invertebrate community composition

Benthic macroinvertebrates (BMIs) and benthic algae are the primary biota used for bioassessments in rivers, streams, and estuaries. Freshwater BMI are comprised mostly of aquatic insects but also include crustaceans, mollusks, and worms. BMI assemblages are found in most waterbodies and are reliable indicators of biological health because they are relatively stationary and respond predictably to a variety of environmental stressors. In California, an index of stream condition has been developed based on BMI (California Stream Condition Index (CSCI; Mazor et al. 2016)) and is now in routine use.

In a targeted monitoring program, characterization of the grazer and zooplankton community allows for an assessment of potential consumers of FHAB species but generally only will provide only associative insights on top-down controls unless paired with grazing rate information. Grazing rates are very useful measures but extend outside the scope of the resources available to most ambient monitoring programs and are generally included in research studies.

Toxins/Taste & Odor Compounds

Measures of algal secondary metabolites including cyanotoxins and tase and odor compounds provide a direct indication of impaired beneficial uses. These compounds impair beneficial uses through multiple pathways described extensively in the Chapter 2 of this report. Cyanotoxins and taste and odor compounds can be collected and extracted from a variety of sample matrix types (e.g., water, benthic mat material, sediments, tissues and passive samplers) and can be analyses using several approaches. The most common approaches for quantifying cyanotoxins are via immunological approaches such as ELISA (Enzyme Linked ImmunoSorbent Assay) and via analytical approaches such as LC-MS (Liquid Chromatography – Mass Spectrometry). ELISA approaches offer the benefit of being more rapid, affordable and accessible than most analytical methods, but ELISA can experience decreased performance in complex sample matrices. ELISA also does not provide information about concentrations of specific cyanotoxin variants within a given toxin class. Since ELISA is an antibody-based approach, the antibodies in the assay react with either a specific compounds or chemical groups shared among compounds. This is most pertinent in the consideration of microcystins, since toxicity varies widely across the more than 200 variants of microcystin. ELISA assays typically are designed to react with the ADDA subgroup, which is common to the structure of all microcystins and nodularin. LC-MS can overcome several of these limitations and differentiate and quantify many of the variants within each cyanotoxin class. LC-MS can also avoid many of the matrix issues encountered with ELISA analysis. LC-MS analysis of cyanotoxins, however, typically requires longer processing times and is more expensive and technically intensive than ELISA.

R22/D31: Total planktonic/benthic toxin samples

Quantitative cyanotoxin concentrations can be measured from water column samples or from benthic mats. Concentrations of cyanotoxins in water are generally quantified as a mass of toxin per unit volume. Cyanotoxins in water can be measured in the dissolved pool which is a measure of extracellular toxin or in the particulate pool which represents intracellular toxins and toxins adsorbed to particles. Each pool can impact beneficial uses in a different way. Total toxin is a combined measure of toxin within both the dissolved and particulate pools. The measurement of total toxins is most common in ambient monitoring since it is a summative estimation of potential impacts to the beneficial uses of a waterbody. Cyanotoxins can also be measured in benthic mat samples. Cyanotoxins concentrations in mats are typically expressed as a mass of cyanotoxin per unit volume of sample extract or by mass of cyanotoxin per unit mass of mat material if AFDM or other unit of biomass are collected that the same time.

R23/D31: Via passive sampler

Passive samplers are samplers that are able to passively adsorb algal toxins dissolved in the water column. These devices are typically inexpensive and are constructed with resin or gels that can bind toxins present in the environment. The most common type of passive sampler used for algal toxins are SPATT (Solid Phase Adsorption Toxin Tracking) samplers. Passive samplers can generally be deployed in any waterbody type (fresh, marine, estuarine) and are extremely sensitive. Passive samplers are useful in determining toxin prevalence, and particularly in exploratory work in waterbodies with little or no previous HAB monitoring data available. Passive samplers do not provide data that is readily comparable to existing recreational health thresholds.

R24/D31: Toxin gene counts

The biosynthetic pathways for the production of multiple classes of cyanotoxins have been elucidated, which allows for the molecular detection of the genes associated with toxin production. qPCR (quantitative polymerase chain reaction) allows for the enumeration of the number of toxin producing genes in a sample. The quantity of toxin gene sequences in a sample generically tracks with the amount of toxin within a given system, however a universal relationship between gene copy number and toxin concentration does not exist. Samples with elevated gene copy numbers should be confirmed with addition direct measures of cyanotoxins. This approach is very well suited to waterbody-specific programs where the relationship between gene copy numbers and direct measurements of toxin can be developed. qPCR is very sensitive, and in many cases, toxin genes can be detected prior to the detection of cyanotoxins in water samples. In these cases, toxin genes can provide an early indicator of the formation of a toxin producing FHAB event. qPCR assays for toxin genes are more inexpensive than traditional measurements of toxins.

R25/D31: Tissue toxins, MIB, geosmin

The tissues of fish and shellfish can become contaminated with cyanotoxins as well as taste and odor compounds via food web exposure. Several studies (see section 4.1.2) have shown that concentrations of cyanotoxins are above the State’s safe to eat recommendation. Similarly, some studies have shown that taste and odor compounds can degrade the palatability of several different fish species. The tissues of these organisms can be collected and extracted to assess the concentrations of the compounds. The collection and preparation of fish and shellfish for analysis can be costly and labor intensive. Tissue matrixes are complex and are generally best suited for analysis via analytical methods. The analysis of cyanobacterial secondary metabolites is generally recommended for waterbodies or watersheds with known FHAB issues.

R26/D31: MIB, Geosmin, Sulfur

Taste and odor compounds can be measured in the water column where they can cause issues at very low concentrations. These compounds are of greatest concern in source waters and in waterbodies that are raw water sources for drinking water production and in waterbodies where they may contaminate tissues. Taste and odor compounds can be measured both via ELISA and LC-MS. Detection of these compounds can also indicate the presence of the cyanobacterial producers, many of which can also produce cyanotoxins. Therefore, taste and odor compounds may serve as an early warning of the presence of cyanotoxins.

R27/D31: Sediment toxins

Sediments can be contaminated with cyanotoxins during and following the demise of a bloom. Cyanotoxins in sediments can provide an indication of previous bloom activity and may also represent a long-term source for cyanotoxins. Currently, little is known about how long toxins remain in sediments and if they may contaminate food webs, impacting aquatic life and fishable species.

External Drivers

External drivers consist of the combination of natural gradients (climate, geology, elevation/slope, soils, rainfall, etc.) and human activities (land use, water withdrawals and releases, fertilizer application, etc.) that are external to the waterbody and can influence FHABs (Table 2.4). Many of these indicators (and example metrics) can be assessed through a variety of geographic information system (GIS) office assessments and field observations (e.g., catchment flow, riparian cover).

External Drivers – Climate

D1 – D4: Air Temperature, Precipitation, Wind, Solar Irradiance

External climatic factors can be significant drivers of FHAB events. Air temperature, which is a function of season and regional climate, is a significant factor in controlling water temperature and overall waterbody dynamics. Similarly, precipitation, regional wind patterns and irradiance all play significant roles in waterbody and watershed dynamics. Precipitation, or lack of precipitation, can modify factors such as lake level, stream flow rate and can also cause significant nutrient inputs via surface runoff. Wind can shift currents or cause water column mixing. Irradiance provides energy to photosynthetic organisms, which can stimulate growth. One or more of these metrics are generally available from local weather stations at or nearby waterbodies. Modeled climate data are also available (e.g., PRISM climate data[36]). Most of these metrics can also be measured in the field, however, instantaneous measures of these metrics are less useful, and time averaged measures are can be more informative in driver assessments. Exceptions to this could be visual assessment of shading or riparian cover surrounding a waterbody.

[36] NACSE (2020). PRISM Climate Data. Retrieved from https://prism.oregonstate.edu/

External Drivers – Land use, geology and soils

D5 -D9: Catchment Land Use, Slope, Hydrology, Geology and Soils

Many catchment features can be accessed via GIS. Multiple databases with hundreds of catchment metrics are available, largely due the concerted efforts of the US EPA. The Stream-Catchment (StreamCat; Hill et al. 2016) and Lake-Catchment (LakeCat; Hill et al. 2018) dataset contains an extensive collection of landscape metrics for streams, lakes and reservoirs and their associated catchments within the conterminous U.S. StreamCat and LakeCat includes both natural and human-related landscape features. The data are summarized both for individual lake catchments and for cumulative upslope watersheds. Although the data are readily available, the processing and selection of specific data needed for analyses requires technical expertise. Additional discussion of this metric can be found in Section 5.2.2. Examples of data sources can be found in Table 2.4.

External Drivers – Nutrient Loading

D10, D11 and D12: Catchment Nutrient Loading, Atmospheric Nutrient Deposition and Groundwater

Similar to the physical and geological catchment data described above, catchment nutrient loading into waterbodies can be assessed using publicly available databases and modeling products (e.g., USGS Sparrow modeling outputs[37]). Similarly, atmospheric nutrient deposition into waterbodies and nearby catchments can be assessed from data collected from NADP (National Atmospheric Deposition Program[38]) or from modeled data products (Community Multiscale Air Quality Modeling System[39]). Groundwater is a potential nutrient source to surface waters that is understudied but may have major impacts on primary production in some systems. Groundwater monitoring programs such as the National Groundwater Monitoring Network[40] hosts a publicly available database that can be used to begin to address questions about nutrient loads in groundwater.

External Drivers - Pesticides

D13: Human Uses

Pesticides are chemicals used to control undesirable pests, such as fungus, weeds and insects. The application of pesticides is common in agriculture and also in urban areas. Pesticides can drain from where they are applied and contaminate waterways, causing potential harm to aquatic life. The interactions between these compounds and the development of FHABs is complex and pesticides may be toxic to cyanobacteria directly and/or potentially shift algal communities[41] or be harmful to zooplankton[42] which may also shift algal communities and potentially promote the

[37] USGS (2020). SPARROW modeling: Estimating nutrient, sediment, and dissolved solids transport. Retrieved from https://www.usgs.gov/mission-areas/water-resources/science/sparrow-modeling-estimating-nutrient-sediment-and-dissolved?qt-science_center_objects=0#qt-science_center_objects

[38] NADP (2020). National Atmospheric Deposition Program Maps and Data. Retrieved from http://nadp.slh.wisc.edu/data/

[39] EPA (2020). CMAQ: The Community Multiscale Air Quality Modeling System. Retrieved from http://www.epa.gov/cmaq

[40] NGWMN (2019). National Ground-Water Monitoring Network (NGWMN) Data Portal. Retrieved from https://cida.usgs.gov/ngwmn/

[41] Ma, J. (2005). Differential sensitivity of three cyanobacterial and five green algal species to organotins and pyrethroids pesticides. *Science of the Total Environment*, *341*(1-3), 109-117.

