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California Freshwater Harmful Algal Blooms Assessment and Support Strategy

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California Freshwater Harmful Algal Blooms Assessment and Support Strategy

California State Water Resources Control Board

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I. Executive Summary

Harmful algal blooms (HABs) and algal toxins have increased globally in geographic range, frequency, duration, and severity in recent years. These increases have been attributed to various anthropogenic factors; the most significant include climate change, nutrient loading, and water residence time. HABs are problematic because they can affect multiple beneficial uses including recreation, aquatic life, and drinking water by reducing aesthetics, lowering dissolved oxygen concentration, causing taste and odor problems, and producing potent toxins. In recent years, cyanobacteria blooms and their associated toxins have gained national attention due to the severity of issues in the Midwest, and resulted in the release of health advisory values for drinking water by U.S. Environmental Protection Agency.

In California, toxic HABs caused by cyanobacteria (CyanoHABs) have been a recurring and escalating issue throughout the state, particularly in the Klamath River watershed, Clear Lake, Pinto Lake, Sacramento and San Joaquin River Delta, Lake Elsinore, and East San Francisco Bay Area lakes. Additionally, Copco and Iron Gate Reservoirs, the Klamath River, and Pinto Lake were placed on the State's 303d list due to impairment caused by cyanotoxins. In 2012, the State's Surface Water Ambient Monitoring Program (SWAMP) sponsored a statewide workshop in response to the growing concern about cyanotoxins. One of the key recommendations from the workshop was to develop a statewide long-term vision and strategic plan to address CyanoHABs and other freshwater HABs.

The goal of the California Freshwater HAB Assessment and Support Strategy is to articulate a coordinated and widely supported long-term program to assess, communicate, and manage CyanoHABs, cyanotoxins, and other nuisance freshwater HABs. The Assessment and Support Strategy framework has 3 components: (1) response to HAB events; (2) field assessment and ambient monitoring programs; and (3) risk assessment for potential HAB events. There are several components of infrastructure needed in order to support and implement this Strategy:

- *Satellite imagery* to identify and track cyanobacteria blooms
- *Centralized website and reporting system* to provide data management, visualization, and reporting capabilities
- *Guidance documents* on event response and management strategies
- *Laboratory resources* to support local event response
- *Training* on HAB characteristics and use of guidance documents
- *Applied research and tool development*
- *Outreach* aimed at providing educational materials to policymakers, health care professionals, veterinarians, and the public

SWAMP will provide funding towards the first five components of this infrastructure. USEPA has and will continue to provide significant laboratory resources for bloom response.

Satellite imagery will be used for (1) notifying waterbody managers of blooms detected in their waterbody, (2) a biweekly (during bloom season) bulletin and quarterly newsletter,

(3) an historical analysis of trends in large waterbodies, (4) reporting status of blooms on the website, and (5) informing status and trends monitoring.

A publicly available, centralized website is under development with the capacity for (1) database management and storage, (2) data access (downloadable), (3) data visualization, and (4) centralized information exchange for both reporting a bloom and notifying a wide audience of a bloom advisory or HAB event.

Guidance documents are an integral component of the infrastructure needed to support assessment and monitoring of HAB events. There will be three event response guidance documents to describe actions to employ during a HAB event, and provide a consistent set of procedures for water resource managers to follow including sampling, health and safety, and performance based quality assurance criteria.

The California Cyanobacteria Harmful Algal Bloom (CCHAB) Network, a multi-agency workgroup with representatives from state, local, and federal agencies, tribes, and the regulated, academic, and nonprofit communities, is developing waterbody posting and public notification, and toxin thresholds to update the 2010 Draft Voluntary Guidance. A summary of the updated Voluntary Guidance will be included in the event response guidance.

A comprehensive training program is being developed that focuses on all aspects of the guidance documents and is aimed at water resource managers, regulators, and agencies that conduct field sample collection and laboratory analysis.

Applied research is necessary to advance the technological development of methods related to satellite imagery analysis, toxin detection and analysis, automated optical identification of taxa, and mitigation and remediation.

The Outreach component, once funded, should be aimed at citizens, policymakers, health care providers and veterinarians, and public agencies (such as city municipalities, county health agencies). There is a critical need to increase public awareness of HABs including increasing recognition, public safety, and timely reporting of HABs, or associated events. There is also a need to develop a network of agency staff, waterbody managers, tribes and environmental health departments, and associated protocols for communication and coordination when cyanobacteria blooms occur.

Although SWAMP has funded much of the infrastructure of the Assessment and Support Strategy, there are still components that will need to be performed by other agencies and groups. HABs and associated toxins relate directly to the missions of a wide range of agencies in California; therefore identification of the mission and role of each agency, and coordination of these various agencies will lead to efficient use of all resources directed at HAB monitoring and mitigation throughout California. The purpose of this document is not to assign tasks, but to develop a framework for discussion by the involved agencies and the CCHAB Network so this strategy can be coordinated and implemented.

II. Introduction

A. Freshwater Harmful Algal Blooms in the Environment

Under certain environmental conditions in freshwater systems, single celled bacteria, called "cyanobacteria", can increase rapidly in biomass resulting in a "harmful algal bloom" (HAB), which in some cases can produce toxins. HABs can have negative impacts on the environment and raise serious concerns for drinking water sources, recreational use, pets, wildlife, and livestock. Additional information on harmful algae in the freshwater environment can be found in Appendix A. In recent years, harmful algae blooms from cyanobacteria (CyanoHABs), and associated cyanotoxins, have gained national attention due to increases in the frequency and severity of blooms, and their impacts on drinking water sources.

There are several well-documented problem areas in California that have been monitored through either assessment studies or water quality monitoring programs. Some of the areas with recurrent toxic cyanobacteria blooms include the Klamath River watershed (including Copco and Iron Gate Reservoirs), Clear Lake, Pinto Lake, lower Sacramento and San Joaquin Rivers and Delta, Lake Elsinore and several East San Francisco Bay Area lakes. The Klamath River and Pinto Lake have been placed on the State's 303d list due to impairment caused by cyanotoxins. More details on several of these programs are found in Appendix B.

More recently, cyanobacteria and cyanotoxin data have been collected opportunistically through several programs. These data indicate that cyanobacteria are prevalent throughout California in all types of waterbodies sampled (lakes, rivers, streams, wetlands, estuaries and coastal). Recent statewide assessment surveys of wadeable streams found that benthic cyanobacteria and related cyanotoxins are widely present, suggesting that these streams can be a significant cyanotoxin source to receiving waters (Fetscher et al., 2015). In statewide studies conducted from 2007 through 2013, samples were collected from more than 1,200 wadeable stream reaches. Analysis revealed a high occurrence of potentially toxic benthic cyanobacteria taxa, and detection of microcystins in one-third of reaches and 34% of stream kilometers. Detected toxins included lyngbyatoxin, saxitoxins, anatoxin-*a*, and microcystins (Fetscher et al., 2015). Additionally, the State Water Quality Control Board's Surface Water Ambient Monitoring Program (SWAMP) has measured cyanotoxins in sediment at the bottom of major watersheds in a majority of sampling sites.

B. Agency Responses

The California Cyanobacteria Harmful Algal Bloom (CCHAB) Network provides a forum for bringing together agencies, tribes, and organizations. The CCHAB Network was first established in 2006 as the Statewide Blue-Green Algae Work Group, in response to record-setting toxin producing blooms in Klamath River reservoirs. That Work Group, in collaboration with the State Water Resources Control Board (SWRCB), California Department of Public Health (CDPH), and Office of Environmental Health and Hazard Assessment (OEHHA), developed a draft guidance document (*"Cyanobacteria in California Recreational Water Bodies: Providing Voluntary Guidance about Harmful Algal Blooms, Their Monitoring, and Public Notification"*) to provide background information on cyanoHABs, and establish thresholds for posting and lifting advisory warnings for bloom-affected waterbodies. In 2010, the group updated the guidance document and included a decision tree for posting health advisory warnings and recommendations for health advisory warning signs. The 2010 draft guidance document can be found at: http://www.cdph.ca.gov/HealthInfo/environhealth/water/Documents/BGA/BGAdraftvoluntarystatewideguidance-07-09-2010.pdf.

In 2012, the working group was renamed and formalized into the CCHAB Network to coordinate efforts in addressing HABs throughout California. The CCHAB Network has representatives from federal, state, and local agencies, tribes, and the regulated, academic, and nonprofit communities. The CCHAB Network recently became a new Workgroup of the California Water Quality Monitoring Council (Monitoring Council) in order to strengthen ties between water quality programs, and is developing a cyanoHABs web portal for the Council's "My Water Quality" website (http://www.mywaterquality.ca.gov/). CCHAB is currently updating the 2010 draft guidance document.

In 2012, SWAMP sponsored a statewide workshop that included participants from regulatory, state, federal, and local agencies, scientists, resource managers, and non-governmental organizations, as well as several national cyanobacteria experts. The following key recommendations were developed at the workshop (this document fulfills recommendation #1):

1. Develop a long-term vision and strategic plan for statewide coordination to address cyanotoxins.
2. Develop and prioritize multi-agency management actions needed and identify the near-term policy actions of the various agencies responsible for freshwater HAB management.
3. Synthesize existing information and monitoring efforts and identify data gaps.
4. Develop standardized protocols for sampling and analytical methods.
5. Develop communication tools for sharing, accessing, and communicating HAB events and information.
6. Identify the best use of SWAMP monitoring and assessment resources, as well as additional partnerships and funding to support the long-term strategy.

