The effect of the Temporary Urgency Change Petition and Emergency Drought Barrier on Harmful Algal Blooms and Aquatic Weeds

2022 Study Plan

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STUDY PLAN PROCESS

In compliance with the conditions of the Order, the cyanotoxin monitoring plan (Appendix A) was submitted to the State Water Board on April 20th, 2022. Comments on the plan were received on May 3rd, 2022, and study plan authors met with the Water Board Staff to present the planned analysis on May 4th. This study plan, as well as responses to the comments provided by the State Water Board, were submitted to the Board on May 10th, 2022. The framework for this plan was presented at the Interagency Ecological Program (IEP) Science Management Team and the IEP Phytoplankton Project Work team. Verbal comments received during these meetings were incorporated in the study plan. This plan was also distributed for comments to the IEP Phytoplankton Project Work Team, the Environmental Protection Agency, and the California Department of Fish and Wildlife. No comments were received. Study authors met with the State Water Board staff on May 24th, 2022 to discuss additional comments. All comments have been incorporated into this study plan, which is now considered final.

INTRODUCTION

Condition 8 of the April 2022 Temporary Urgency Change Order for the Central Valley Project and State Water Project requires a special study of harmful algal blooms (HABs) in the Sacramento–San Joaquin Delta (Delta), particularly HABs caused by cyanobacteria (i.e., cyanoHABs), and the spread of submerged aquatic vegetation (SAV) and floating aquatic vegetation (FAV) also referred to as "aquatic weeds". This study will include a synthesis of existing data as well as several new studies of cyanotoxins, satellite imagery, phytoplankton pigment fluorescence, and hyperspectral imagery.

Specifically, the TUCO says:

> In coordination with the State Water Board, Central Valley Water Board, IEP, Delta Science Program (DSP), the fisheries agencies, and USEPA, DWR and

> Reclamation shall continue and build upon the special study on the prevalence and extent of harmful algal blooms (HABs) and expansion of invasive aquatic weeds in the Delta as required by the 2021 TUCP, 2021 Emergency Drought Salinity Barrier (EDSB) Certification, and the 2022 Order on Reconsideration of the 2021 TUCP. The special study shall identify the effects of this TUCP Order, any future TUCP Orders, and any associated actions including drought barriers on the prevalence and extent of HABs and expansion of invasive weeds in the Delta. The study shall include the measurements of cyanotoxin concentrations in areas where this TUCP Order may modify hydrodynamics to Delta waterways. The cyanotoxin samples shall be collected consistent with the requirements of any approved extension of the EDSB certification, including, at a minimum, the types of cyanotoxins analyzed, locations, frequency, triggers for additional monitoring, and methods. The draft study plan shall be submitted by April 20, 2022, to the coordinating entities identified in the condition for review and comment. The final study plan incorporating the coordinating entities' comments are due to the State Water Board by May 10, 2022. Cyanotoxin monitoring shall be initiated in May 2022.
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> The report shall summarize impacts to sub-regions of the Delta consistent with the localized nature of HABs and aquatic weeds and analyze potential for (or presence of) disproportionate impacts to vulnerable communities with respect to drinking water quality, contact and non-contact recreation, impacts to tribal cultural resources, and impacts to aesthetics including odors and the visual character of Delta waterways where HABs and aquatic weeds are prevalent or where this TUCP Order may modify hydrodynamics to Delta waterways. This work shall be coordinated with IEP and DSP, and any broader watershed evaluation of HABs and aquatic weeds.
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> An interim draft Report shall be submitted to the State Water Board by December 15, 2022, summarizing the results available at that time. A summary of the interim draft report shall be presented at a public Board meeting in January 2023, or as designated by the Deputy Director of the Division of Water Rights. A completed, draft Report shall be submitted to the State Water Board by April 1, 2023, released for public comment, and presented at a public Board meeting as determined in coordination with the Deputy Director of the Division of Water Rights. In coordination with the State Water Board, Central Valley Water Board, IEP, DSP, CDFW, and USEPA, DWR and Reclamation shall review and consider comments from the State Water Board, other agencies, and the public and modify the final report as appropriate based on these comments. A complete, final report shall be submitted to the State Water Board 30 days after receipt of public and State Water Board staff comments unless the Deputy Director for the Division of Water Rights grants and extension.

This study plan outlines the approach that DWR and Reclamation will take in producing the report required by Condition 8. The study will include both collection of additional cyanotoxin samples and synthesis of existing

data collection to create a comprehensive picture of cyanoHABs across the Delta.