[42] Hanazato, T. (2001). Pesticide effects on freshwater zooplankton: an ecological perspective. *Environmental pollution*, *112*(1), 1-10.

dominance of cyanobacteria. Pesticides can be measured in water by a variety of analytical methods[43] including multiple types of chromatography and multiple modes of detection including mass spectrometry, NMR spectroscopy (Nuclear Magnetic Resonance), infrared spectroscopy and UV spectroscopy. Because of the diversity of pesticide compounds and lack of standardized methods, measurements can be difficult, expensive and time-consuming. Another assessment of pesticides can be indirectly derived from assessing the rates of pesticide application within a catchment.

External Drivers – Events

D14: Disruptive Environmental Events (e.g., floods, fires, chemical spills.)

Disruptive environmental events are on the rise within the State. Particularly, larger and more intense fires have been occurring in recent years. The impacts of these events on FHAB events is largely understudied, but likely result in large inputs of nutrients via multiple pathways (e.g., increased inputs of soils into watersheds in burn areas, inputs of phosphorus and other compounds from flame retardant use, etc.). Floods can cause changes in the waterbody or channel morphology and introduce significant amounts of nutrients and other compounds from the surrounding catchment into waterbodies. These effects can begin to be understood through pairing FHAB response indicators with data related to these events within a given catchment.

Internal Drivers

Internal environmental drivers can generally be grouped into categories of physical, biogeochemical, and biological, each of which have their own inherent spatial and temporal scales (Table 2.4). These indicators and specific metrics tend to focus on assessment of the "state" of the waterbody (depth, TN, TP, light, dissolved oxygen). Notably, measurement of process rates can be incredibly useful and informative however, their measures typically require expertise to design and interpret appropriately along with higher sampling resources and are not suitable for many monitoring programs. The indicators below are focused on assessment of waterbody state, but rate data can be valuable for watershed- to waterbody-specific assessments and research special studies.

Internal Drivers – Physical

The physical processes within and immediately surrounding a waterbody are important drivers of FHAB events. The motions and physical properties of water can mediate and promote the growth of specific toxigenic species. Physical drivers can include both the specific physical conditions and processes occurring in a waterbody and the characteristics of a given waterbody or watershed (depth, geomorphology, etc.) that govern the nature of physical processes.

D15: Waterbody Hydrology/Hydrodynamics

Measure of waterbody hydrology and hydrodynamics (e.g., water surface elevation, stratification, flow, velocity) are typically measured at index sites or as integrative measures over the segment. Temporal scales of variability range from minutes to interannual, so continuous monitoring via data sondes, moorings or installed gauges is optimal when resources allow.

[43] Chau, A. S. (2018). *Analysis of Pesticides in Water: Volume I: Significance, Principles, Techniques, and Chemistry of Pesticides*. CRC press.

Otherwise, instantaneous measures are essential and need to be repeated during each field visit but cannot be used to assess temporal lags in FHAB response measures or the effects of events (e.g., storms) that occurred in between site visits. Hydrodynamic observations at index sites are useful but not always representative of physical processes that impact FHABs at larger vertical and horizontal spatial scale. Integrative hydrologic or hydrodynamic measures can be developed from statistical (e.g., Statewide flow hydrologic alteration metrics) or waterbody-specific numerical models that can provide useful predictive measures.

D16 and D19: Geomorphology and Physical Habitat

Geomorphology and physical habitat measures (also sometimes called hydrography) are the physical features of waterbodies and the surrounding land areas. These features can be assessed comprehensively (e.g., bathymetry), at an index site (deepest point, e.g., Figure 4.4) or as an integrative measure (wetted channel dimensions, sediment grain size, Figure 4.5) at a waterbody or segment scale. In lakes, these measures may be slower to change; in streams and estuaries, morphological and physical measures can change radically from sampling period to sampling period due to erosion and depositional events that occur during storms and long-shore transport of sand (e.g., estuary sand bars). USGS maintains a national database of hydrography products that can also provide useful data for mapping and modeling[44].

D17: Water Temperature

Temperature is the measure of the thermal energy within water and is a fundamental physical property. Water temperature is a critical driver of physical processes such as water column structure, chemical processes such as nutrient cycling and biological processes such as microbial growth rates. Temperature can be measured as a discrete spot measure at the time of collection of other indicators or as a continuous measurement over longer timescales (24 hours, weeks to months). Water temperature is anticipated to increase due to climate change. Development of long-term datasets of temperature will be important for the assessment of the impacts of climate change.

D18: Salinity and Conductivity

Salinity and conductivity is an indicator of dissolved ionic compounds, salts, in water. Organisms have optimal salinity ranges; therefore, salinity can impact the suitability of aquatic habitat as well as shape algal community composition. Salinity can also be an indicator freshwater influence in coastal systems and an indicator of long residence time, anthropogenic inputs or terrestrial/geochemical inputs in freshwater systems.

Internal Drivers – Biogeochemical

Biogeochemical indicators are typically measured at index sites or as integrative measures over the segment or as a vertical profile of the water column. Temporal scales of variability range from minutes to interannual, so continuous monitoring via data sondes mounted in tandem with moorings or installed hydrodynamic gauges is optimal when resources allow. Otherwise, discrete samples are typical and need to be repeated during each field visit but cannot be used to assess temporal lags in FHAB response measures or the effects of events (e.g., storms) that occurred in

[44] USGS (2016). National Hydrography. Retrieved from https://www.usgs.gov/core-science-systems/ngp/national-hydrography

between site visits. Choice in specific metrics is key and should be guided by the conceptual model for the study.

D20 & D21: Light Attenuation

Light attenuation was discussed at length in the sections above, with details about specific metrics in R1- R3.

D22-24: Nutrients

Nutrients within a waterbody are essential for the growth of algae and aquatic plants. Key macronutrients in freshwater systems are nitrogen (N), phosphorus (P) and potassium (K). For diatoms silicate (SiO_3) is a key nutrient as well. Other nutrients required for growth are calcium (Ca), magnesium (Mg), and sulfur (S). In a majority of aquatic ecosystems, N and P are the growth limiting nutrients and are the most commonly measured nutrients in the assessment of FHAB drivers and trophic status of a waterbody. Nutrient measurements in the water column can be made to assess the concentrations of nutrients within the dissolved pool, which are generally considered bioavailable or in the particulate pool which represents nutrients bound up in plankton or adsorbed to particles. Measure of total nitrogen (TN) or total phosphorus (TP) are a measure of combined particulate and dissolved pools. Dissolved inorganic nutrient concentrations are what is considered “bioavailable” to an FHAB bloom, but the TN and TP concentrations are more representative of overall nutrient status and trophic state in lakes (Yuan et al. 2014). Total water column nutrient concentrations, however, can yield a false negative in streams or estuaries if most of the nutrients are locked up in macroalgal biomass, which is not typically sampled in a discrete water sample.

Measurements of nitrogen in sediments were discussed above in section R7 and R9. Phosphorus can also be measured in sediments. Lake sediments can serve as a reservoir for nutrients, particularly P, which can become resuspended into the water column.

D25: Water Column Organic Matter

Water column organic matter was discussed in the sections above, with details about specific metrics in R9.

D26: Sediment/Benthic Organic Matter

Sediment/benthic organic matter was discussed in the sections above, with details about specific metrics in R7 and R9.

D27: Carbonate Chemistry

Carbonate chemistry, and pH in particular, was discussed in the sections above, with details about specific metrics in R5.

D28: Ionic Composition

Ionic compounds are charged compounds, generally salt ions, that are naturally occurring constituents of aquatic ecosystems. The ionic strength of a waterbody can impact the ecology of the systems since organisms have optimal ranges and preferences. Generally ionic compounds are measured in a bulk measurement of ionic strength, which can be assessed as electrical conductivity, salinity or total dissolved solids (TDS). Individual cations (Na, Ca, Mg or K) and anions (Cl, HCO_3, CO_3 and SO_4) can also be quantified to determine ionic composition. This type of measurement is appropriate in some cases to determine which ion(s) may be related to an observed biological effect. Individual ions are typically measured by ion chromatography.

D29: Dissolved Oxygen

Dissolved oxygen was discussed in the sections above, with details about specific metrics in R7 and R4.

D30: Stable Isotopes

Stable isotope measurements can be used to assess biogeochemical cycling and nutrient source tracking, particularly in lakes. Isotope ratio differences in substances containing hydrogen (2H/1H, usually written D/H), carbon ($^{13}C/^{12}C$), nitrogen ($^{15}N/^{14}N$) oxygen ($^{18}O/^{16}O$), and sulfur ($^{34}S/^{32}S$) are commonly used in lake studies[45]. These studies are typically best suited to waterbody-specific studies including the use of tracer enrichment studies or natural abundance studies. These approaches can be used to address questions about nutrient sources, fates, cycling rates or the functioning of food webs.

Internal Drivers – Biological

Internal biological drivers are primarily FHAB specific indicators that are related to FHAB biomass, community composition, and cyanotoxins. These are key response indicators and one or more of these metrics should be paired with previously described driver metrics.

D31: Algal Taxonomy

Algal taxonomy, both biomass measures and community composition, were discussed in detail in metrics R8 – R20. Algal taxonomy metrics can be measured in tandem with previously described driver metrics to gain associative relationships between algal biomass and coarse algal taxonomy. Waterbody-specific measurements are most ideal for a mechanistic understanding of drivers of shifts in algal community composition.

D32: Algal Toxins

Algal toxins were discussed in detail in metrics R22 – R27. As with algal taxonomy, algal toxins can be examined as a response variable with previously described driver metrics. Similarly, waterbody-specific studies are needed to develop a mechanistic understanding of the drivers of cyanotoxins, however generalized associative relationships can be developed between internal and external drivers and cyanotoxins over broader spatial scales.

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[45] Pearson F.J., Coplen T.B. (1978) Stable Isotope Studies of Lakes. In: Lerman A. (eds) Lakes. Springer, New York, NY. https://doi.org/10.1007/978-2-4757-1152-3_10

D33: Grazers/Zooplankton

Grazers and zooplankton indicators were discussed in the sections above, with details about specific metrics in R21.