In 2012, the Centers for Disease Control (CDC), U.S. Environmental Protection Agency (USEPA), and the U.S. Geological Survey (USGS) established the Inland Harmful Algal Blooms Discussion Group to continue and enhance communication on inland harmful algal bloom issues nationwide. This informal discussion group includes representatives from over 40 states, including California. An event that heightened awareness of the risks of cyanobacteria blooms occurred in 2014, when approximately 500,000 residents of Toledo, Ohio were without drinking water for several days as a result of a cyanobacteria bloom that impacted the city's source water, Lake Erie.

In 2015, the USEPA released health advisories for drinking water for the cyanobacteria toxins, microcystin and cylindrospermopsin. Health advisories provide states, drinking water utilities, and the public with information on health effects of microcystins and cylindrospermopsin, analytical methods to test for cyanotoxins in water samples, and treatment technologies to remove cyanobacteria toxins from drinking water. The USEPA included cyanobacteria and cyanotoxins on the drinking water Contaminant Candidate List as constituents that may require regulation under the Safe Drinking Water Act. Toxin thresholds for drinking water (USEPA, 2015) and recreational water (OEHHA, 2012) have been developed and are shown in Appendix C.

Currently, 22 states have freshwater HAB monitoring programs that vary significantly in purpose and organization, as well as type and frequency of monitoring (http://www2.epa.gov/nutrient-policy-data/states-freshwater-habs-monitoring-programs). SWAMP has initiated a Freshwater Harmful Algal Blooms (FHAB) program to help build the infrastructure for assessment, as well as provide support for dealing with freshwater HABs in the State of California.

C. Purpose of this Document

The purpose of this Strategy is to develop a program to inform management decisions for protecting public health and the environment. It provides a roadmap for the tools and guidance needed to support agencies and organizations as they address harmful algal blooms in freshwater. This document is intended to provide a framework for the Water Boards and other agencies to move forward in addressing freshwater HABs in a coordinated way.

Figure 1 shows the components of the Strategy. Some of the components are currently funded by SWAMP or other agencies, but there are other components for which resources and responsible agencies will need to be identified. The purpose of this document is not to assign tasks, but to develop a framework for implementation by SWAMP, the CCHAB Network and other concerned parties. It emphasizes infrastructure needed to manage blooms through monitoring, satellite imaging, information gathering and dissemination, remediation, and mitigation strategies (see Figure 2). In addition, funding mechanisms are identified that could potentially support this program in the long term. SWAMP has dedicated funding to this effort, but additional partners and resources will be necessary to fully implement this strategy.

The ideas in this strategy build upon elements already established through the SWAMP FHAB Program and the CCHAB, as well as through interviews with program leads from other states with established monitoring programs. The states contacted include Washington, Florida, New York, Vermont, Oregon, and Utah. In addition, members of CCHAB representing federal, state and local agencies, tribes, and scientific organizations within California provided input. It is necessary for these groups to participate in this strategy in order to achieve a coordinated response. A participants list can be found at the beginning of this document.

III. Freshwater HAB Assessment and Support Framework

The freshwater HAB assessment and support framework has three components, (A) response to HAB events, (B) field assessment and ambient monitoring, and (C) risk assessment for potential HAB events (Figure 1).

A. Response to HAB Events

The Response to HAB Events component focuses on the immediate monitoring and response actions applicable during a HAB event, including response to suspicious scum or illness, and mortality events potentially associated with HABs. It also includes the long-term actions needed to ensure an appropriate response to HAB events. Long-term actions include development of local action plans and implementation of management and remediation strategies. The infrastructure designed to support this strategy, especially in regard to event response, is described in detail in Section IV.

Event Response guidance documents are being compiled by SWAMP and CCHAB to provide expanded guidance on sampling, analysis, posting, thresholds, and remediation.

One of these documents, the CCHAB 2010 "Cyanobacteria in Recreational Water Bodies: Providing Voluntary Guidance about Harmful Algal Blooms, Their Monitoring, and Public Notification", will include waterbody posting and public notification guidance, as well as toxin thresholds for recreational exposure.

SWAMP is developing the second of these documents, a sampling and laboratory analysis guide that will include Standard Operating Procedures for field collection and laboratory methods, tiered approach to sampling and analysis, performance based quality assurance, and health and safety guidelines.

SWAMP is seeking funding for the final guidance document, a Management and Remediation Guide that will summarize available strategies and approaches for addressing a bloom. It should include summaries of the advantages and disadvantages of available methods, provide method selection criteria, give examples of success (or failure) for each method to mitigate or control HABs, and identify multi-objective benefits, considerations, and cost information associated with alternatives. Although SWAMP has funds for a workshop on this topic, which will be made available online, funding for a guidance document has not been identified.

These guidance documents will be available to the public and to all water quality regulatory agencies through the CCHAB Portal on "My Water Quality" (http://www.mywaterquality.ca.gov/monitoring_council/cyanohab_network/) and the SWAMP website (http://www.waterboards.ca.gov/water_issues/programs/swamp/), and will be distributed to public health agencies, waterbody managers, drinking water source managers, water-based recreation companies, and wildlife organizations.

Another part of HAB event response includes the routine processing of satellite imagery for early detection of blooms in waterbodies. SWRCB (via SWAMP) will fund or provide this processing, for event response and for tracking trends. In spring 2015, the National Oceanic and Atmospheric Administration (NOAA) provided initial training for Geographic Information Systems (GIS) specialists in California to use the algorithms to process satellite imagery. This approach will provide immediate and cost-effective monitoring across a range of spatial and temporal scales not previously feasible using field-based monitoring, allowing for waterbody managers of waterbodies to be notified if a bloom is detected. Processed images will be posted online to a centralized website. Currently, San Francisco Estuary Institute (SFEI) has been contracted to perform these tasks.

SWAMP has limited laboratory resources that can be made available to waterbody managers for toxin sample analysis when other resources are not available. Criteria are being developed to guide the use of these resources, which will be coordinated with other analytical resources (e.g., USEPA resources for total microcystin analysis by enzyme-linked immunosorbent assay (ELISA) kits).

B. Field Assessments and Ambient Monitoring

The field assessments and ambient monitoring component is designed to assess the extent, status, and trends of HABs and associated toxins at the state, regional, watershed, or site specific waterbody scales.

Waterbodies or watersheds prone to HABs, or potentially at high risk based on risk assessments, should be routinely monitored in order to determine immediate health risks to the public, pets, wildlife, and livestock, and the impairment of other beneficial uses. Ideally, monitoring of these watersheds and waterbodies should include biological, chemical, and physical measurements to determine the following:

- Frequency, magnitude, and duration of HABs and toxins associated with a waterbody, watershed, or region
- Seasonality of blooms and toxin production
- Underlying drivers of HAB development

At a minimum, waterbodies that have experienced harmful algal blooms should be visually inspected frequently during the bloom season. If a bloom is suspected, water samples should be collected and analyzed for species composition. If a HAB species is identified, toxin analysis should be conducted.

HABs and associated toxins should be included as part of existing water quality, watershed, and volunteer monitoring programs where appropriate. Existing monitoring programs provide leveraged resources and additional information that can be used to identify and implement appropriate response, as well as methods of remediation or mitigation. HAB development is often tightly linked with sustained nutrient loading to waterbodies; therefore, nutrient regulatory programs such as Total Daily Maximum Loads (TMDLs) should include HABs in their core analytes for data collection and analysis.

Citizen science and volunteer monitoring programs exist throughout California and can add HABs to their data collection efforts where appropriate. An example of one program that has been collecting cyanobacteria and toxin data is the Eel River Recovery Project, a citizen-based watershed monitoring and education group focused on the Eel River in Northern California (http://www.eelriverrecovery.org/) where anatoxin-a and cyanoHAB effects have been documented.

Environmental stressors associated with bloom initiation, maintenance, and toxin production need to be identified wherever possible. While these factors are being studied by many at the national and international levels, regional and local level information is critical to responding successfully to cyanoHABs. Understanding the drivers of bloom formation is critical to determining appropriate management strategies to successfully mitigate HABs, and to implement cost-effective, long-term remediation plans.

To understand the spatial extent of cyanobacteria and toxins in the environment, existing probabilistic field programs should be leveraged to include indicators associated with cyanobacteria blooms. These programs include the USEPA's National Aquatic Resource Surveys, SWAMP Bioaccumulation Monitoring Program, SWAMP Perennial Streams Assessment (PSA), and regional stormwater monitoring programs like the Southern California Stormwater Monitoring Coalition (SMC) and San Francisco Bay Area's Regional Monitoring Coalition (RMC).

Where possible, nutrients, chlorophyll-a, phycocyanin, cyanobacteria, and HAB algae identification and enumeration, as well as associated toxins, should be added to the list of analytes collected and analyzed by existing condition assessment programs. The inclusion of these indicators will provide improved datasets to characterize the extent of cyanobacteria blooms in the area assessed, assist in verifying satellite bloom reporting, and in identification of key environmental stressors associated with HAB development and persistence. The extent of waterbodies or watersheds affected by HABs and associated toxins can be estimated from such probabilistic assessments, and waterbodies or regions with recurring HABs can be prioritized for more intensive routine monitoring.

The limitations of adding cyanobacteria monitoring to existing efforts are: 1) most of these programs are in streams and rivers, and not in lakes where most of the recreational and drinking water use take place; and 2) this approach is inadequate for fully understanding the temporal or spatial variability of blooms. CyanoHABs can be very patchy; therefore waterbody-specific studies need more intensive study design, both in space and time, to understand these patterns. As funds become available, routine monitoring programs, specifically designed for freshwater HABs, will provide a mechanism to overcome the limitations of assessment based programs and to decipher spatial and temporal patterns in taxonomy, toxin production, and the stressors associated with blooms.