Summary of actions

This study plan will focus on the impacts of the 2022 April-June TUCP and the West False River Emergency Drought Barrier (EDB or "Barrier"). The TUCP included four changes to Water Rights decision 1641, namely:

(1) Reduces the Delta outflow requirement as measured by the Net Delta Outflow Index (NDOI) from a minimum of 7,100 cubic-feet per second (cfs) on a 3-day running average to 4,000 cfs on a 14-day running average.[4]
(2) Moves the Western Delta agricultural salinity compliance point on the Sacramento River at Emmaton 2.5 to 3 miles upstream to Threemile Slough.
(3) Limits the maximum export rate to 1,500 cfs whenever unmodified D-1641 requirements are not being met.
(4) Reduces the minimum monthly average flow requirement on the San Joaquin River at Airport Way Bridge, Vernalis from 710-1140 cfs (April 1-14 and May 16-June 30) and 3,110-3,540 cfs (April 15 – May 15) to a minimum monthly average of 710 cfs.[5]

The 2021 EDB is a temporary physical rock fill barrier in West False River, near Franks Tract, that reduces the intrusion of high-salinity water into the Central and South Delta. During drought conditions, water stored in upstream reservoirs may be insufficient to repel salinity moving upstream from San Francisco Bay. Without the protection of the drought salinity barrier, saltwater intrusions could render Delta water unusable for agricultural needs, reduce habitat value for aquatic species, and affect roughly 25 million Californians who rely on the export of this water for personal use. The 2021 EDB was installed in June of 2021 and left in place thought the remainder of the year. A notch in the top of the barrier was cut in January of 2022 to allow for fish passage during the winter, then re-filled in April of 2022 to restore its effectiveness as a salinity barrier.

Goals and Research Questions

This study has the following goals and associated research questions:

1. Describe the impact of the 2022 April-June TUCP and Barrier on Harmful Algal Blooms.
    a. Where and when did cyanoHABs occur in 2022?

b. What were the toxicities associated with cyanoHABs in 2022?

c. Were cyanoHABs in 2022 better or worse than similar dry years, either for the Delta as a whole or regionally, based on areas hydrologically impacted by the TUCP/Barrier?

d. What were the major drivers associated with bloom formation?

2. Describe the impact of the April-June TUCP and Barrier on aquatic vegetation.

    a. What was the distribution of weeds in 2022?

    b. How did coverage and community composition of weeds 2022 compare to similar dry years, for the Delta as a whole and regionally, based on areas hydrologically impacted by the TUCP/Barrier?

    c. What were the major drivers associated with weed distribution and coverage?

3. Describe the impact of the change in HABs and weeds caused by the April-June TUCP/Barrier on human uses of the Delta, in particular impacts to vulnerable communities.

    a. What is the impact of HABs and weeds on vulnerable communities?

    b. Where were increases in HABs or weeds thought to be caused by the TUCP/Barrier?

    c. Were areas impacted by the TUCP/Barrier disproportionately represented by vulnerable communities?

Regional analysis

The impacts of the April-June TUCP and Barrier will not be uniform across the area of the Delta, therefore, we have divided many of our analyses into regions based on the projected changes to flow caused by the TUCP and Barrier (Figure 1).

- In the upper Sacramento River, reduced inflows will cause increased residence time, though we expect minimal

changes to maximum and minimum velocities, which are primarily controlled by tides.

- In the Cache/Liberty region, residence time is controlled mainly through tidal dispersion,

- In the Lower Sacramento, the Barrier will cause salinity to increase and reduced inflows will cause increased residence time, though we expect minimal changes to maximum and minimum velocities.

- In the Lower San Joaquin, the barrier will cause salinity to increase. There will be local increases to flows and current speed on the San Andreas Reach.

- In Franks Tract, the Barrier will cause a significant increase in residence time, particularly on the western side of the tract. Maximum current speed and tidal flows will decrease through False River and increase through Fisherman's Cut and Old River.

- South of Franks Tract, the Barrier will cause salinity to decrease and residence time to increase in Old River, with a smaller effect in Middle River. Residence time in this area is controlled mainly by Exports, so low, health-and-safety export levels will result in longer residence time than during wetter years.

- Reductions to San Joaquin Flow will increased residence time in the South Delta and Lower San Joaquin.

- Suisun Marsh and Suisun Bay will have slight increases in salinity, but this is not expected to influence HABs or Weeds in these regions, so data from these regions are not shown in this report.