APPENDIX 4. EXAMPLES OF TRIBAL MONITORING PROGRAMS

Clear Lake Cyanotoxin Monitoring Program

Clear Lake is the largest freshwater lake in California. It has a cyanobacteria and cyanotoxin monitoring program (Clear Lake Cyanotoxin Monitoring Program, CLCMP) that was established and is run collaboratively by two shoreline tribes, Big Valley Band of Pomo Indians (Big Valley) and Elem Indian Colony (Elem). These tribal governments had observed regular impacts of FHABs in Clear Lake since 2009, and with the absence of routine cyanotoxin monitoring from other local or state agencies, formed the Clear Lake Cyanotoxin Monitoring Program in 2014. Initially, Big Valley and Elem collaborated to conduct sampling at eight shoreline locations following a large bloom in September 2014. The Tribes also established the Clear Lake Cyanobacterial Task Force in 2014 to foster communication and collaboration between the Tribes, the local and state agencies working on the lake, and US EPA to better protect the beneficial uses of Clear Lake.

Since 2014, the CLCMP has expanded, and the Tribes monitor 20 shoreline locations around the lake. These include sites of cultural significance to all Pomo Tribes including sites where ceremonies or festivals may happen as well as shorelines that are on tribal lands. Other sites were chosen strategically to learn more about the status, trends, and drivers of FHABs in the lake. These additional sites are where recreation is common, near known septic systems or seawalls, sites near high densities of aquatic vegetation, and locations near the US EPA superfund site on the lake. Sampling occurs every 2 weeks during the summertime period of May to October. Monitoring frequency is also timed to occur prior to specific tribal activities in order for the tribes to make informed decisions about interacting with the water. Monitoring frequency around the lake is reduced to monthly samples during the winter and early spring, when FHAB events around the lake tend to be less common. Samples have been collected for the determination of cyanotoxin concentrations since the beginning of the program, and multiple indicators have been added during the life of the program. Additional indicators that have been added over time include cyanobacteria community composition via microscopy, qPCR for toxin genes, chlorophyll-*a* and phycocyanin, and basic water quality parameters such as temperature, salinity, pH, and DO via data sondes.

In addition to monitoring, the Tribes have collaborated to conduct special studies about the impacts of FHABs on Clear Lake. The Tribes received funding from CalEPA in 2016 to study the toxin concentrations in the tissues of ten culturally significant fish and shellfish species. The results of this study indicated that several culturally significant species had tissue concentrations that exceeded the OEHHA action levels for recreational fishing. This will ultimately be used by the Tribes to better inform tribal subsistence uses.

The Tribes have prioritized collaboration, open data, and communication of monitoring results with the public. Since 2018, Big Valley and Elem have actively collaborated with the California Department of Water Resources to expand their monitoring to collect samples in the center of each lake arm, in addition to the shoreline sampling events. The CLCMP has a federally accepted QAPP and the data generated by the tribes is submitted to the WQX database. In addition to submitting the data to a publicly available database, the Tribes also share their data with SWAMP for inclusion on the HAB Incident Report Map and with Lake County. The monitoring data are also updated regularly on the Big Valley EPA webpage (https://www.bvrancheria.com/clearlakecyanotoxins). The Tribes also make a specific effort to share their data with members of the general public through the establishment of a Clear Lake Water Quality social media page on Facebook, which reaches more than 2,000 people in the Clear Lake and surrounding communities (https://www.facebook.com/ClearLakeWaterQuality/).

Klamath Basin Tribal Monitoring

The Klamath River flows approximately 420 km from Upper Klamath Lake in southern Oregon through northern California to the Pacific Ocean at Requa in Del Norte County, California. Tribes in the Basin - the Karuk Tribe, Yurok Tribe, Hoopa Tribe, Quartz Valley Indian Reservation and Klamath Tribes – have worked individually and collectively to protect tribally important resources (including salmonids and water quality) in the Klamath River by conducting water quality monitoring (temperature, nutrients DO, pH, etc.), developing special studies of fisheries and water quality, and leading groups addressing these issues.

In the early 2000's, several significant activities were occurring which engaged tribes to protect fisheries and water quality. In the fall of 2002, over 34,000 returning adult fall Chinook salmon died in the lower 45 miles of the Klamath River when low flows delayed migration upstream and fish disease proliferated in the crowded warm water. Preceding 2006, the tribes conducted studies and otherwise documented impacts of the PacifiCorp-owned Klamath Hydroelectric Project, including four dams and the Iron Gate and Copco Reservoirs, for which FERC operating permits were to expire in 2006. Additionally, in accordance with a consent decree, the US EPA and North Coast Regional Board were developing TMDLs for the Shasta, Scott, Salmon, Trinity, and Klamath rivers.

Cyanobacterial HABs were first documented in Iron Gate and Copco reservoirs, in 2004 by the Karuk Tribe. Their water quality monitoring program was expanded in 2005 to include FHAB monitoring, and that monitoring documented significant and prolonged blooms of *Microcystis* in Iron Gate and Copco reservoirs. Subsequently, the Karuk and Yurok tribes have continued to conduct annual FHAB monitoring, under various legal agreements, conducted special studies, and taken leadership roles to address FHABs in the Klamath River Basin.

Special study and monitoring activities spearheaded by the Tribes in the region have provided a better understanding about FHABs. Years of monitoring data have shown that *Microcystis* spp. blooms occur annually in Copco and Iron Gate Reservoirs and both cells and microcystins are transported downstream throughout the river and estuary system (Kann and Corum 2009; Otten et al. 2015; Genzoli and Kann 2017). Studies on microcystin bioaccumulation have shown that microcystins are present in fish and shellfish in the Klamath River; tissues of many of these organisms were found to contain microcystins when the toxin was low or below detection in the surrounding waters (Kann et al. 2010; Kann et al. 2013). Ultimately, this work has supported major management actions and has provided the data to support actions to remove several of the hydroelectric dams that have been a major driver of the FHAB impacts throughout the Klamath River Basin.

Tribal collaboration included participating as steering committee and Work group members of the Klamath Blue Green Algae (BGA) Work Group, formed in 2006 to study the occurrence, distribution and causes of FHABs in the Klamath River, using funds from a PacifiCorp – public utilities commission settlement. Accomplishments of the Work Group included funding a study of nutrient-limiting factors on cyanobacteria growth in Iron Gate Reservoir (Pia Moisander, 2008), and successfully creating a unified monitoring program for cyanobacteria and cyanotoxin sampling throughout the Klamath River Basin by coordinating the ongoing monitoring of the tribes, PacifiCorp, state agencies and others. The Klamath BGA Work Group developed consistent protocols for sample collection, preparation and analysis, resulting in the BGA sampling protocol, identified laboratories with expertise for cyanotoxin analyses, and developed and implemented thresholds for public health warnings and protocols for signage and press releases. The Klamath BGA Work Group ultimately became the State BGA Work Group, the precursor of today's CCHAB Network.

Since 2008, water quality monitoring in the Klamath River has been conducted by the Yurok Tribe, the Karuk Tribe and PacifiCorp under various agreements. In 2008, an "Agreement in Principle" was signed to remove four of the dams on the Klamath River by 2020; that Agreement provided $500,000 per year to conduct water quality monitoring, including public health monitoring - sampling and analysis for cell identification and enumeration, and cyanotoxins. In 2010, the Agreement in Principle was replaced by the Klamath Hydroelectric Settlement Agreement, which retained funding for water quality monitoring. That monitoring continues (into 2021) in anticipation of dam removal.

Timely conveyance of data to stakeholders and the public became a priority issue. With tribes and PacifiCorp conducting sampling, US EPA provided ELISA-microcystins analysis and the NC RWQCB supported development and hosting of the Klamath Basin BGA tracker website to provide near-real-time data to inform the public of potential risks from cyanotoxins in the Klamath River. The Klamath Basin Monitoring Program (KBMP) provided the centralized, web-based clearinghouse for monitoring data to ensure readily accessible, high quality data with quality assurance procedures. Monitoring data are shared with SWAMP for inclusion on the HAB Incident Report Map. Additionally, the KBMP hosts a website to communicate the presence of FHABs throughout the river to the public (http://www.kbmp.net/bga), and a resource for tribally-produced science including HAB work is available at https://klamathwaterquality.com/.

Work in the Klamath Basin provides a great example of the work by several Tribe's Natural Resources programs taking leadership roles in monitoring and research of important water quality concerns like FHABs.

Appendix 5. Foundational Data Useful for Decision Support: Role of Predictive FHAB Models

Section 7.1 of the main report laid out the premise that the two distinctly different user interfaces that could serve as decision support would share and draw from five basic types of data and model output:

- Satellite remote sensing
- FHAB event monitoring data
- Ambient recreational or fishable use field monitoring data
- All other ambient field monitoring data (including both responses and drivers)
- FHAB predictive models

With the exception of FHAB predictive models, these data sources and the needs for improved data visualization have been comprehensively discussed in Chapters 3-6 and in Section 7.2. Beyond modernization of databases, automation of quality assurance, and quality control data checkers, discussion of specific improvements or visualizations of existing data that are needed to facilitate building these decision support systems should be scoped with the intended user audience and as such is beyond the scope of this document.

In this section, we focus instead on describing the need, development, and potential uses for predictive FHAB models.

Why Predictive FHAB Models?

Monitoring of toxic FHABs is expensive and in the near term, California is facing considerable data gaps on the extent and drivers of FHABs in all its surface waters and available resources to address this have not been identified. In the interim, we propose using existing data to predict, based on relationships between external and internal drivers and FHAB response, the probability that FHABs would occur in all the State's inland waterbodies (lakes, reservoirs, stream, and river segments). Such models would be key for prioritizing more intensive monitoring and to formulate regional control strategies (e.g., NPS and PS controls, WDR, environmental flows, etc.).

Challenges and Vision for Californian FHAB Models

Causal modeling of eutrophication drivers and outcomes is in routine application to manage nutrients and eutrophication in watersheds and waterbodies around the globe (e.g., total maximum daily loads, TMDLs); modeling approaches range in complexity from statistical stress-response modeling to numerical computer models. In contrast, the science of predicting <u>toxic</u> HAB events from waterbody hydrodynamics and water quality is still an emerging and rapidly evolving area of science (Stauffer et al. 2019; Burford et al. 2020). Hindcasts and seasonal forecasting based on proxies of cyanobacterial biomass are most advanced for well-studied waterbodies (e.g., Lake Erie, Stumpf et al. 2012; Bridgeman et al. 2013; Obenour et al. 2014), but the science of prediction of toxic events at a whole-waterbody scale is in its infancy

(Burford et al. 2020). Given these challenges, we focus on incremental steps that could be useful to assemble building blocks of predictive FHAB risk models. In particular, empirical models can be used to develop statewide or regional risk relationships of probability of FHAB outcomes as a function of environmental drivers (Yuan et al. 2014; Yuan and Pollard 2014; Hill et al. 2018). We note the utility, but do not discuss, modeling to produce waterbody-specific hindcast or short-term forecasts of FHAB events (e.g., Wynne et al. 2015). We focus discussion of predictive models for wadeable streams, lakes, and reservoirs because these waterbody types encompass the majority of the State's surface waters and knowing the risk of FHABs upstream can give a very simple ranking of risk in their downstream non-wadeable rivers and coastal confluences. Ultimately, given the complexity of hydrology and other environmental drivers, coastal confluences and non-wadeable rivers would be good candidates for waterbody-specific models.