C. Risk Assessment

The main goal of risk assessment is to determine the target regions, watersheds, or waterbodies experiencing HABS, or at risk for HABs, to prioritize for assessment, monitoring, remediation, and risk management. The risk assessment approach can be used to assess large geographic areas with minimal resources as a first order mechanism to evaluate potential HAB issues in a region. This approach narrows the number of waterbodies for monitoring and assessment studies, since it is not fiscally feasible to monitor all waterbodies in a region, or throughout a large geographic area, like California.

Statewide Scale: There are three analyses that can be conducted at the statewide scale.

An ***historical analysis of blooms*** derived from satellite imagery, as well as other data, is being conducted, with SWAMP funding, to identify lakes larger than 100 hectares (~250 acres) that experience blooms, and to assess seasonal and spatial trends at individual waters and throughout the state. The historical analysis will address the period from 2002-2012, using imagery from the European Space Agency's (ESA) Medium-spectral Resolution Imaging Spectrometer (MERIS), and other data sources.

Ongoing satellite imagery analysis will identify waterbodies with recurrent harmful algal blooms. These waterbodies would be considered higher risk.

A ***landscape risk analysis*** could be conducted using GIS and remote sensing data to weigh risk factors and identify high-priority waterbodies for field assessments and monitoring. Existing GIS data layers such as waterbody types and beneficial uses, together with regional information about waterbody use by the public, pets, wildlife, and livestock, point and non-point nutrient sources, hydrological modifications, and current land use could be used to prioritize locations for monitoring in screening assessment. Additionally, collated records of historical blooms from ad hoc studies, remote sensing, or ambient monitoring could provide additional screening criteria.

The products from a landscape risk assessment could include a publically-available GIS interface that provides maps with layers addressing (1) waterbody locations, (2) beneficial use, (3) recreational water contact activities, (4) records of historical HABs, and (5) distribution and abundance of environmental stressors that may increase the probability of blooms. Each of these products could be developed as a separate assessment study. Together, the results of these studies could be used to prioritize waterbodies for monitoring and field assessments. However, though useful information may be derived from this effort, it is resource intensive and may not be predictive, and therefore is considered a lower priority than other components of this Strategy.

IV. Infrastructure to Support Monitoring and Assessment Strategy

There are several components of infrastructure needed to support and implement the Monitoring and Assessment Strategy, including (1) satellite monitoring for cyanoHABs, (2) a centralized data management system with website and reporting capabilities, (3) guidance documents on a wide variety of topics, (4) laboratory resources, (5) training, and (6) outreach. Figure 2 summarizes these components.

A. Satellite Monitoring

The National Cyanobacteria Assessment Network (CyAN) Project is a collaboration of federal agencies including USEPA, NOAA, USGS, and National Aeronautics and Space Administration (NASA) working to integrate satellite information into water quality programs and management decisions nationwide. The CyAN project will expedite public health advisories through early detection of cyanoHABs. The satellite imagery used by the CyAN project provides a synoptic view of the development, and temporal and spatial distribution of cyanoHABs, by distinguishing between chlorophyll and phycocyanin (Wynne et al., 2010, Stumpf et al., 2012). Currently, the use of satellite imagery is limited to lakes larger than 100 ha (~250 acres), however research is being conducted to be able to detect blooms in smaller waterbodies using the Sentinel 2 and Landsat satellites.

California is one of several βeta-test states for the CyAN project. SWAMP has provided funding to support development of the methods for California and will be an early participant for receiving, processing, and posting satellite imagery online. SWAMP is developing a protocol to contact waterbody managers about when and where cyanobacteria blooms are occurring based on satellite information. SWAMP will support download, analysis, interpretation, and posting for web access to satellite imagery until this becomes available nationally via the CyAN Project (anticipated in 2020). After the CyAN project begins, this strategy assumes that much of the analysis will be conducted through the national program; however, California will continue to require download and interpretation of satellite imagery, and communication with water managers. This strategy assumes SWAMP will continue to provide this role.

B. Centralized Database and Website with a Reporting System

A publically available, centralized database and website is under development as part of the SWAMP Freshwater HABs program. This will have the capacity for (1) database management and storage of satellite and related data, with the website providing (2) data access (downloadable), (3) data visualization, and (4) centralized reporting capabilities for both public reporting of blooms or illness, and notification to a wide audience of a bloom advisory or HAB event. The website will be housed within the California Water Quality Monitoring Council's "My Water Quality" website. It is currently expected to include downloadable GIS data layers of bloom analyses, bloom maps, web-based data upload tools, incident reports (including animal and human illness or death), and bloom information. The reporting system will provide a mechanism for the public and water resource managers to report HABs, or suspected HAB events to help identify HAB hotspots. This system will facilitate water resource manager and agency awareness for sampling, posting, and closure of suspect waterbodies.

An associated database will store satellite information, as well as descriptive bloom information, and will be populated by data from waterbody managers and monitoring programs. A template will be provided that will enable upload of taxa and toxin data to the California Environmental Data Exchange Network (CEDEN). Data will be publically accessible and downloadable on the website, wherever feasible. The website will have mapping capabilities that allow for visualization of HAB datasets, and will be able to overlay other water quality datasets.

Existing websites, such as the one developed for the Klamath River, will be used as models for the statewide website. The Klamath Basin Water Quality Monitoring Program has a "blue-green algae tracker" interactive web map (http://kbmp.net/maps-data/blue-green-algae-tracker). The tracker uses current information to map cyanobacteria blooms throughout the Klamath Basin to inform the public, research, management, and stakeholder communities of the current conditions, bloom events, and health threshold exceedances. Other states have similar HAB trackers that can serve as models for the California website. Some of these report current HAB event locations and provide waterbody safety status, including information about alerts and advisories.

HAB data reporting will be conducted through the centralized website and will include the following:

- Reporting mechanism for the public, waterbody managers, veterinarians, and state and local agencies to report a bloom, or animal illness or mortality events potentially associated with a bloom
- Short-term, timely notifications of blooms and animal mortality events
    - These may be based on the blooms reported or satellite imagery
- Newsletter or bulletin issued on a routine basis providing information about blooms, toxins, and reports of illness or mortality
- Maps showing blooms based on reported events and satellite imagery of high biomass and cyanobacteria dominance.

HAB reporting applications are being developed for smartphones by USEPA as part of the CyAN project. These applications will be one way to meet California's reporting needs and should be capable of connection to the website to obtain access to HAB reports. Additionally, the application will access website data so the public can utilize smartphones to obtain the most current advisories and information. At this time, this is not part of the Freshwater HAB Program and would require additional resources to implement.

C. Event Response Guidance Documents

Guidance documents are an integral component of the infrastructure needed to support assessment and monitoring of HABs.

The ***Event Response Guidance documents*** will include:

- standard operating procedures for sample collection methods for multiple beneficial uses (including aquatic life, recreational contact, and drinking water) and waterbody types
- standard operating procedures for laboratory toxin and taxonomic analyses
- health and safety recommendations for laboratory and field sample handling
- performance based quality assurance guidance
- decision frameworks for sampling and analysis, and a protocol for waterbody manager response, and agency and public notification
- a summary of California's established toxin thresholds for protection of public and pet health in recreational waters including the CCHAB posting thresholds, as well as USEPA's health advisory values for drinking waters
- a list of agencies and laboratories to contact for sample analysis services and guidance, and for illness and mortality events
- remediation and mitigation guidance

SWAMP Freshwater HAB Event Response Guidance Plan - SWAMP is developing ***Standard Operating Procedures*** (SOPs) and quality assurance guidance documents for field sample collection in all waterbody types (lakes, rivers, creeks, wetlands, estuaries, and coastal waters), laboratory sample analysis methods, and health and safety recommendations. The main purpose of this guidance is to ensure that consistent sample collection and analysis are conducted throughout the state by field assessment and monitoring programs to facilitate comparisons of data across programs, and ensure the safety of all individuals.

The field collection SOP will include identification of indicators needed to determine the immediate risk to public health, wildlife, pets, and livestock. Detailed instructions on how to sample algae and cyanobacteria, and water column chemistry (including toxins) within different types of waterbodies will be provided in the SOPs. Sampling design considerations will be conveyed in the SOPs in order to ensure samples collected are representative and have sufficient statistical power. These methods will be designed to standardize data collection for all relevant parameters in order to meet quality assurance and quality control requirements, also detailed in these documents. The SOP will provide health and safety procedures to ensure the safety of all individuals involved in sample collection and handling. SOPs for most water quality parameters can be found on the SWAMP website: http://www.waterboards.ca.gov/water_issues/programs/swamp/tools.shtml#methods

The laboratory section will focus on sample preparation, analysis, and reporting and will include: (1) SOPs for all of the toxin and taxonomic identification methods, (2) performance based quality assurance parameters for each analysis method (e.g. sensitivity, percent recovery, reproducibility, unequivocal identification) for these methods, and (3) a ***decision framework*** for analyzing cyanobacteria and cyanotoxins for event-response sampling. The decision tree framework is important to determine the toxin(s) of interest, how the samples will be prepared, the type of analysis that will be utilized, and how these data will be interpreted and used. The SOP will provide health and safety procedures to ensure the safety of all individuals involved in laboratory analysis.