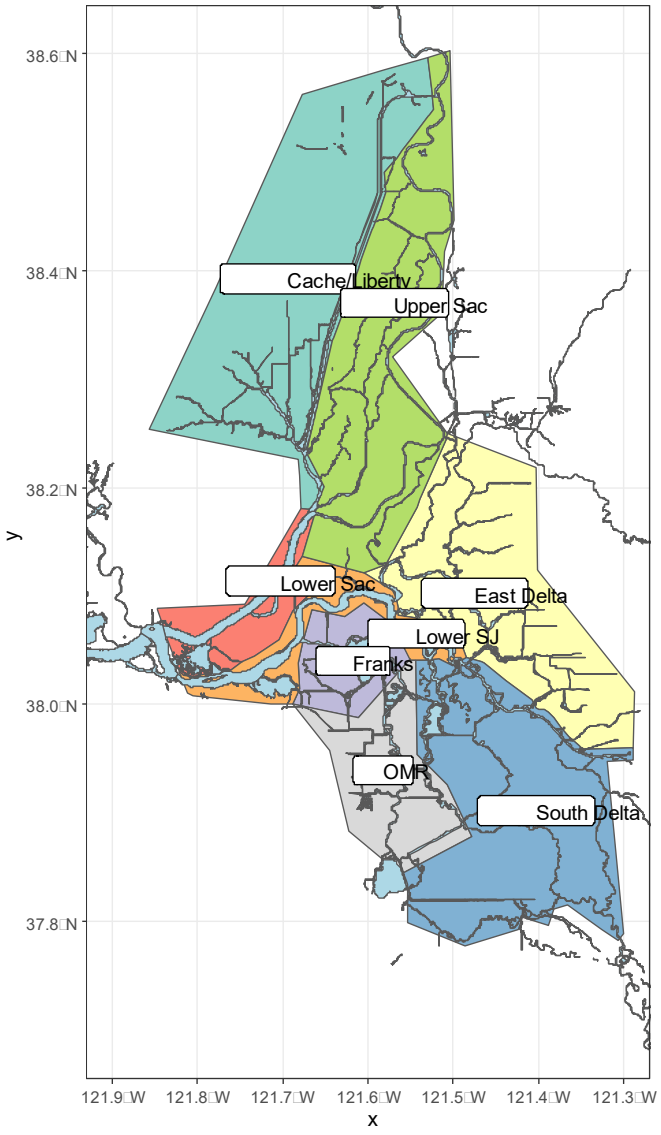

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Figure 1. Regions used for analysis

HARMFUL ALGAL BLOOMS

Background

HABs in the Delta

Blooms of the toxin-producing cyanobacteria *Microcystis aeruginosa* have been observed in the Delta by researchers working at DWR and other agencies since the late 1990s. These blooms were first documented visually appearing as little lettuce-like flakes in the water (Lehman and Waller 2003). Studies of these blooms have demonstrated that these blooms contain multiple microcystin toxins. In sufficiently high concentrations, these act as liver toxins (Lehman et al. 2005), and the presence of low concentrations in the Delta is cause for concern. Investigations after 2005 have found that the blooms frequently are composed of a mix of *Aphanizomenon* sp., *Microcystis* sp., *Dolichospermum* (formerly *Anabaena)* sp., *Planktothrix* sp. and *Pseudoanabaena* sp. (Lehman et al. 2010; Mioni et al. 2012), however research to date has focused primarily on *Microcystis*.

Overall, the Central and South Delta have the highest surface concentrations of *Microcystis* and *Aphanizomenon* (Berg and Sutula 2015; Lehman et al. 2013; Lehman et al. 2008; Lehman et al. 2018; Mioni et al. 2012). Starting in 2012, very high abundances of *Microcystis* colonies were observed in the South-East Delta region in the Turning Basin of the Stockton Shipping Channel, in Discovery Bay, and at Rough and Ready Island (Lehman et al. 2018; Spier et al. 2013). *Microcystis* abundance is typically much lower in Suisun Bay west of Antioch and north of Collinsville on the Sacramento River (Lehman et al. 2013; Lehman et al. 2005; Lehman et al. 2008; Lehman et al. 2018; Mioni et al. 2012).

Drivers

A worldwide increase in the incidence of cyanoHABs has prompted a great deal of research into the conditions that favor the growth of these species (Carmichael 2008; Chorus and Welker 2021; Hudnell 2008; Hudnell 2010; O'Neil et al. 2012; Paerl and Paul 2012). Environmental conditions favoring cyanoHAB formation typically

include calm and stratified water, warm water temperatures, high light, and an ample supply of nutrients (Berg and Sutula 2015; Huber et al. 2012; Lehman et al. 2013; Lehman et al. 2018; Paerl et al. 2011). The most successful strategies for mitigating cyanoHABs have focused on these environmental factors, including increasing the flow of water, promoting mixing of the water column, and reducing the supply of nutrients (Paerl et al. 2011).