FHAB Model Development in California's Waterbodies: Data Assets and Previous Work

In the near-term, three types of empirical statistical models of FHAB responses and environmental drivers would be of great utility to rank watershed and waterbodies by FHAB risk (**SS24, Appendix 6**):

- Wadeable streams, based on field data
- Lake and reservoir, based on field data
- Lake and reservoir, based on remotely sensed FHAB responses

Beta versions of these models are under development and could be refined over time, with improved data availability.

Wadeable Streams Empirical Models. Relative to lakes, data on FHAB responses and environmental drivers are relatively abundant, with notable data gaps in the Central Valley region. Generally, the conceptual approach for developing empirical stress response models consists of using environmental drivers (StreamCAT, internal drivers such as nutrients, flow, etc.) to predict FHAB outcomes that are contained in the stream bioassessment protocols that already in widespread use (Fetscher et al. 2013, e.g., benthic Chl-a, toxigenic benthic FHAB species, ADFM, macroalgal or microalgal percent cover); cyanotoxins are notably not included in the majority of sampling programs.

With the work of Fetscher et al. (2014), we can preview what a beta version of these types of empirical wadeable streams stress-response models reveal. Using Bayesian CART modeling, they found that landscape variables (land use, latitude), nutrients, temperature, and Julian day (timing of sampling) were significant predictors of benthic Chl-a, AFDM, percent cover, and total macroalgal biovolume (Figure 7.5). When a reduced set of predictive variables were included, Bayesian CART models explained up to 81% of variability in benthic Chl-a in validation datasets (Fetscher et al. 2014). Revised versions of these models are needed, updated to include an expanded list of FHAB outcomes (toxigenic benthic species), using a now much larger, available dataset, including the now available StreamCAT. Careful thought should be given to the independent variables considered in model, because variables used to drive the predictive models will constrain their ultimate utility (Fetscher et al. 2014). An iterative exchange with water quality managers on intended applications can help to refine the model approach to maximize its utility for FHAB management.

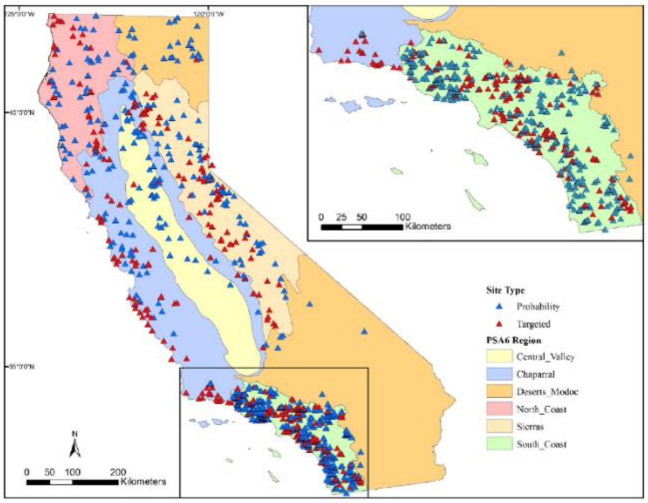

Figure A5.1. Sites for which FHAB responses (probability and targeted) occur as of 2014, shown by the Perennial Stream Assessment (PSA) ecoregion in which they occur. State bioassessment programs use a combination of Omernik (1995) ecoregions and Regional Water Quality Control Board boundaries to partition the state for assessment purposes. "PSA6" refers to the version of the classification scheme that encompasses six ecoregions. Data from these sites were used in the development of empirical stream stressor response models (see Figure 7.6).

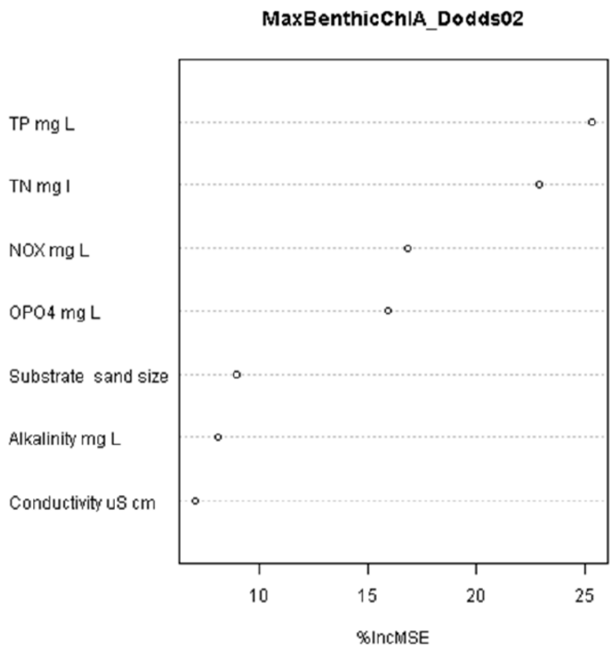

Figure A5.2. Relative influence of variables for the best performing models of max wadeable stream benthic chlorophyll-a. Predictor variables are ranked on the Y-axis and the mean squared error values are listed on the x-axis. Explanation of variables can be found in Fetscher et al. (2014).

Lake and Reservoirs Empirical Models. In contrast to wadeable streams, where environmental data are abundant and in the public domain, the majority of lake and reservoir data in California are privately held and conducted using disparate monitoring approaches. The State Water Board sponsored an initial effort at data compilation of CCHAB partner and other data publicly accessible in state and federal databases. Sutula et al. (2016) found data for only 155 of California's more than 2,500 lakes larger than 20 acres. There is a dozen or more lakes around the state where persistent FHAB problems occur and where the majority of FHAB data are found; because statewide or regional predictive FHAB models require data on a large number of lakes and reservoirs with stressors and responses across the "disturbance gradient," these data might be useful to constructing site-specific FHAB response models, but can only play a minor role in regional or statewide model development. The most data (~100 lakes and reservoirs) come from one-time sampling events conducted by the National Lakes Assessment (NLA).

Table A5.1. The number of data records, unique stations and lakes per analyte group or combination of analyte for California based in the 2016 statewide data collection.

Analyte Group	California		
	Number of Data Records	Number Unique Stations	Number of Lakes
Chlorophyll-a	2388	427	155
Total Nitrogen (TN)	1592	692	136
Total Phosphorus (TP)	2941	332	184
Chlorophyll-a + TN	2714	213	116
Chlorophyll-a + TP	1447	209	123
Microcystin	326	84	148
Microcystin + Chlorophyll-a	168	201	76

Several national efforts to develop predictive eutrophication models based on the NLA data provide illustrative approaches that California can consider and even provide ideas of how to bridge the data gap in the near term. For example, Hill et al. (2018) used the LAKECat landscape dataset to predict eutrophication outcomes in the National Lakes dataset. The Hill et al. (2018) model correctly predicted the trophic state of 72% of NLA lakes, and the model to predict the probability of eutrophication at 297,071 <u>unsampled lakes</u> across the continental US. While the Hill et al. (2018) model is heavily influenced by irrigated agriculture that dominates large portions of lake watersheds in the U.S., the applicability of such an approach to California lakes and reservoirs is clear; they note *"the large suite of LakeCat metrics could be used to improve analyses of lakes at broad spatial extents, improve the applicability of analyses to unsampled lakes…"* While we do not recommend a "plug and play" of the Hill et al. (2018) model to California lakes risk assessment, we do recommend adapting their approach to develop empirical statistical models based on FHAB responses (i.e., algal biomass, toxigenic algal species, toxins, hypoxia, water clarity) versus external (landscape) and internal drivers.

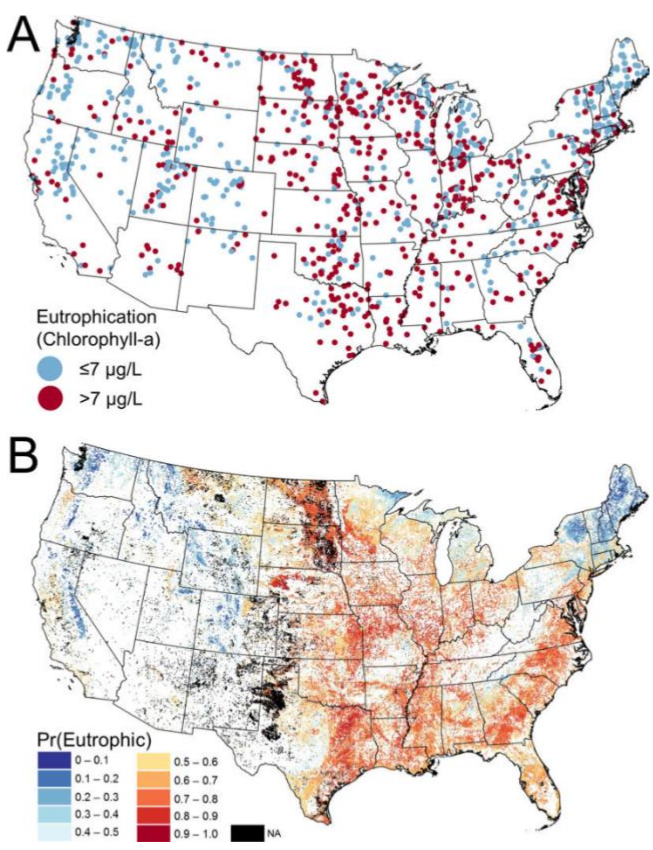

Figure A5.3. From Hill et al. (2018). A.) A binary classification of lake samples into eutrophic and noneutrophic conditions based on chlorophyll a concentrations. The USEPA used a criterion of > 7 µg/L to designate lakes as eutrophic. B.) Predicted probabilities of lake eutrophication [Pr(Eutrophication)] based on a random forest model that used LakeCat metrics as predictor variables. The map represents each lake as a single point. Black points are lakes that were excluded from the National Lakes Assessment sampling frame.