At the time of this writing the SOPs discussed above are funded projects under the SWAMP Freshwater HABs Program, and are estimated to be completed in 2016.

As part of ***performance based quality assurance***, SWAMP has developed measurement quality objectives (MQOs) and sample handling requirements for cyanobacteria and cyanotoxin measurements for SWAMP funded monitoring projects and SWAMP comparable projects (http://www.waterboards.ca.gov/water_issues/programs/swamp/mqo_cyanotoxin.shtml). The intent of the MQOs is to ensure data collected for regulatory or waterbody assessment purposes are of known and consistent quality to support management decisions. Data collected for screening or research purposes will need to meet minimum requirements established by the method utilized or project specifications. The data generated by SWAMP and SWAMP comparable programs are made available to the public through CEDEN. The quality assurance objectives currently designed for SWAMP may be adapted for the purposes of other state water quality monitoring programs. Additional information can be found at the SWAMP Information Management and Quality Assurance Center (SWAMP IQ).

The recently released SWAMP MQOs focus on the two most common cyanotoxin analysis methodology groups used by SWAMP: ligand-binding assays (e.g. by enzyme linked immunosorbent assay or ELISA) and analytical chemistry assays (by liquid chromatography-mass spectrometry or LC-MS). SWAMP IQ plans to update MQO documents based on the needs of proposed SWAMP HAB monitoring.

The event response guidance will also include a ***list of agencies*** and laboratories to contact for sample analysis (including taxonomic identification and toxin analysis), and agencies that need to be notified when there is a bloom. The plan will be widely distributed to all water quality regulatory agencies, public health agencies, water resource managers, and wildlife rescue organizations.

CCHAB Guidance -"Cyanobacteria in California Recreational Water Bodies: Providing Voluntary Guidance about Harmful Algal Blooms, Their Monitoring, and Public Notification"

This document was developed in 2010 and is currently undergoing updates and revisions (http://www.cdph.ca.gov/HealthInfo/environhealth/water/Documents/BGA/BGAdraftvoluntarystatewideguidance-07-09-2010.pdf).

The guidance includes, among other topics, the following components:

- decision tree for providing public notification, and posting and lifting advisory warnings for bloom affected waterbodies
- a narrative explaining the steps in the decision tree
- recommended types of sampling and frequencies
- cyanotoxin toxicity thresholds for recreational exposure

- description and basis of cyanotoxin thresholds
- examples of signage for public warning

The CCHAB Guidance will be an important component of the overall event response guidance for dealing with freshwater harmful algal blooms and associated toxins.

A ***Bloom Management and Remediation Guidance*** document is also needed, and should include watershed and waterbody approaches to HAB management. There are many methods currently utilized for management and remediation that include (but are not limited to) the following:

- Reduction of nutrient inputs
- Inhibition of internal nutrient loads from sediments (such as chemical treatments, floating treatment wetland technology or dredging)
- Mixing and destratification of the water column
- Increased flushing or flow rates to reduce water retention time
- Waterbody treatments with algaecides
- Biological manipulations
- Ultrasound

The guidance document should summarize the advantages and disadvantages of each of these methods and provide selection criteria and examples of success (or failure) of each method to mitigate or control HABs. Although SWAMP has funded training on management and remediation of cyanobacteria blooms, the guidance document is not currently funded.

D. Laboratory Resources

The SWAMP program has set aside some resources for ***laboratory analysis*** so that water managers with insufficient resources can identify blooms, and will be developing criteria for their use. USEPA also provides services for some waterbodies experiencing recurrent, serious blooms. However, additional resources for sample analysis need to be secured. Laboratories capable of conducting analyses will be listed in the Event Response Guidance Document. An ***inter-laboratory comparison*** should be conducted to ensure data is comparable across laboratories. Performance based quality assurance metrics should be documented for the inter-laboratory comparison.

E. Training

There are two types of training programs needed to ensure successful implementation of the Monitoring and Assessment Strategy. All of this training is currently funded through SWAMP.

A ***comprehensive training program*** focused on all aspects of the guidance documents, and geared toward waterbody and watershed managers, regulators, and agencies conducting field sample collection and laboratory analysis, is being developed. This training program will help improve awareness, recognition, and reporting of HAB events.

In-person training workshops are being conducted throughout the state. At the time of this writing, the SWAMP Freshwater HAB program is sponsoring multiple workshops to provide training on the following topics:

- HAB general information, including taxonomy and identification, and types of toxins
- Water quality and public health issues caused by HABs
- Programs and resources within CA
    - CCHAB voluntary guidance document
    - Toxin thresholds for recreational exposure
    - Management and mitigation strategies for HABs
    - SWAMP sampling and analysis guidance document
    - SWAMP Freshwater HAB program and CCHAB network

Training materials will be distributed to workshop participants and the workshops are being recorded and posted on YouTube, where they will be made available on the centralized website. SWAMP is conducting these trainings in summer 2015 and 2016.

A ***bloom management and remediation workshop*** is planned and will provide more detailed information on ways to address blooms. The material presented should be summarized in the "Bloom Management and Remediation" guidance document discussed above. This workshop will focus on tools for lake managers to address nutrient sources and mitigation techniques within lake environments.

F. Applied Research and Tool Development

Technology to support bloom identification and analysis is developing rapidly and California should continually evaluate and adapt programs, as appropriate, to take advantage of new analytical methods, imagery analysis approaches, and other tools. As such, research needs may arise to support adapting these technologies for our program needs. Not all of these can be anticipated, however, several currently developing methods are described below.

One immediate need is satellite imagery analysis to support bloom identification in smaller scaled waterbodies. The Medium Resolution Imaging Spectrometer (MERIS) satellite imagery currently being used to initiate the imagery analysis program is limited to larger waterbodies, as is the Ocean Land Color Instrument (OLCI) sensor on the Sentinel-3 satellite. Analysis from higher resolution imagery could be added to provide information on smaller waterbodies. Paired Sentinel-2 satellites with multi-spectral imaging will provide much higher resolution imagery. However, the algorithms to detect cyanoHABs need to be improved. This can be done by collecting reflectance data at lakes and rivers to build a larger library of high-resolution spectra under a variety of conditions. In addition, LandSat imagery is collected at 1-m resolution and is currently being evaluated by staff at NOAA for its utility at detection of blooms in smaller systems. It would be useful to compare the efficacy of these two approaches to decide on what will work best for the State.

A number of new methods are also emerging for analysis of cyanotoxins including using polymerase chain reaction (PCR) and other molecular technologies, pattern recognition software, and other technological advances. In order to make best use of these methods, they need to be evaluated for inclusion in the SWAMP laboratory methods guidance, and appropriate quality assurance measures need to be developed to guide their use. The current use of Quantitative PCR (qPCR) in Ohio as well as pilot studies in California will provide useful data for its possible future inclusion as a toxin screening method.

There are a number of mitigation and remediation methods described for cyanoHABs, and there may be a need to evaluate the efficacy of some of these methods and test new ones. For example, research may be necessary to evaluate reductions in nutrient loading associated with treatment methods, impacts on bloom severity and frequency, and most appropriate conditions for application of the method. This information will be included in the remediation guidance as it is updated periodically.

G. Outreach and Education

An ***Outreach and Education Program*** has not been funded at the time of this writing but should be developed and geared toward citizens, policymakers, health care professionals, veterinarians, and public agencies (such as city municipalities, county health, and environmental management agencies). There is a critical need to increase public awareness of HABs in order to increase recognition, public safety, and timely reporting of instances of HAB blooms or associated events. The Outreach and Education Program should adapt the training materials (from the Training component of the infrastructure), including guidance documents and HAB background materials, to educate the general public and policymakers. Much of the training material can be introduced in workshops and webinars, with webinar presentations posted on the centralized website, along with the training materials. Other states, in particular Florida, have excellent outreach and education programs that can serve as models.

Other educational tools that should be developed include ***factsheets*** on HABs and HAB specific social media sites. Several factsheets already exist through USEPA R9 (http://www2.epa.gov/region-9-documents/harmful-algal-blooms-questions-and-resources), the California Harmful Algal Bloom Monitoring and Alert Program (HABMAP; http://www.habmap.info/documents.html), the Southern California Coastal Water Research Project (http://www.sccwrp.org/Documents/FactSheets.aspx), University of California Santa Cruz (Kudela Lab; http://oceandatacenter.ucsc.edu/home/outreach/CyanoHAB.pdf), and the City of Watsonville's Pinto Lake program (http://cityofwatsonville.org/public-works-utilities/pinto-lake-park/help-save-pinto-lake/issues-facing-pinto-lake). Many states use ***social media*** applications to communicate with the public as to where blooms are occurring, and where waterbodies are posted or closed due to HABs. In addition, there are municipalities that use social media sites, such as Facebook and Twitter, to post information for the public, a practice that could be adopted for California. A successful outreach program should incorporate multiple forms of media to reach the largest number of people about HAB risks and events.

Another important aspect of outreach is developing the **protocols** needed to communicate about blooms and coordinate when blooms occur. Contact lists need to be developed that include lake managers, environmental health department staff, tribes, and water purveyors. This could be done at a statewide or regional level. Regional workshops could be held to introduce members of the network and to establish protocols for communication and coordination.

V. Potential Funding Mechanisms

While the resources have been provided to build most (but not all) of the infrastructure required to implement this Strategy by the SWAMP Freshwater HABs program (see Figure 1), long-term resources and funding mechanisms need to be identified to maintain the program and fund the remaining components.