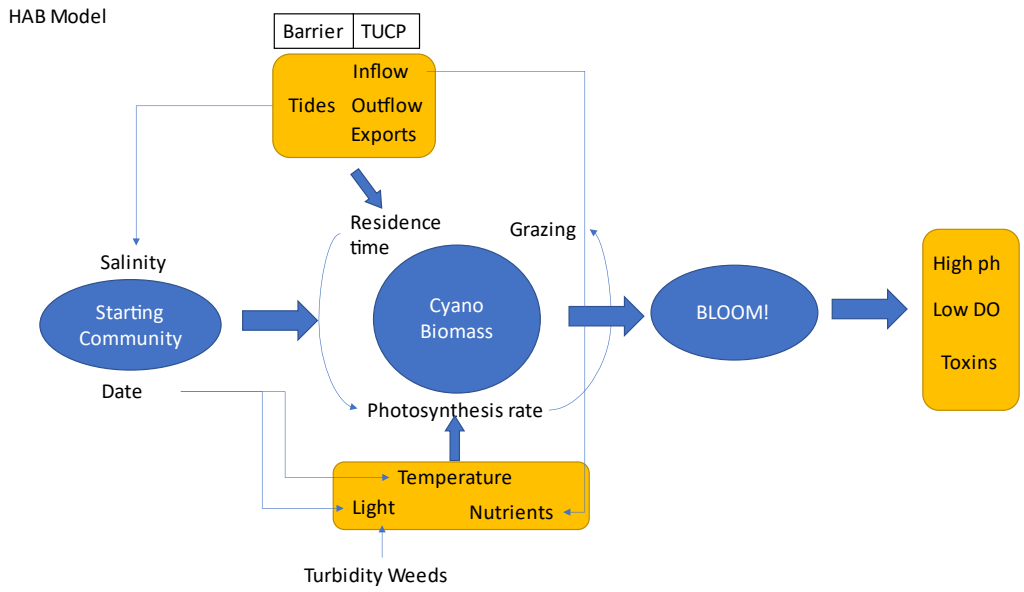


Figure 2. Conceptual model of the influence of hydrology and other factors on harmful algal blooms.

We have developed a conceptual model for how environmental factors impact cyanobacterial blooms (Figure 2). Cyanobacterial blooms are controlled by limitations on their photosynthetic rate or by external factors that remove them from the system. Limitations to their photosynthetic rate include nutrient supply, water temperature, and light availability (Lehman et al. 2013; Lehman et al. 2018). Nutrients in the system are controlled by both non-point sources – runoff from agriculture – and point sources – chiefly wastewater treatment plants within the Delta (Senn et al. 2020). Some cyanobacteria can also fix nitrogen gas dissolved in the water, though *Microcystis* (the dominant toxigenic cyanobacteria in the Delta) cannot. Nutrient concentrations peak in the winter and spring when high flows increase loading of nutrients from the watershed and decrease during the summer when there is less runoff and when primary productivity and nutrient uptake

by phytoplankton are at their peaks. In the Delta, summertime chlorophyll concentrations are typically relatively low (2.5-3.5 µg/L), and nutrients are generally not considered limiting to phytoplankton growth and biomass accumulation (Jassby 2008). However, sporadically large phytoplankton blooms occur that completely deplete the available nitrogen supply.

Water temperatures in the Delta have increased over the period of record (Bashevkin et al. 2022), with substantial increases starting in 1999 (Brooks et al. 2011). Water temperatures in the Delta are driven mainly by air temperatures (Vroom et al. 2017), and periods of low inflow also tend to be warmer (Bashevkin and Mahardja 2022). Temperatures vary spatially within the Delta with warmer temperatures in the South Delta and cooler temperatures along the Sacramento River and in Suisun Bay (Bashevkin et al. 2022).

Light availability changes with solar irradiance and turbidity. While cloud cover and smoke may block sunlight temporarily, summer light availability is controlled mainly by turbidity. Turbidity in the Delta is driven by sediment concentration of the incoming water, water velocity and wind. The largest sediment inputs in the Delta occur during winter storms, so summer conditions will have clearer water, and sediment inputs in the Delta have been decreasing over the past 50 years, causing a trend toward increased water clarity (Schoellhamer 2011). As water slows, suspended particles sink and cause the water to clear further. During the summer, water velocity is controlled by tidal action, so (as for residence time) water velocity on the local scale is most impacted by physical characteristics of the Delta, particularly the presence of submerged vegetation. Vegetation causes the water to slow, and the trend toward increasing water clarity in the Delta has been linked to the increase in aquatic vegetation over the past twenty years (Hestir et al. 2016). Wind increases sediment re-suspension and turbidity in extended areas of shallow open water, such as Suisun Bay, but is less of a factor in narrow channels or areas with dense vegetation (Bever et al. 2018).