The statistical modeling approaches developed to support EPA OST's recently released Draft Ambient Nutrient Water Quality Criteria Recommendations for Lakes and Reservoirs provides some good examples of "decision support" models and a roadmap for how states with limited data can develop improved lake stress-eutrophication models, pivoting off of national modeling efforts. EPA's statistical model are intended to support decisions on nutrient and eutrophication criteria. EPA developed several statistical models relating chlorophyll-a, TN and TP to phycocyanin, cyanobacterial cell volume, microcystin, and lake hypoxic volume (among other endpoints; e.g., Figure A5.4). EPA then combined these relationships through Bayesian Network analyses to offer an R shiny app interactive model that relates the probability of exceeding an targeted MC concentration, given an allowable exceedance probability and credible interval (see document for discussion), where users can change the targeted MC concentration and allowable uncertainties (Figure A5.5). Other shiny app models are given, in particular to relate TN and TP to chlorophyll a (EPA OW 2020).

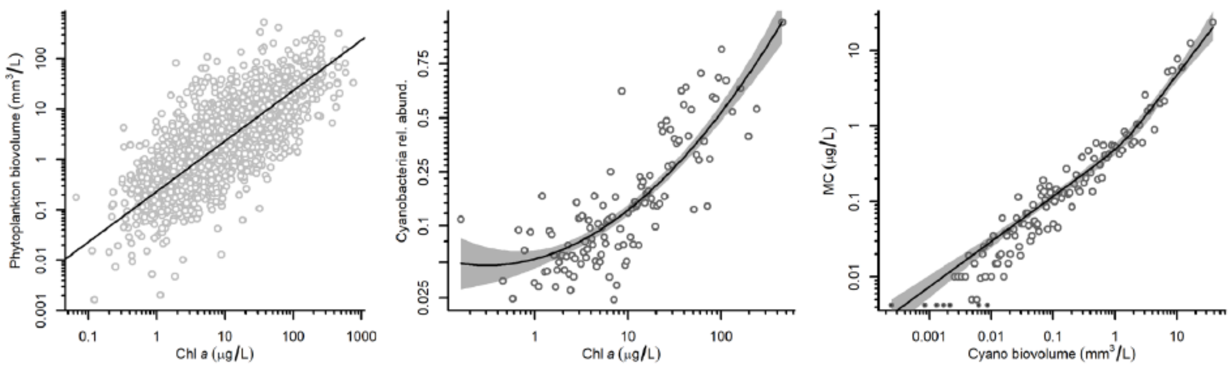

Figure A5.4. Modeled relationships for the microcystin (MC) model. Left panel: relationship between Chl-a and phytoplankton biovolume; open circles: observed measurements of Chl-a and phytoplankton biovolume; solid line: has a slope of 1. Middle panel: relationship between Chl-a and cyanobacterial relative biovolume; open circles: average cyanobacterial relative biovolume in ~20 samples at the indicated Chl-a concentration; solid line: estimated mean relationship; gray shading: 90% credible intervals about the mean relationship; vertical axis: has been logit-transformed. Right panel: relationship between cyanobiovolume and MC; open circles: average MC in ~20 samples at the indicated cyanobiovolume; solid line: mean relationship; gray shading: 90% credible intervals about the mean relationship.

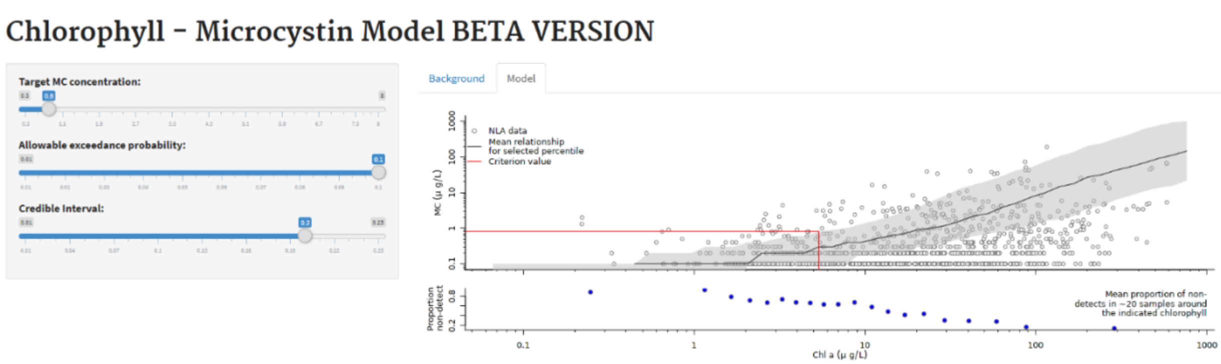

Figure A5.5. Screenshot of EPA chlorophyll-a -microcystin model featured on R shiny app, showing the ability to toggle values for targeted microcystin concentration and allowable uncertainty (exceedance probability and credible interval).

EPA provides a roadmap for states to develop a suite of customized models, pivoting off of nationally-sourced NLA, but allowing the flexibility to incorporate more abundant state data to increase sample size and therefore decrease uncertainty, where available. They provide specific case studies of how this can be done and have invited partnerships with state programs to develop such models. The State Water Board biostimulatory program is pursuing such a partnership to attempt to develop a refined set of lake and reservoir biostimulatory (eutrophication) stress response models, in which FHABs is one of several targeted outcomes that could be predicted based on: 1) climate data, 2) LakeCat landscape data, 3) internal drivers (TN and TP, among other variables).

Availability of satellite remote sensing data provides an opportunity to develop an alternative FHAB risk modeling, based on relationship of these same sets of environmental drivers relationship to remotely sensed CIcyano, Chl-a and water clarity. Here again, California is partnering with EPA ORD to test out a California specific model that relates these FHAB outcomes in the 255 lakes and reservoirs to landscape variables (LakeCAT) and other publicly available datasets.

Appendix 6. Description Special Studies

Special studies are designed to answer or inform specific technical questions that contribute to the design of the program or advance the development of particular component of monitoring program implementation (e.g., standardized operating procedures) or projects to improve the interpretation of core monitoring results. Special studies were prioritized with two audiences in mind.

First, special studies were prioritized to support implementation of the six strategic recommendations (Chapter 8). The intended audience of these prioritized studies is Water Boards program managers to help inform funding decisions in support of program implementation. As special studies were aligned with each specific recommended action, components were considered for implementation over three timescales of “immediate” (< 2 years), “near-term” (2-5 years), and “long-term” (> 5 years) based on the information or outcomes related to a specific element, as well the linkages of specific actions to other core recommendations and approaches. In this way, the special studies and specific actions recommendations build off each other and, in many cases, special studies are needed before a specific action can be implemented.

Second, a suite of studies was identified as priorities for collaborative research or partner funding as their advancement would support the FHAB monitoring program.

The sections below, the special studies are described and linked, when appropriate, to the Strategy Recommendation (Table A6.1, see Chapter 8).

Recommendation 1 Immediate

SS0: Develop the partner program implementation guidance components

The TAC agreed that recreational health is an immediate priority for this FHAB partner monitoring program. The first step in program development is to decide on the scale and scope of the program. Once the program scale and scope are determined, investments in the core program infrastructure are the next step, including standardized methods, partner training, documentation, and quality assurance and control procedures. A special study is needed to develop the voluntary program implementation guidance needed to administer this program, including standardized protocols and documentation, training and intercalibration. While SWAMP protocols exist for many of the core and recommended indicators of the partner, they should be specifically reviewed for their use in the partner program. Some new SOPs will need to be developed including qualitative approaches to assess algal abundance (visual indicators, percent cover metrics, similar to those used in New Zealand) for lower resource tier of the partner program. These indicators should be linked to a recreational HABs risk index (SS1). Specific effort should be made to harmonize the protocols developed for the partner program with state-led ambient monitoring and incident response efforts. Analytical methods need to be standardized in order to understand the comparability of methods such as ELISA, LC-MS and to calibrate qPCR methods against microscopy.

Table A6.1. List of special studies, including study number, linked recommendation number, section referenced, and title.

Section Referenced	Study No.	Rec. #	Priority	Special Study Title
3.2.6	SS0	1	Immediate	Develop the partner program implementation guidance components
3.2.6	SS1	1, 4, 6	Immediate	Develop a recreational HAB assessment based on visual indicators
3.2.7	SS2	1	Immediate	Proactively identify partners, focusing on tribes, communities of color and economically disadvantaged groups.
4.1.2, 4.1.3	SS3	1	Immediate	Develop toxin triggers to assess risk of impacts of FHABs to tribal & cultural uses and subsistence fishing
7.1	SS4	1	Immediate	Determine user needs for FHAB decision support systems
7.1	SS5	1	Immediate	Develop partner program open data systems
3.2.4	SS6	1	Long term	Develop partner program elements for additional beneficial uses
3.1.3	SS7	2	Immediate	Add available satellite derived FHAB response and driver metrics
3.1.3	SS8	2	Immediate	Develop standardized analytical metrics for imagery data
3.1.3	SS9	2	Immediate	Develop QA documentation on remotely sensed data products
3.1.3	SS10	2	Immediate	Develop CIcyano field verification protocols
3.1.3, 4.1-4.2, 5.3.1	SS11	2	Immediate	Develop remotely sensed chlorophyll triggers
3.1.3	SS12	2	Near term	Develop a routine workflow to use satellite imagery data in reports and listing decisions
4.2.1, 5.3.1	SS13	2	Immediate	Conduct a pilot project to use Sentinel-2 data in a regional or statewide status and trends assessment
4.2.2	SS14	3	Immediate	Create the design for a state-led recreational use survey
4.2.2	SS15	3	Immediate	Assess FHAB impacts on enclosed beaches in partnership with BSMP (AB 411)
4.2.2	SS16	3	Immediate	Develop a standardized cyanotoxin tissue analysis protocol
4.2.2	SS17	3	Immediate	Conduct a pilot project to routinely monitor shellfish cyanotoxins in coastal zones
4.2.2	SS18	3	Immediate	Assess toxin bioaccumulation and depuration rates in recreational fish in California lake and rivers
4.1.4	SS19	4	Immediate	Develop FHAB species condition indices in wadable stream
4.1.4, 4.15	SS20	4	Immediate	Develop FHAB species condition indices in lakes and reservoirs
4.1.4, 4.15	SS21	4	Immediate	Develop FHAB species condition indices in estuaries
4.2.2	SS22	4	Immediate	Improve quantitative measure of algal abundance and extend protocols to assess lentic systems
4.1.4, 4.1.5	SS23	4	Immediate	Develop standardized molecular methods for FHAB monitoring
7.3	SS24	4	Immediate	Build the capacity to conduct landscape FHAB screening assessments
5.2.3	SS25	4	Immediate	Review SWAMP protocols for adequacy in measuring internal FHAB drivers
3.1.3	SS26	Partner	N/A	Pilot use of drone imagery for FHAB ambient monitoring
4.1.4	SS27	Partner	N/A	Develop assessment thresholds for cyanotoxin impacts on aquatic life
4.1.4, 5.3.1	SS28	Partner	N/A	Determine the feasibility of sediment cyanotoxin surveys for assessment of FHAB trends and drivers
5.2.4, 5.3.1	SS29	Partner	N/A	Develop ambient monitoring approach to assess climate change impact
5.3.1	SS30	Partner	N/A	Sediment core analysis of historical phytoplankton community shifts
4.1.1	SS31	Partner	N/A	Quantify the socio-economic and cultural impacts of FHABs
4.1	SS32	Partner	N/A	Improved toxin triggers for benthic mats, chronic toxin exposure and exposure to multiple toxins
5.2	SS33	Partner	N/A	Interactions between surface water FHABs and groundwater

SS1: Proactively identify HAB partners, focusing on tribes, communities of color and economically disadvantaged groups.