Approaches in Other States: There are several approaches used by other states to maintain HAB monitoring programs that include a combination of the following mechanisms:

- Consistent funding through legislation
- Designated funds through state, county, or local agencies
- State mandated, fee-based funding
- Leveraged resources provided by existing monitoring programs or volunteer citizen scientist based programs
- Grants from federal (USEPA, NOAA, CDC, FDA) or state funding programs

The program in Washington combines state mandated, fee-based funding, consistent funding through legislature, and grants from federal programs in order to maintain HAB monitoring. Their marine and freshwater HABs programs were initially established with federal funding through a NOAA grant that laid the groundwork and built the infrastructure required for program initiation. The Washington State Legislature established the Freshwater Algae Control Program (currently called the Aquatic Algae Control Program). The funding for this program comes from $1 vessel registration fees which generates $540,000 per biennium. The Washington State Department of Ecology manages the program and budgets funds for laboratory costs of event response samples (algal taxonomic identification and toxin analysis) ($60,000 per year), the staff time to facilitate and coordinate the program, and annual grants to state and local government for freshwater algae projects (approximately $150,000 per year). This type of integrated interagency monitoring program also establishes cooperation between federal, state, and local health agencies.

Vermont's Lake Champlain monitoring program is leveraged off an existing nutrient TMDL monitoring program, but the initial funding for the HABs component (i.e. purchases of equipment and supplies, taxonomic and toxin analysis training etc.) was provided through a federal grant, and partnership with the academic community. The TMDL monitoring program collects HAB samples and the sample analysis is funded through designated State funds from the Department of Health.

Some states have freshwater HAB monitoring programs that are based on volunteer monitoring and therefore the funding required to maintain the program is minimal. New York's program is leveraged on an existing, volunteer-based, lake water quality monitoring program (Citizen Statewide Lake Assessment Program), which samples for water quality parameters on a routine basis. The Department of Environmental Conservation received funding from several federal grants to support sample analysis, with trained citizen scientist volunteers collecting samples. Since there is no formal funding or staff resources provided by the state agencies, the State's partnership with academic scientists has been instrumental to the program's success.

Still other states, such as Florida, perform the monitoring through the state agencies, Department of Environmental Protection, Department of Fish and Wildlife, Department of Health, and the water districts and health agencies. The funding for sample analysis comes from designated funds from state agencies. However, Florida's guidelines for posting waterbody advisories and public notification only require that there is a visible bloom; managers are not required to wait for sample results to determine if the bloom is toxic. This provides more flexibility with sampling and decreases the need for rapid event response. Florida also has the most extensive online tracking effort which allows public health professionals, environmental scientists, and managers to access the data and bloom reports in real-time.

Approaches for California: California will likely use a combination of approaches to fund this monitoring and assessment strategy for freshwater HABs. Funding mechanisms may include the following: 1) CWA Section 106 funds from SWAMP; 2) Water Bond grants; 3) other legislation; 4) redirection of existing funds; 5) Fees or taxes; 6) local and tribal agency contributions; 7) leveraged programs; and 8) volunteer activities.

Current SWAMP funding going to HABs monitoring comes from EPA ***Clean Water Act Section 106 funds***. Currently, three years of funding have been approved (2014 - 2017). While this funding may continue in some form in future years, there are several other SWAMP monitoring programs competing for this resource. As the cost of monitoring increases each year, the amount of monitoring this fund can support diminishes. In addition, the funds currently provided do not fully support the proposed elements of this strategy. Therefore, additional funds will need to be identified.

Grant funding would be particularly useful for building program infrastructure, developing approaches for risk assessment or for mitigation and remediation projects. California has periodically approved sizeable ***water bonds***, including the Water Quality, Supply, and Infrastructure Improvement Act of 2014 (Proposition 1). Proposition 1 does not call out specific funding for toxic algae blooms. However, there are a number of grant programs funded by Proposition 1 and managed by various agencies that could potentially be applicable. These grants typically can be expected to fund projects for a period of approximately 3 years. There are several programs that could be considered, for example, the Department of Fish and Wildlife's "Watershed Restoration" and "Delta Water Quality and Ecosystem Restoration" grant programs may be appropriate sources. One consideration is that most grant programs are focused on implementation rather than on monitoring. In the future, participating CCHAB members who are not precluded from lobbying should work with legislators to ensure that specific language is included in water bonds related to funding of projects to manage and track toxic algae blooms.

Federal 319 grants are also available and could be another viable option, particularly for mitigation and remediation projects in water bodies with recurrent blooms. Many of the existing efforts to establish monitoring programs in individual waterbodies, or manage blooms, in California have been funded by grants. However, because grant funding is short-lived, it is not a stable basis for long term monitoring activities.

New ***legislation*** could be developed and implemented to fund or facilitate funding of monitoring, management, and education and outreach activities. In particular, Assembly Bill 300 (Monning) was submitted in 2015, requiring the SWRCB to establish and coordinate an "Algal Bloom Task Force" to assess and prioritize actions and research needed to prevent or mitigate blooms, and to make recommendations on funding, prevention, and long-term mitigation. This bill was in the Senate Appropriations Committee in October 2015 but has since been suspended. If it becomes law, it will help direct funds from other sources (such as Proposition 1) towards research, projects, and programs recommended by the Task Force. It does not provide funding directly. Other legislation could be developed to do so, for example through instituting ***fees or taxes*** on vessel registration (e.g. Washington), fertilizers, etc. Development of legislation is an activity which cannot be undertaken by state agency staff.

Without new legislation, stable state program funding could be obtained through **redirection of state funds** currently used for other purposes. Clearly, this has its disadvantages, in that programs are originated for specific and necessary reasons, typically have dedicated funding, and are addressing their own mandates. However, if cyanobacteria blooms continue to increase in size and frequency, the urgency associated with protecting public health and the environment may demand reprioritization of resources.

Local agencies and tribes are already contributing significantly to bloom management and monitoring. For example, in response to a nutrient TMDL, Lake County monitors Clear Lake and, in coordination with other stakeholders, has developed a monitoring and implementation plan. The Klamath Basin Monitoring Program is a coordinated, multi-organizational effort that includes basin-wide water quality monitoring, a data portal, and a plan for long-term stewardship, protection, and restoration of beneficial uses of the Klamath watershed. As blooms develop in waterbodies within the jurisdictions of local agencies, local response will be needed and local resources may be tapped. A major purpose of the infrastructural program elements developed through this strategy is to support these efforts, minimize costs, and maximize efficiencies in bloom response.

There are already a number of examples in California of **leveraging programs** for efficient monitoring. For example, the SWAMP Stream Pollution Trends (SPOT) program has included monitoring for cyanotoxins at integrator sites at the bottoms of major watersheds throughout the State of California. The SWAMP Perennial Streams Assessment (PSA) program has included toxin producing taxa and toxin analysis in its probabilistic assessment of benthic algae. The Southern California Stormwater Monitoring Coalition has included similar sampling in its watershed assessment projects. The Southern California Coastal Water Research Project has leveraged monitoring by member agencies to learn more about the distribution of toxins and toxin producing taxa. Agencies and organizations participating in management and monitoring of cyanoHABs should continue to make use of their own monitoring program infrastructure, along with SWAMP products developed as part of the Freshwater HABs Program, to make cyanobacteria and toxin monitoring cost effective.

In California, the Marine Biotoxin Monitoring Program (facilitated by the CDPH, Division of Drinking Water and Environmental Management) is dependent on ***volunteers*** to monitor shellfish toxin levels and toxin producing marine algae. The volunteers conduct weekly monitoring, sample collection, and data upload, which allows the funding requirements for the program to be kept at a minimum. The program was initially established through FDA emergency response funds, and the coordinator position and sample analysis are the only components that require annual funds. This program provides an excellent example of how limited resources can be stretched by effective use of volunteer assistance. Volunteers are an important part of other existing programs, such as the Klamath Basin Monitoring Program.

VI. Partners Roles

Figure 1 illustrates the components of the assessment and support strategy framework that are mostly funded through SWAMP, partially being performed by other local, regional, state, or federal agencies, and those not currently being addressed. The purpose of this chapter is to identify the components of the framework that are not being addressed, but need to be, and to identify the agencies that have roles and responsibilities related to these tasks. It is not the intention of this document to assign tasks, but to match the tasks that should be performed with those normally performed by these agencies, in order to coordinate and implement a robust freshwater HABs program in California. Although coordination will provide funding efficiencies, additional funding (see previous chapter) must be accessed in order for agencies to take on these tasks. CCHAB would be the best forum for discussing and establishing these roles.

HABs and associated toxins relate directly to the missions of a wide range of agencies in California such as those dealing with human and wildlife adverse health effects, recreational impairments, and water supply; therefore, there is a broad base of agencies and user groups for which the Assessment and Support Strategy is relevant. Coordinating framework tasks with the mission and role of each agency will lead to efficient use of all resources directed at HAB monitoring and mitigation throughout California.

The agencies in California whose missions involve the protection of public and wildlife health and beneficial use impairments include (but are not limited to): SWRCB, Regional Water Boards, OEHHA, CDFW, CDPH, CDWR, USEPA, USGS, USFWS, Tribal Governments, cities and municipalities, and local and county health departments. Partnerships should be established between these agencies and other water quality or HAB monitoring programs to monitor for HABs, either routinely or during events (such as the Eel River Recovery Project volunteer monitoring program for cyanotoxins, Klamath Basin Water Quality Monitoring Program).

Below is a list of tasks identified by the Strategy that need to be performed, or performed more fully, and the agencies that have related responsibilities. See Figure 1 and the section in the document that corresponds with the particular task for a full description.