HAB impacts are felt disproportionately by tribes and communities of color. FHAB impacts compound other adverse conditions common in economically disadvantaged communities such as limited access to recreational opportunities, clean water, health care and affordable and safe housing. These impacts will accelerate with climate change.

SS2: Develop a recreational HAB assessment based on visual indicators

Currently, there is not a readily interpretable metric for interpreting data related to community composition and visual indicators, particularly to members of the public. The partner program is designed to have multiple visually based indicators (e.g., community composition via microscopy, visual scum assessment), and Tier 1 groups will primarily be collecting visual indicator data although these data are not currently actionable in the same way as cyanotoxin data. To make these data more easily interpretable and actionable, these observations could be summarized as a single recreational HAB index that could be interpreted like the caution, warning and danger triggers used for cyanotoxins. This HAB risk index could be used for locations where only observational indicators are collected by voluntary groups. The development of this index would need to be developed as a special study. This index could be developed by the collection of co-located visual, community and cyanotoxin measurements and then establishing tipping points where the probability of exceeding toxin triggers is elevated. Many observations across a gradient of environments will be needed so assembly of a suitable database to establish a risk index may take many years. Concerted efforts to collect these data should begin in the immediate future to move towards the development of this index.

Abundances of algae or cyanobacteria that reduce aesthetics are an indicator of recreational use impairment; the TAC noted that while the precedent exists for their use as TMDL targets, thresholds for aesthetic impacts are not routinely used for 303(d) listing. A special study is needed to synthesize the basis for REC2 triggers for lakes, streams and rivers and coastal confluences.

SS3: Develop cyanotoxin triggers appropriate to assess risk of impacts of FHABs to tribal, cultural uses, and tribal subsistence fishing

Tribal and cultural activities and subsistence fishing activities can involve multiple routes of exposure, often a tradition will involve one or more route of exposure. Exposure pathways can involve direct ingestion of water or ingestion of particles, aerosols from the ingestion or handling of plants, and/or consumption of contaminated food items. These types of exposure are unique from recreational exposure and require special consideration. Guidelines used for recreational exposure may not be sufficiently protective of Tribal uses since the assumption underpinning exposure frequency and severity do not account for tribal uses. Special studies are needed to determine how these additional exposures may negatively impact tribal members and determine if guidelines specific to tribal and cultural water uses should be developed.

Similarly, consumption guidelines developed by OEHHA may not be suitable for evaluation of tribal subsistence due to higher consumption rates. These thresholds should be carefully evaluated and determine if alternative assessment guidelines should be considered that take more relevant exposure scenarios into account. In particular, a consumption rate, or range of consumption rates, that is more representative of a tribal subsistence rates should be established and compared to consumption rates used in the development of the current OEHHA guidelines. This exercise should be conducted in close collaboration with the tribes in California to ensure relevant rates are determined. Depending on these findings of this initial effort, additional guidelines specific to tribal subsistence uses should be developed.

SS4: Develop partner program open data systems

The success of the partner program will depend on effective data management, dissemination, and visualization, as partners who contribute their data will want rapid accessibility and relevant visualizations to analyze FHABs conditions in their watershed or region. Specific effort is required to create data management and visualization infrastructure, including means for partners to visualize their data. Water Boards staff need to develop a vision and workplan that scales with level of investment and size of the partner program. Open data systems should be prioritized and specific protocols for data management, and data visualization/reporting need to be developed. SS4 is also relevant for Recommendation 6.

SS5: Determine user needs for FHAB decision support systems

Develop the vision, including key data sources, data visualizations and GUI interface functionality, for each type of decision support, through interactions with intended user groups (targeted FHAB monitoring program partners). Outreach and focus groups should be held with intended user groups to determine the specific needs and priorities of each group. Based on the interactions, the specific vision for each type of decision support tool should be clearly defined and a work plan should be created to support the development of each tool. SS5 is also relevant for Recommendation 6.

Recommendation 1 Long Term

SS6: Develop partner program implementation components for additional beneficial uses

Recreational health was identified as an immediate priority for the initial development of the FHAB partner monitoring program, but other beneficial uses were identified by the TAC as a longer-term priority. To support these goals, the development of FHAB monitoring protocols for other core beneficial uses and environmental drivers will need to be specifically developed. In the long-term, the FHAB partner program is envisioned to expand to assess the status and trends of FHABs for additional beneficial uses beyond recreational uses and incorporate FHAB environmental drivers. Assessment tools (e.g., thresholds and/or guidance levels) for other beneficial uses, in particular for fishable and aquatic life, are currently less well-developed but specific SOPs and training modules should be developed as more risk indicators and thresholds are developed for additional beneficial uses.

Recommendation 2 Immediate

SS7: Add available satellite derived FHAB response and driver metrics

Remotely sensed chlorophyll-a concentration and water clarity are readily available from current Sentinel-3 imagery products. These data are useful for the assessment of FHABs and data including CI_noncyano and Chl-a from OLCI should be added to the current database and increase accessibility of data to the public. Specific effort should be made to collaborate with NOAA to add these indicators to the California data workflows and any additional data on drivers (e.g., temperature). Data management and storage infrastructure will need to be updated accordingly to accommodate these data. Additionally, these data should be integrated into concurrent efforts to standardize analytical methods (SS8), guidance for data use in management applications (SS9) and in the development of SOPs for field verification (SS10).

SS8: Develop standardized analytical metrics for imagery data

In recent years, methods have been published to calculate key satellite remote sensing assessment metrics to describe frequency, extent, and magnitude of blooms. A special study could be conducted to review and further customize these analytical metrics for application in California. These metrics could serve management information needs to integrate satellite data into reports, including comparison of an individual lake against others in the region or state. To increase the ease of use, guidance documentation should provide products such as an R package or code that could be readily adopted into assessment workflows.

SS9: Develop QA documentation for remotely sensed data products

Satellite imagery is largely underused in management applications. One key hurdle is the lack of relevant documentation on the quality and uncertainty of these data products. To increase and promote the use of satellite imagery data in management decisions, such as use as a supporting line of evidence in 303(d) listing decisions, these documents need to be developed. Specifically, a quality assurance project plan (or equivalent) should be developed that includes analysis methods, data management and validation, quality assurance controls, the uncertainty associated with imagery products and best practices for data product use need to be developed. A synthesis of current understanding of the uncertainty of CIcyano values and other satellite imagery products should also be included in this document.

SS10: Develop CIcyano field verification protocols

Ongoing field verification of satellite imagery products in California waterbodies is a priority. However, these data are best collected in collaboration with other academic and research partners. Therefore, a specific strategy, SOP, and data management system for satellite field verification should be developed, so that external partners can help participate in collecting data and submit it to a common database. These efforts are envisioned to continue to ground-truth satellite data, improve the CA-specific algorithm and overall data quality characterization. These efforts should be conducted in close collaboration with expert workgroup and the strategy and subsequent SOP should be published and widely distributed among partners in the state.

SS11: Develop remotely sensed chlorophyll-a thresholds

To improve utility of remotely sensed data for management decisions, thresholds should be defined that link satellite data (CIcyano and chlorophyll-a) to risk of exceeding thresholds of *in situ* pigment data (chlorophyll-a and phycocyanin) that impair beneficial uses. The infrastructure to conduct this data match up process is readily available since in recent years, approaches have been developed to streamline matching co-located *in situ* measurements with satellite observations (Ross et al. 2019), making this an accessible approach. As additional in-situ data are developed this relationship can be refined over time.

SS12: Develop a routine workflow to use satellite imagery data in reports and listing decisions

Using the routine workflows developed in SS8, a status and trends report should be generated for Sentinel-3 OLCI derived CIcyano and chlorophyll-a products in large lakes (>160 ha), as this data are currently the most temporally and spatially resolved data on FHAB events in the state. California can look to other states that have already begun incorporating this information into their decisions for examples of approaches. The remote sensing working group recommended that an annual report on the status, trends of CIcyano index values and chlorophyll-a be derived. It is recommended that these analyses be streamlined for use in an annual report that is citable by water quality managers and that specific guidance be developed for use of these data in listing decisions.

Recommendation 2 Near Term

SS13: Conduct a pilot project to use Sentinel-2 data in a regional or statewide status and trends assessment

The TAC recommended a special study to pilot the use of Sentinel-2 for status and trends, which has higher resolution, and therefore could extend the majority of the California's 14,000 lakes and reservoirs (> 1 ha). SFEI has already begun work to pilot the use of these higher resolution data. If these efforts are fruitful, the study could be expanded to include environmental drivers as well. This study should also assess the infrastructure that would need to be developed to incorporate Sentinel-2 data into routinely available FHAB satellite imagery and decision support given the large amount of data that would need to be managed for the State. If long term adoption of Sentinel-2 data are determined to be feasible, the specific data infrastructure, analytical metrics, and data visualization for processing Sentinel-2 data should be documented and a work plan should be developed to support implementation.

Recommendation 3 Immediate

SS14: Create the design for a state-led recreational use survey

Recreational use monitoring is a clear priority of the FHABs program in the immediate future. As multiple efforts are implemented to determine the status and trends of FHABs on recreation, the Water Boards have prioritized partnerships wherever possible. However, a state-led component will need to be integrated to fill in data gaps that are not readily filled by any partner data. The details of this approach need to be guided by Water Boards management priorities. The Water Boards partnership priorities and approaches should be decided and the spatial and temporal design elements of recreational use survey for state-led efforts should be defined in a monitoring plan. Among these considerations, the current FHAB pre-holiday assessment could be considered as part of the field-survey and the feasibility of supporting an expansion/enhancement this effort should be determined in light of the overall Water Boards priorities. In order to complete the design, a comprehensive inventory of recreational use sites at waterbodies across the state is needed. FHAB monitoring program partners (Regional Boards, tribes, county and municipal governments) would need to collaborate to create a comprehensive inventory (e.g., tables and GIS layers following Open Data principles) of recreational use locations across the state.

SS15: Assess FHAB impacts on enclosed beaches in partnership with BSMP (AB 411)

A special study could be conducted at enclosed beaches with "C" grades or lower to assess the summertime FHAB health risks to beachgoers. This effort should include specific consideration of the viability, long-term utility and sustainability of leveraging BSMP (AB 411) program efforts to monitor enclosed beaches at coastal confluences through the addition of specific FHAB indicators to the ongoing sampling efforts.

SS16: Develop a standardized cyanotoxin tissue analysis protocol

Currently there are no standardized cyanotoxin tissue analysis methods. The Water Boards prioritized multiple assessments of cyanotoxins in fish and shellfish tissue, therefore, a standardized approach(es) should be defined to support these efforts. Currently, a NOAA MERHAB grant awarded to Chris Gobler at SUNY-Stony Brook and Raphael Kudela at UCSC is supporting the development of standardized approaches for the analysis of microcystins in shellfish tissues. Upon completion, this standardized protocol should be considered for adoption by SWAMP for use by the FHAB monitoring program. This protocol should be accompanied by standardized data transfer formats for upload to statewide databases (e.g., CEDEN), plus appropriate training modules to ensure consistent implementation. Additional study may be warranted to determine if this shellfish method is suitable for other tissue types such as fish, and if necessary, an additional analysis method for fish tissue should be developed and adopted.

SS17: Conduct a pilot project to routinely monitor shellfish cyanotoxins in coastal zones

A special study was prioritized to determine the utility and cost-effectiveness of a formal partnership with CDPH to monitor shellfish for cyanotoxins. The Water Boards and CDPH should collaborate to conduct additional toxin analyses on shellfish collected as a part of CDPH's longstanding biotoxins program. The Water Boards could fund the additional cyanotoxin analyses at specific sites of concern. This effort should evaluate the viability, long-term utility and sustainability of developing a longer lasting partnership based on the pilot data.

Another component of this study could examine whether the existing recommended precautions for fish and shellfish consumption based on visual indicators and cyanotoxins in water and existing marine shellfish advisories/quarantines are sufficient to address any occurrence of elevated fish/shellfish tissue concentrations in edible tissues. Some states incorporate a time period after visual indicators or water cyanotoxin concentrations are below thresholds before fish/shellfish consumption is recommended. If appropriate, these recommendations based on visual indicators or water cyanotoxin concentrations would reduce the costs and efforts (compared to additional fish/shellfish tissue collection and analysis) by focusing on existing sampling for which standardized sampling and analytical methods, existing thresholds, and timely communication avenues are currently available.

SS18: Assess toxin bioaccumulation and depuration rates in sports and recreational fish in California lake and rivers

The impacts of FHABs on fishable (recreational and subsistence) uses are largely under characterized, but these impacts should be assessed to determine the need for widespread monitoring of fish and shellfish tissues, since the collection and analysis of these samples is labor and resource intensive. Several studies have shown the contamination of fish tissues with cyanotoxins, this literature should be synthesized to summarize the current understanding of the prevalence of cyanotoxins in tissues, as well as the bioaccumulation and depuration rates for species caught through subsistence and recreational fishing in lakes and reservoirs, streams and rivers. This is key information for developing effective monitoring approaches (e.g., making decisions on indicator species and temporal and spatial design considerations). Additional effort could be made to conduct A pilot project during a single year that collects fish in ~3-5 lakes with chronic HAB problems to identify the species most likely to exhibit FHAB toxins to supplement the currently published data.

As an add on to this special study, it would be helpful to consider if those current advisories (recommend against shellfish and fish viscera consumption at the caution level, recommend against fish filet consumption with danger level) cover the conditions under which any fish/shellfish tissue exceedances were observed. Similarly, an annual statewide quarantine on sport-harvested mussels (from May 1 through October 31) may also reduce potential exposure to cyanotoxins and this could be incorporated into this special study.

Recommendation 4 Immediate

SS19-21: Develop FHAB species condition indices in wadable streams, lakes and reservoirs, and estuaries

Molecular FHAB assessments can be immediately added to the wadable bioassessment program. To support the interpretation of molecular community composition data, an FHAB ASCI (algal stream condition index) could be developed that specifically reports out on the diversity and relative abundance of FHAB species relative to references; we recommend that this be considered under a special study. Index development could be conducted through the analysis of existing molecular barcoding data from the bioassessment program, with additional data being added as continued observations are conducted.

As molecular based FHAB assessments increase in lakes, reservoirs and estuaries, an equivalent FHAB ASCI for each waterbody type can be developed. Compared to streams, considerably less molecular barcoding data are currently available in these systems, but collection of this data should be prioritized where possible in waterbody assessment and monitoring programs to support the development of these indices. Assembly of a suitable database to establish each index may take many years, therefore efforts to collect these data should begin in the immediate future to move towards index development.

SS22: Adapt existing algal bioassessment protocols to improve quantitative measure of abundance and extend protocols to assess lentic systems

Current stream monitoring methods in California are optimized for bioassessment and the existing method to assess algal abundance is semi-quantitative. A special study is needed improve existing algal bioassessment measures to better align with FHAB needs. Protocols should be expanded to include methods to assess benthic and pelagic assessments of lentic habitats such as lakes and reservoirs. Specific element that would need to be developed/adapted include field sampling SOPs (which can leverage similar programs like the NLA program run by the U.S. EPA), data management infrastructure and training modules to conduct lake bioassessments, focusing first on algal indicators (abundance, algal community composition via molecular barcoding) and toxin measures.

SS23: Develop standardized molecular methods for FHAB monitoring

Molecular barcoding and qPCR approaches to assess abundance are under development by various research labs within California and some molecular approaches for molecular barcoding of algae have been adopted by the bioassessment program. As molecular approaches become more commonplace in monitoring programs, the comparability of data across programs is vital. Standardized protocols should be adopted to minimize the variation introduced by the use of multiple approaches. Protocols and characterization of benthic and planktonic blooms are needed. A specific bioinformatics pipeline and database would need to be developed that covers the diversity of California waterbodies and is widely shared with diverse users. A special study is needed to catalogue the current usage of these approaches in the state and to specifically develop protocols capabilities to routinely integrate these approaches into monitoring programs to assess and report out on abundances all waterbody types.

SS24 Build the capacity to conduct landscape FHAB screening assessments.

Specific work should be conducted to develop predictive FHAB response models for lakes and reservoirs (remote sensing and field data-based) and in wadeable streams. See workplan for incremental effort underway (Appendix III)

SS25 Review SWAMP protocols for adequacy in measuring internal FHAB drivers

SWAMP protocols exist for many of internal drivers (Table 2.4). These SOPs should be reviewed and revised as needed to improve their efficacy to measure FHAB internal drivers.

Recommended for Partner Funding

Eight special studies are designated as high priority for collaborative research and partner funding, either through federal or state funding vehicles. This is considered an incomplete list of what could be done to further support the FHAB monitoring program.

SS26: Pilot use of drone imagery for FHAB ambient monitoring

A special study could be conducted to explore the feasibility of generating routine drone imagery of waterbodies to assess FHAB extent and magnitude. This application could be particularly useful if generated through a volunteer program; however, it would require SOPs and a training component to assure sufficient data quality to be useful.

SS27: Develop assessment thresholds for cyanotoxin impacts on aquatic life

This special study would consist of a comprehensive review of literature to evaluate the basis for thresholds or triggers of cyanotoxin impacts on aquatic life and identify core data gaps. Current work towards this goal are underway at SCCWRP and will be shared with the FHABs program for consideration in future programmatic expansions.

SS28: Determine the feasibility of sediment cyanotoxin surveys for assessment of FHAB trends and drivers

The TAC specifically discussed the question of what sediment toxin measures represent, whether that be an integration toxin accumulated over time of degraded planktonic FHAB bloom or benthic FHAB sources. There is conflicting evidence about the residence time of cyanotoxins in the sediments following blooms. Some work suggest cyanotoxins might be rapidly degraded, while other studies suggest that some classes of cyanotoxins can persist in sediments for many months. Ultimately, a special study would need to be conducted to address these questions to determine the feasibility of this study design for statewide implementation. Additionally, sediment collection and toxin extraction protocols exist but have not been adopted by SWAMP.

SS29: Develop ambient monitoring approach to assess climate change impact

Specific design approaches are needed to address climate change impacts on FHABs (see Burford et al. 2020 for comprehensive review), many of which can be considered research special studies. However, California's FHAB monitoring programs can help to answer to answer a key management question: "What is the contribution of global versus local anthropogenic activities on FHAB status, trends and drivers?" An appropriate design to answer this question would be to assess the status and trends in FHAB at minimally disturbed reference waterbodies throughout the state, by ecoregion and waterbody type. The design for this type of FHAB monitoring program component should be specifically developed through a special study.

SS30: Sediment core analysis of historical phytoplankton community shifts

The TAC suggested that a special study might look at changes in lake sediment cores to identify how the phytoplankton composition in general and the dominance of cyanobacteria in particular has changed over time. This could be done at a subset of lakes around the state, with strata reflecting key differences in catchment land use (ag, timber, urban) as well as potential influence of atmospheric deposition of nitrogen and acidifying constituents.

SS31 Quantify the socio-economic and cultural impacts of FHABs

FHABs are already having important impacts on California's economy and communities, the value and extent of which has not been systematically quantified and represent a critical knowledge gap. Considering the many beneficial uses of freshwater ecosystems, the societal impacts of FHABS can be severe, including: impacts to public health (Backer and Moore 2010), commercial fisheries and aquaculture, recreation and tourism, home values and commercial real estate (Bingham et al. 2016), and disruption to social and cultural practices, with economic losses and social impacts to both individual and community (Dodds et al. 2009; Dyson and Huppert 2010; Sanseverino et al. 2016; Willis et al. 2018).