Immediate Event Response for individual waterbodies is usually performed by agencies responsible for those waterbodies in consultation with local (county or city) environmental health departments. Responsible parties can include waterbody managers, parks departments, drinking water agencies, or environmental health departments. Infrastructure developed by SWAMP will assist these agencies in responding to cyanobacteria blooms, however, there needs to be a clear chain of command and responsibilities established for initiating and conducting monitoring, as well as alerting the public and other agencies. Currently, SWAMP has contracted with the SFEI to monitor waterbodies larger than 100 hectares (~250 acres) through satellite imagery, and to contact waterbody managers when a cyanobacteria bloom is detected. In addition, surveillance of especially high risk waterbodies should be conducted throughout the bloom season so that blooms can be detected in the early stages.

In the Klamath and Eel Rivers, groups have been formed that include waterbody managers, environmental health departments, the Regional Water Quality Control Board (Regional Water Board), tribes and volunteers to perform these tasks. Data collection to support listings and mitigation could be performed by these agencies/groups with assistance from the Regional Water Board in that area.

Long Term Event Response for individual waterbodies will also be supported by SWAMP infrastructure. Satellite monitoring and development of a data management system and website have been contracted to SFEI. The same entities involved in immediate event response should be involved in long term response. Since the responsibility of Regional Water Boards is to develop listings for impaired waterbodies and remediation strategies, including TMDLs, Regional Water Boards should be one of the lead agencies. Nutrient TMDLs being developed should be designed to protect against cyanobacteria blooms. Local Action Plans should be developed by local waterbody management agencies in collaboration with other involved agencies and tribes, and should have a process for public input and sharing data.

Field Assessment and Ambient Monitoring of individual waterbodies or watersheds should be performed, particularly during periods when blooms would be most likely to occur (e.g. warmer weather, longer light periods, and droughts). The same entities that respond to HAB events, both short and long term, on an individual waterbody could also be involved in ambient monitoring. However, other agencies that normally monitor these waterbodies could also conduct HAB monitoring (such as the CDWR or regional SWAMP programs).

Field Assessments and Ambient Monitoring at the State or Regional Scale are being conducted by a multitude of agencies (see Field Assessment and Monitoring section III.B.) by adding cyanobacteria parameters to existing monitoring programs. Programs currently being developed, such as the Delta RMP, should include cyanobacteria and associated toxins in their list of analytes. Monitoring programs should consider the appropriate temporal and spatial scales necessary to effectively monitor cyanobacteria and cyanotoxins.

The use of satellite imagery is a way of monitoring cyanobacteria blooms that captures the temporal and spatial scale needed to assess blooms in waterbodies. This type of monitoring is being conducted by SWAMP, through SFEI, and may be conducted by CyAN, a national program, after 2020 (see section IV. A. - Satellite monitoring). However, additional resources are needed to extend and communicate this information. SWAMP satellite monitoring is only funded through 2017.

Assessing Risk at State and Regional Scale will partially be completed by an historical analysis of satellite and field data from 2002-2012 being conducted by SFEI and funded through SWAMP. Similar analyses should be conducted on a regular basis, such as every 10 years. A landscape risk analysis could be conducted by various agencies; however, this analysis could be very resource intensive and may not be predictive. Waterbodies that are indicated to be high risk through these analyses should be monitored on a regular basis.

Applied research and tool development is needed so the best tools and methods for detecting, quantifying, and remediating cyanobacteria blooms can be used. Three important applied research needs at this time are: 1) additional satellite imagery analysis for detection of blooms in waterbodies smaller than 250 acres; 2) improvements to methods for quantifying toxins in blooms, especially in turnaround time; and 3) improvements to methods for remediation and mitigation of blooms. Currently, federal agencies working on CyAN, as well as academic researchers, are improving remote sensing capabilities so that blooms can be detected more quickly and in smaller water bodies. Researchers at private companies and public universities are working on methods to decrease the time in which valid quantifiable results can be obtained from water and bloom samples, such as gene detection through qPCR. There is also work being conducted, especially in Australia, South Africa, Europe and China, to improve the mitigation and remediation methods for blooms. The Central Coast Regional Water Board has been awarded federal 319 grant funds for a mitigation/remediation project in Pinto Lake, Watsonville. In the future, there will probably be additional areas of research that will require funding and support.

Outreach is not being performed by any agency and is one of the highest priority tasks in this strategy. In 2015, there were dog deaths at Lake Chabot (San Leandro), on the Russian River, and the Sacramento River that appeared to be associated with cyanotoxins in these waterbodies. In each case, there was confusion regarding the course of action and how to alert the public. Guidance documents and training, being developed by SWAMP and CCHAB, will help to develop clear, standardized procedures to follow when a bloom is identified or a death or illness that seems to be related to a bloom occurs. However, the public, responsible agencies, veterinarians, and health care professionals need to be informed about cyanotoxins to perform their role effectively.

The Department of Public Health's Environmental Health Investigation Branch (EHIB) has previously conducted education and outreach on fish mercury contamination in the Delta through the Fish Mercury Project (FMP). Under FMP, EHIB conducted needs assessments with community-based organizations representing diverse fishing populations, as well as with other stakeholders. The needs assessments included a variety of tools such as focus groups, meetings, interviews, etc. They also formed a stakeholder advisory group to provide input on project activities, funded community-based education projects through a grants program, conducted training, provided technical assistance, held two public forums, and developed multilingual materials. In addition, they evaluated the comprehension of advisory messages through interviews with fish consumers. Currently, EHIB is developing signage for cyanobacteria blooms that will be used by CCHAB in their guidance. EHIB has the experience and, with funding, a cyanotoxin education and outreach project could be enacted. Frequently Asked Questions (FAQs) have already been developed by USEPA Region 9 and others that could be used for this project.

Another part of outreach is developing the protocols needed to coordinate and communicate about blooms. Several groups including SFEI, California Association of Lake Managers (CALMs), and the North Coast Regional Water Quality Control Board are currently developing a list of contacts for bloom notification based on satellite imagery, to coordinate and communicate about blooms. The list should include lake managers, environmental health departments, water purveyors, and tribes. Regional Water Boards could facilitate this process by holding regional workshops to introduce members of the network and to develop protocols for communication and coordination. At the time of this writing, the North Coast Regional Water Quality Control Board is embarking on this process. Their process could be used as a model by other Regional Water Boards for developing regional networks.

VII. Strategy Review

With our understanding of CyanoHABs and the associated health risk to the public, pets, wildlife, and livestock continuing to evolve, the monitoring and assessment framework should be re-evaluated every 5 years by the CCHAB network to determine if the existing goals are being met, and to determine if there are any additional objectives that need to be included. Areas of program success should be highlighted in the amended document and any program weaknesses should be discussed and addressed when the Strategy is reviewed and revised.

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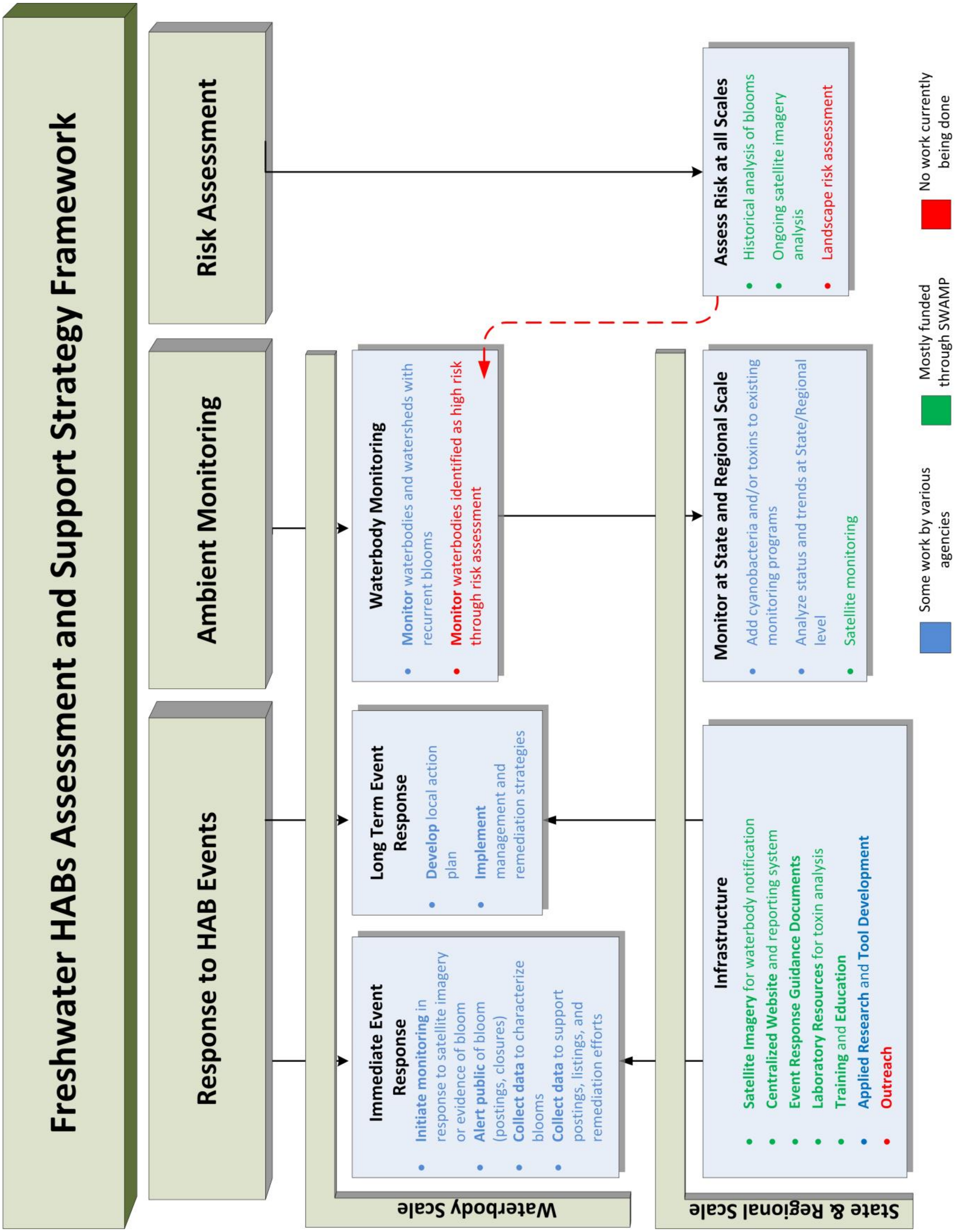

Figure 1. Freshwater HAB Assessment and Support Framework

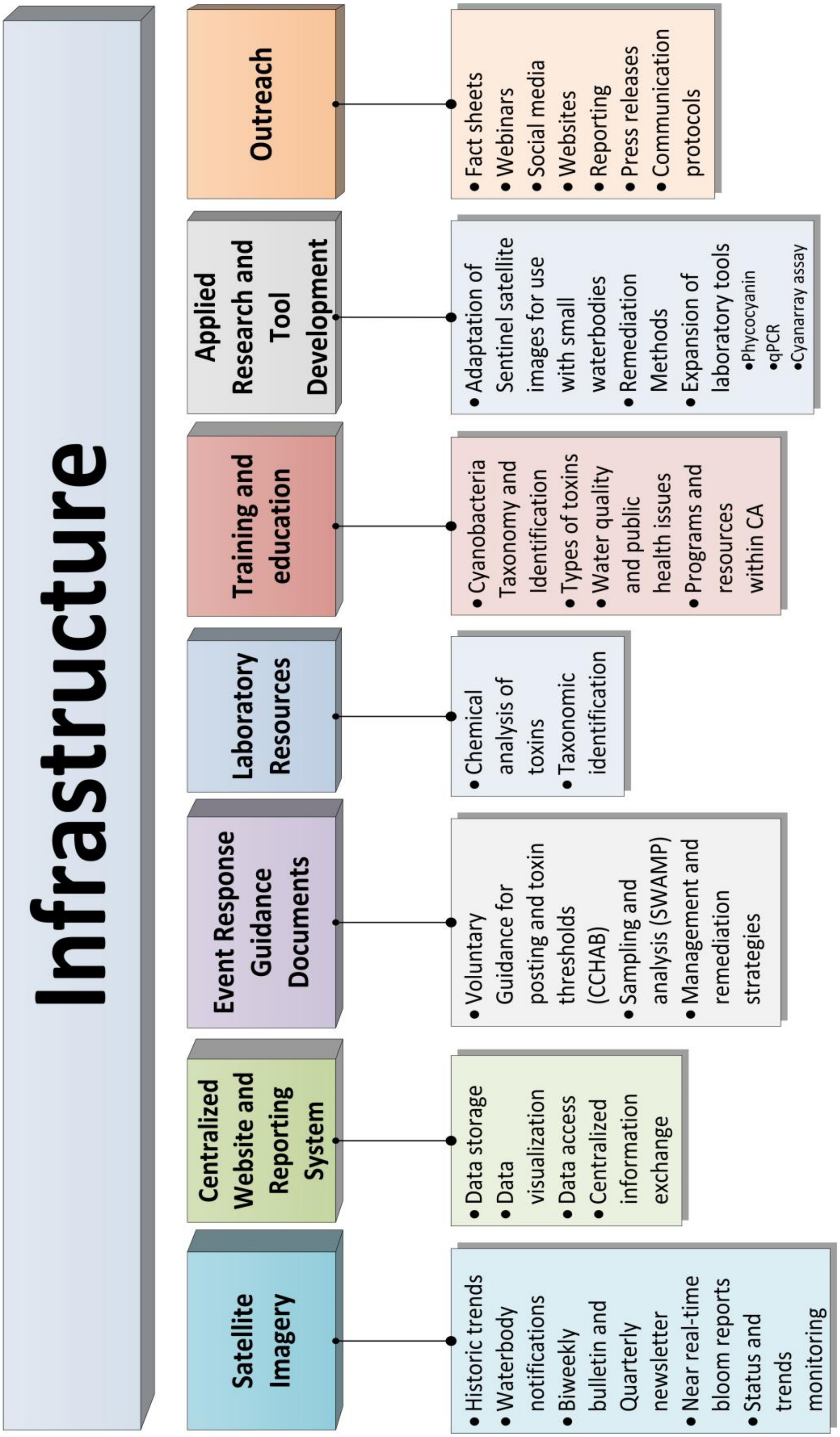

Figure 2. Infrastructure needed to support the Assessment and Support Framework

Appendix A. Background on Harmful Algal Blooms

At the base of the food chain in fresh, brackish, and marine systems are photosynthetic cyanobacteria and algae. Both single-celled, microscopic and larger, multicellular forms exist. These cyanobacteria and algae provide organic matter and energy to higher trophic levels. Under certain environmental conditions, a rapid increase or accumulation of microscopic algae can occur, and "harmful algal blooms" (HABs) may result, that can have negative impacts on the environment, people, pets, wildlife, or livestock, as well as the economy. The harmful mechanisms can be related to chemical effects (the production of toxins), biochemical effects from biomass accumulation (anoxia, hypoxia, habitat alteration), or physical features (spines that cause gill irritation). The main focus of this strategy is on freshwater HABs that produce toxins, although these toxin-producers may also be found, or cause issues, in brackish and marine environments (see Appendix B for regional concerns in California).

The most researched group of freshwater HABs is the cyanobacteria, or blue-green algae. These are problematic because they can impede recreational and beneficial uses of waterbodies by reducing aesthetics, lowering dissolved oxygen concentration, causing taste and odor problems in drinking water, and producing potent cyanotoxins, associated with illness and mortality in people, pets, livestock, and wildlife. Cyanobacteria blooms and their associated toxins have increased globally in geographic distribution, frequency, duration, and severity (Chen et al., 1993; Dawson; 1998; Amorim and Vasconcelos, 1999; Domingos et al., 1999; Lehman et al., 2005; Guo, 2007; Paerl and Huisman, 2008; Hudnell, 2010; Paerl and Paul, 2012). Non-cyanobacteria HAB events have also increased, the most common of which is the golden haptophyte alga, *Prymnesium parvum*, which has caused fish kills in the east, mid-west and southern states, and recently in Southern California, resulting in the impairment of beneficial uses of recreational lakes.

There are a large number of environmental factors that have been linked to bloom increases and toxin production (reviews by O'Neil et al., 2012; Paerl and Otten, 2013). These include climate change, nutrient over-enrichment, temperature, salinity, water residence time, vertical stratification, organic matter enrichment, and high pH (Paerl, 1988; Shapiro and Wright, 1990; Paerl, 1996; Paerl and Fulton, 2006; Carmichael, 2008; Paerl and Huisman, 2009; Paerl et al., 2011; O'Neil et al, 2012; Paerl and Paul, 2012; Paerl and Otten, 2013). The specific nutrients controlling cyanobacteria blooms have been debated in recent years. Historically, phosphorus has been the primary nutrient attributed to controlling cyanobacteria blooms in freshwater systems. However, recent studies have shown that nitrogen also controls cyanobacteria blooms, so that both nitrogen and phosphorous, and their ratio, need to be considered in water quality management strategies (Conley et al., 2009; Scott and McCarthy, 2010; Xu et al., 2010; Paerl et al., 2011; Wilhelm et al., 2011; Paerl and Otten, 2013).

Appendix B. California Regional CyanoHABs

There are several cyanobacteria "hot spots" in California where blooms are recurrent and, as a result, monitoring programs have been established. These areas include the Klamath Basin, Pinto Lake and Monterey Bay, San Francisco Bay area and Delta, Clear Lake and Southern California (Figure 3).

Klamath Basin

The Klamath Basin Water Quality Monitoring Program is the most well-established routine monitoring program in the State. Funded through the Klamath Hydroelectric Settlement Agreement, this monitoring is part of a larger effort organized by members of the Klamath Basin Monitoring Program, which includes a basin-wide water quality monitoring and coordination program, data portal, and a plan for long-term stewardship, protection, and restoration of all beneficial uses within the watershed. While a variety of toxin producing species have been documented in the watershed, (such as *Aphanizomenon flos-aquae, Anabaena circinalis, Gloeotrichia echinulate,* and *Oscillatoria* sp.) samples annually have had high cell densities of *Microcystis aeruginosa* and high concentrations of its toxin, microcystin, since 2004 (Kann, 2004; Jacoby and Kann, 2007; Fetcho, 2007; Moisander et al., 2009). *Microcystis aeruginosa* cells and microcystin have been documented in mussels (bivalves) and fish tissue collected from the river (Kann, 2008).