In their evaluation of the socioeconomic impacts of the 2015 US West Coast domoic acid event, Moore et al. 2020) stated some fundamentals that are also broadly applicable to inland FHABs:

> *Our knowledge of how human societies cope with HABs is extremely limited. In part this is due to poor characterization of the socioeconomic impacts of HABs (Bauer et al.2010). ..[Even when HAB socioeconomic impacts have been conducted]…they cannot adequately identify interactions across sectors or the pathways of how losses in one sector can permeate communities to impact other sectors (Ritzman et al. 2018). These assessments are also typically conducted with little or no regard to thresholds that would render some businesses nonviable without external support, or to the underlying social vulnerabilities of communities or populations within them that could result in disproportionate impact.*
>
> *Social impact assessments of HABs and HAB management strategies are almost nonexistent (Ekstrom et al. 2020), even though HABs cause severe social and cultural disruption for individuals, families, tribes, occupational groups, recreational groups, and geographic communities.*
>
> *Our incomplete understanding of the socioeconomic impacts of HABs, and of communities' abilities to respond to them, has limited the development of adaptation strategies to help communities build resilience to future events. This knowledge gap likely also contributes to the inability of communities to create their own individualized action plans.*

The impacts of FHABs may be felt disproportionately by tribes and communities of color. FHAB impacts may compound other adverse conditions common in economically disadvantaged communities including limited access to recreational opportunities and clean water. Insufficient monitoring in low resource communities may create added risk to these communities. At minimum, several special studies are needed to quantify the socio-economic and cultural impacts of FHABs in California and to identify the key indicators and metrics to measure and track these impacts.

SS32 Improved toxin triggers for benthic mats, chronic toxin exposure, and exposure to multiple toxins

The CCHAB Network currently has recreational cyanotoxin trigger levels for water samples meant to be protective of human health, however these guidelines do not currently specifically address benthic mats, chronic exposure to cyanotoxins or exposures to multiple toxins. Guidance levels for these scenarios are important for recreational health monitoring and studies by partners to help inform protective and implement triggers for these issues would be valuable. OEHHA published mat cyanotoxin action levels based on milligrams toxin per kilogram dry weight of mat mass. This work could provide the foundation for toxin triggers for mat samples along with the development of SOPs for how to collect mat samples and associated samples (e.g., AFDM) to apply the OEHHA action levels. The effects of chronic exposure and multiple exposures to cyanotoxins is an area of active research and the impacts are not well understood. Partner research on these topics that can help inform the development of guidance on these types of exposure.

SS33 Interactions between surface water FHABs and groundwater

Little is known about the interactions between FHABs in surface water and groundwater. Studies have demonstrated that groundwater can be a source of nutrients into surface waters, potentially enhancing bloom activity. However, very little is known about how FHABs in surface waters may interact with groundwater. In particular, it is poorly understood if cyanotoxins contaminate groundwater, the persistence of cyanotoxins in groundwater, and if the concentrations of cyanotoxins in groundwater might cause harmful impact on human or ecosystem health. Partner research exploring the interactions between surface water FHAB events and groundwater can help inform the potential risks associated with these interactions and determine potential mitigation and management actions that should be taken.

APPENDIX 7. DOCUMENTATION OF SAMPLE COLLECTION AND ANALYSIS COSTS FOR FHAB MONITORING

This appendix provides cost information from other SWAMP monitoring programs to help estimate the costs of collecting and analyzing samples for an FHAB Monitoring program (Recommendations 1 and 3 in Chapter 8). This appendix does not include costs for report writing, data analysis, data infrastructure, and some other miscellaneous costs that may need to be considered for FHAB monitoring.

The cost of FHABs monitoring can be divided into several categories: laboratory analyses, equipment, supplies, travel, shipping, and staffing. For the BOG and PSA monitoring programs, the costs of staff salary, equipment, supplies, travel, and shipping are combined into the fieldwork costs per site. A list of the fieldwork costs for these monitoring programs is given in Table A7.1. Laboratory costs for BOG and PSA are given in Table A7.2, and laboratory costs for FHAB Incident Response are given in Table A7.3. Additional cost scenarios can be explored at https://sccwrp.shinyapps.io/CA_FHAB_monitoring_cost/.

Table A7.1. Field work costs for the SWAMP Bioassessment and Bioaccumulation Oversight Group (BOG) monitoring programs from the Water Boards contract with San Jose State University Research Foundation (Agreement 20-006-270), June 2020.

FIELD WORK*	Cost/Site Price**
Bioassessment site collection-field work only (non-random, directed targeted sites)	$2,396.00
Bioassessment site collection-field work only (random, probabilistic)—Initial site screening conducted by funding entity***	$3,700.00
Bioassessment site collection-field work only (random, probabilistic)—Initial site screening conducted by sampling agency***	$4,600.00
Bioassessment field duplicate site collection	$480.00
Bioassessment site repeat site collection	$2,396.00
CRAM field work only (non-random or random - Bioassessment add on)	$1,928.00
Collect sed and-or water samples (Bioassessment add on)	$1,040.00
Field QA duplicate collection for sediment and/or water samples - bioassessment	$520.00
Collect without toxicity (Non-random, directed sites, w/ boat) - chemistry	$2300.00
Bagged bivalve bioaccumulation collection (SMW style)	$7,000.00
Native bivalve bioaccumulation collection	$4,000.00
Fish collected Lake/Reservoir (BOG style)-small	$7,925.00
Fish collected Lake/Reservoir (BOG style)-medium	$8,425.00
Fish collected Lake/Reservoir (BOG style)-large	$9,125.00
Fish collected Lake/Reservoir (BOG style)-extra large	$10,200.00
Fish collected within marine-estuarine (BOG style)	$13,200.00
Inter waterbody decon (with boat) - miscellaneous	$375.00
Inter waterbody decon (without boat) - miscellaneous	$150.00
*Cost Per Unit Pricing: All field sampling/pricing is based on techniques described in the Surface Water Ambient Monitoring Program (SWAMP) Quality Assurance Project Plan (QAPP). ** Cost per sample and cost per site rates shall be set for all three (3) Fiscal Years (FYs) of the contract. All prices shown are inclusive of all Contractor's costs, and include personnel and fringe costs, travel, any equipment, materials/ supplies, operating costs, indirect costs, incidental project related costs, and taxes.	

The fieldwork costs will need to be adapted from the BOG and PSA programs. Shoreline sampling for cyanotoxins would be faster and less involved than either BOG or PSA sampling and would require less funding per site. Collecting samples from a boat and adding additional indicators (e.g., water quality indicators such as nitrogen and phosphorus) would increase fieldwork costs for FHAB monitoring.

For the cost estimates in **Example of cost estimate for two monitoring scenarios** in the Executive Synthesis, we estimated $1,000 and $300 for shoreline and boat-access fieldwork cost for the first site on a waterbody. Each additional site on a waterbody is then an additional 30% cost ($300 and $900, respectively). More accurate fieldwork costs will be estimated as funding is secured for FHAB monitoring.

Table A7.2. Laboratory costs for the SWAMP Bioassessment and Bioaccumulation Oversight Group (BOG) monitoring programs from the Water Boards contract with San Jose State University Research Foundation (Agreement 20-006-270), June 2020.

LABORATORY ANALYSIS*	Cost/Sample Price**
Alkalinity - water	$75.00
Ammonia - water	$75.00
Chlorophyll a - mid range (syringe-filtered) - water	$110.00
Nitrate + Nitrate (NO3/NO2) N, filtered - water	$75.00
Nitrite N, filtered - water	$75.00
Ortho-Phosphate as P, filtered - water	$75.00
Organic Carbon, total - water	$75.00
Organic Carbon, filtered - water	$75.00
Salts suite, total - water	$175.00
Salts suite, filtered - water	$175.00
Silica, filtered - water	$75.00
Suspended Sediment Concentration SSC - water	$80.00
Total Dissolved Solids TDS - water	$90.00
Total Suspended Solids TSS - water	$70.00
Volatile Suspended Solids VSS - water	$75.00
Ash Free Dry Mass (AFDM) - benthic	$110.00
Chlorophyll a - benthic	$135.00
Archive preparation - tissue	$8.00
Composite Preparation (homogenization) - tissue	$130.00
Loss on Ignition (LOI) - sediment	$75.00
Analyses to be determined; price agreed upon prior to receipt by lab- sediment	$450.00
Archive preparation - tissue	$8.00
Composite Preparation (homogenization) - tissue	$130.00
Loss on Ignition (LOI) - sediment	$75.00
Analyses to be determined; price agreed upon prior to receipt by lab- sediment	$450.00

*Cost Per Unit Pricing: All field sampling/pricing is based on techniques described in the Surface Water Ambient Monitoring Program (SWAMP) Quality Assurance Project Plan (QAPP).
** Cost per sample and cost per site rates shall be set for all three (3) Fiscal Years (FYs) of the contract.
All prices shown are inclusive of all Contractor's costs, and include personnel and fringe costs, travel, any equipment, materials/ supplies, operating costs, indirect costs, incidental project related costs, and taxes.

Table A7.3. Cyanotoxin costs from SWAMP FHAB Program through contract with Bend Genetics (Agreement 19-001-270), March 2019.

Service	Cost per sample
Microscopic identification of dominant Cyanobacteria	$40
Cell enumeration (total PTOX cyanobacteria)	$225
qPCR[1] preparation	$36
qPCR microcystin	$50
qPCR anatoxin	$50
qPCR saxitoxin	$50
qPCR cylindrospermopsin	$50
qPCR golden algae	$50
ELISA[2] microcystin/nodularin	$125
ELISA anatoxin	$150
ELISA saxitoxin	$150
ELISA cylindrospermopsin	$150
ELISA 4 Toxin suite (MCY, ATX, STX, CYL)	$513
SPATT[3] Bags (10 bags)	$150
SPATT microcystin	$175
SPATT anatoxin	$200
SPATT saxitoxin	$200
SPATT cylindrospermopsin	$200
Tissue microcystin/nodularin ELISA or LC-MS/MS[4]	$210
Tissue anatoxin ELISA or LC-MS/MS	$210
Tissue saxitoxin ELISA or LC-MS/MS	$210
Tissue cylindrospermopsin ELISA or LC-MS/MS	$210
Chlorophyll-a	$50
Phycocyanin	$50

[1]qPCR: quantitative polymerase chain reaction
[2]ELISA: enzyme-linked immunosorbent assay
[3]SPATT: solid phase adsorption toxin tracker
[4]LC-MS/MS: liquid-chromatography tandem mass spectrometry