The Klamath River has been listed as impaired under the Clean Water Act section 303(d) due to excessive concentrations of microcystins. The highest concentrations of both *M. aeruginosa* cells and microcystin occur in Copco and Iron Gate Reservoirs, but have been detected as far downstream (200 river miles) as the Klamath River Estuary (Otten et al, 2015; Yurok Tribe Environmental Program 2007). To understand the sources and environmental stressors that drive microcystin, and other 303(d) listed impairments, many organizations coordinate monitoring at a number of reservoir and river sites throughout the basin for water quality parameters (turbidity, temperature, dissolved oxygen, nutrients, etc.) as well as for microcystins and algal species enumeration. (http://sfei.maps.arcgis.com/apps/MapSeries/index.html?appid=9b10920b676b4dfebce14f8c4ea70c4d&entry=1)

Pinto Lake and Monterey Bay

Monterey Bay is an area that has also been well studied in recent years. The mortality of over 30 endangered California Sea Otters (*Enhydra lutris*) in Monterey Bay was determined to be due to microcystin intoxication, with ingestion of contaminated marine bivalves suggested as a primary mechanism (Miller et al., 2010). Pinto Lake, a eutrophic lake that experiences frequent cyanobacteria blooms and drains to Monterey Bay via the Pajaro River, was identified as the primary source of the toxin (Miller et al., 2010; Kudela, 2011). Microcystin-laden water from the Pajaro River, and other tributaries to the Bay, flow to the coast where the toxin is biomagnified by bivalves, and ultimately consumed by otters (Miller et al., 2010). In tank studies, microcystins have been shown to bioaccumulate in commercially and recreationally-harvested invertebrates such as Pacific oysters (*Crassostrea gigas*) and mussels (*Mytilus edulis*) (Miller et al., 2010).

Microcystins were shown to be present and persistent in most of the coastal watersheds that flow to the Monterey Bay National Marine Sanctuary from a 3 year time-series survey (Gibble and Kudela, 2014). The survey showed seasonal toxin patterns with highest concentrations in the autumn and spring and concluded that microcystins are a persistent issue in this area. Nutrient loading was determined to be a significant predictor of microcystin concentrations in the watersheds (Gibble and Kudela, 2014). These studies have shown cyanotoxins to have far reaching effects downstream of their origin, and have promoted cyanotoxins from predominantly a freshwater issue to a land-sea interface problem.

San Francisco Bay Area and Delta

Microcystin contamination of the San Francisco Bay and Delta ecosystem has shown similar seasonal characteristics as Monterey Bay (Lehman et al., 2005; Lehman et al., 2008; Moisander et al., 2009), and there is evidence for increasing blooms with climate change (Lehman et al. 2013). Blooms of *Microcystis aeruginosa* have been documented since 1999 in the Delta, and blooms of *Aphanizomenon* sp. and presence of *Anabaena* sp. have also been documented routinely (Lehman and Waller, 2003; Lehman et al., 2010; Mioni et al., 2012). Cyanobacteria blooms have been identified as an impairment in the Delta, and the Central Valley Regional Water Quality Control Board is currently developing a science plan for the Delta on nutrient management policies that consider cyanobacteria bloom management.

Several man-made lakes in the East Bay Regional Parks (eastern San Francisco Bay area) are severely impacted by cyanobacteria blooms, including Lake Temescal, Lake Chabot, and a few others. Bloom severity in recent years has been such that lakes have been closed at times for swimming and contact sports. At least three dog deaths have been linked to these blooms. Monitoring by the East Bay Regional Park District is conducted in response to visual identification of scums and other evidence of blooms.

Clear Lake

Clear Lake has recurring cyanobacteria blooms that have impaired lake beneficial uses, including recreational activities, wildlife habitat and most importantly, drinking water. It has been listed on the 303d list of impaired waterbodies since 1986; however, efforts to reduce phosphorus loads and sediment cycling have failed to decrease cyanoHABs in recent years (Mioni et al., 2012).

Southern California

In Southern California, a number of screening assessments have documented cyanotoxins in multiple waterbody types, including depressional wetlands, lakes, reservoirs, coastal lagoons, and estuaries (Fetscher et al., 2015). A probabilistic survey conducted in the spring in depressional wetlands indicated that microcystins were detected at 25% of tested sites from 2011-2013. Another San Diego based study focused on lakes, estuaries, lagoons, and reservoirs in 2013; passive samplers (solid phase adsorption) detected microcystins at every site, and traditional discrete ("one-time grab") samples were found to underestimate the prevalence of toxin and miss toxic events. Similar results were found in studies of Pinto Lake at weekly timescales (Kudela, 2011).

In 2014, there were so many cyanoHAB blooms in coastal habitats reported to the San Diego Regional Water Board that an *ad hoc* field survey was conducted of estuaries, lagoons, lakes, and reservoirs. Microcystins were detected at several lakes at varying concentrations and microscopic examination of water samples indicated multiple, potentially toxic species at the sites sampled. Four lakes in Riverside, CA were sampled in the spring of 2014 and multiple toxins were detected simultaneously, including cylindrospermopsin, anatoxin-a and microcystins, with several samples containing cyanotoxin concentrations above recreational action level thresholds (see Appendix C for OEHHA action level thresholds). Additionally, four lakes in the Los Angeles and Orange County areas have experienced costly fish kills, attributed to blooms of the toxin producing golden algae, *Prynmesium parvum*.

Figure 3. Areas in California with recurrent blooms and ongoing monitoring activities

Appendix C. Toxin Thresholds

In June, 2015, the USEPA released health advisory guidance for algal toxins in drinking water in order to protect human health. The recommended 10 day health advisory values are 0.3 µg/L for microcystin and 0.7 µg/L for cylindrospermopsin for children younger than school age (values are 1.6 µg/L for microcystin and 3.0 µg/L for cylindrospermopsin for all other ages).

OEHHA has recommended health-based toxin exposure thresholds (also known as "action levels") to protect humans, pets, and livestock during recreational exposure for three cyanotoxins (microcystins, cylindrospermopsin, and anatoxin-a). These health-based exposure thresholds are summarized in Table 1, and published in the "Toxicological summary and suggested action levels to reduce potential adverse health effects of six cyanotoxins" (OEHHA, 2012; http://www.oehha.ca.gov/risk/pdf/cyanotoxins053112.pdf). Action levels have also been developed for fish and shellfish consumption. These exposure thresholds are levels at which no health effects are anticipated, and indicate additional action (i.e. monitoring) may be advised.

The CCHAB Voluntary Guidance document, "Cyanobacteria in California Recreational Water Bodies: Providing Voluntary Guidance about Harmful Algal Blooms, Their Monitoring, and Public Notification" is currently being revised to update the toxin exposure thresholds for posting advisories and warnings.

Table 1. OEHHA Action Thresholds for cyanotoxins in California (from OEHHA, 2012)

	Microcystins (LA, LR, RR, and YR)	Anatoxin-a	Cylindrospermopsin	Media (units)
Human recreational uses[1]	0.8	90	4	Water (µg/L)
Human fish consumption	10	5000	70	Fish (ng/g) ww[2]
Subchronic water intake (dog)[3]	2	100	10	Water (µg/L)
Subchronic crust and mat intake (dog)	0.01	0.3	0.04	Crusts and Mats (mg/kg) dw[4]
Acute water intake (dog)[5]	100	100	200	Water (µg/L)
Acute crust and mat intake (dog)	0.5	0.3	0.5	Crusts and Mats (mg/kg) dw[4]
Subchronic water intake (cattle)[6]	0.9	40	5	Water (µg/L)
Subchronic crust and mat intake (cattle)[6]	0.1	3	0.4	Crusts and Mats (mg/kg) dw[4]
Acute water intake (cattle)[6]	50	40	60	Water (µg/L)

[1]The most highly exposed of all the recreational users were 7- to 10-year-old swimmers. Boaters and water-skiers are less exposed and therefore protected by these action levels. This level should not be used to judge acceptability of drinking water concentrations.

[2]Wet weight (ww) or fresh weight

[3]Subchronic refers to exposure over multiple days

[4]Based on sample dry weight

[5]Acute refers to exposures in a single day

[6]Based on small breed dairy cows because their potential exposure to cyanotoxins is greatest

Appendix D. Abbreviations and Acronyms

CCHAB	California Cyanobacteria Harmful Algal Bloom Network
CDC	Centers for Disease Control
CDFW	California Department of Fish and Wildlife
CDPH	California Department of Public Health
CDWR	California Department of Water Resources
CEDEN	California Environmental Data Exchange Network
CyAN	Cyanobacteria Assessment Network, National
CyanoHAB	Cyanobacteria Harmful Algal Bloom
EHIB	Environmental Health Investigation Branch
ELISA	Enzyme-Linked ImmunoSorbent Assay
ESA	European Space Agency
FHAB	Freshwater Harmful Algal Blooms
FMP	Fish Mercury Project
GIS	Geographic Information Systems
HAB	Harmful Algal Bloom
HABMAP	Harmful Algal Bloom
LC-MS	Liquid Chromatography-Mass Spectrometry
MERIS	Medium Resolution Imaging Spectrometer
Monitoring Council	California Water Quality Monitoring Council
MQO	Measurement Quality Objectives
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
OEHHA	Office of Environmental Health and Hazard Assessment
PSA	Perennial Streams Assessment
RMC	Regional Monitoring Coalition (San Francisco Bay Area)
SFEI	San Francisco Estuary Institute
SMC	Stormwater Monitoring Coalition
SOP	Standard Operating Procedures
SPoT	Stream Pollution Trends
SWAMP	Surface Water Ambient Monitoring Program
SWAMP IQ	SWAMP Information Management and Quality Assurance Center
SWRCB	State Water Resources Control Board
TMDL	Total Daily Maximum Loads
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
Water Boards	Regional Water Quality Control Boards