External factors controlling blooms include flow, residence time, and grazing rates. Residence time in the Delta is controlled by the combined interaction of tidal action, inflows, diversions, and physical characteristics of the Delta. On the large scale, inflows will dominate the inter-annual and intra-annual differences in residence time, with major floods greatly reducing residence time during the winter and spring months. Decreased flow typically occurs during July–September, which coincides with the occurrence of *Microcystis* blooms

(Lehman et al. 2013, 2018, 2020; Spier et al. 2013). At the local scale, particularly at low flow values, tidal action will dominate both residence time and velocity, with greater differences seen on the spring-neap tidal cycle. At low outflow values, changes to the physical characteristics of the Delta, such as installation of barriers, operation of gates, or growth of submerged vegetation will have a greater impact on residence time than changes to outflow since physical changes will alter tidal dynamics.

Most cyanobacteria are not preferred food for planktivorous grazers, though some zooplankton and clams will consume *Microcystis* and other cyanobacteria (Kimmerer et al. 2018; Liu et al. 2009; Silva et al. 2020). Therefore, top-down control of cyanoHABs appears to be rare in the Delta, and blooms are more frequently dissipated through depletion of nutrients and increases in flow.

When nutrients, turbidity, temperature and residence time are all at the right level, a phytoplankton bloom will occur (Glibert et al. 2014). However, the type of bloom will depend on the starting community, nutrients available, and time of year. Early in the season, spring blooms are more often dominated by diatoms and other "beneficial" phytoplankton. Later in the year, when temperatures are warmer, cyanobacteria are more likely to dominate (Lehman et al. 2013). The ratio of nitrogen to phosphorus, and the form of nitrogen present (ammonium versus nitrate) will also favor some taxa over others (Dahm et al. 2016; Wan et al. 2019).

Drought Barrier and TUCP

Given that increased residence time, temperature, and water clarity increase the risk of the occurrence of blooms of *Microcystis* and other cyanoHABs, the drought is expected to result in an increase in both the duration and the severity of blooms of *Microcystis* and other potentially toxic cyanobacteria. Droughts tend to be hotter, with higher water clarity, and lower outflow (Hartman et al 2022). Important concerns are whether the TUCP will increase the effect of the drought on cyanoHABs, and whether the drought barrier in West False River will promote cyanoHABs in the Central Delta by restricting flows and increasing residence times.

The TUCP may increase residence time in the South and Central Delta broadly, by decreasing exports, decreasing San Joaquin River inflow, and decreasing outflow, but is not likely to influence local-scale velocities (which are mostly driven by tidal forces at low outflows). In contrast, the barrier will significantly change tidal dynamics in the

vicinity of Franks Tract and therefore change local velocities and increase residence time within the Tract.

The analysis will be divided into three parts:

1. A description of where and when harmful algae were detected in 2022, across all regions of the Delta, along with the toxin levels observed during blooms, water quality conditions, and hydrologic conditions.

2. A comparison of harmful cyanobacteria levels in the Central Delta and South Delta in 2022 versus 2014-2021 using visual assessments and phytoplankton community composition as enumerated in grab samples.

3. A model of drivers of cyanobacteria observations versus several environmental correlates, with predictions for how changes resulting from the TUCP may have impacted the probability and severity of cyanoHABs.

Methods

Visual Assessments

Most monitoring surveys that collect data on water quality and fisheries in the Delta also collect visual observations of *Microcystis* and other visually detectable algal blooms. Because *Microcystis* colonies are relatively easy to identify visually in the field, this visual ranking gives a general idea of when and where the most common harmful cyanobacteria in the Delta occurs. However, this method does not detect other cyanobacteria taxa that may be present and is subject to observer bias. This method also provides no information on the toxicity of the bloom, since *Microcystis* may or may not carry toxin producing genes and those with toxin-producing genes may not be actively producing the toxin.

A surface water sample is brought on board in a bucket and *Microcystis* is ranked on a scale of 1–5, 1 meaning "absent" and 5 meaning "very high" (**Figure 3**). Although this method is imprecise, it is generally reliable on the for detecting Microcystis and giving a rough estimate of magnitude.

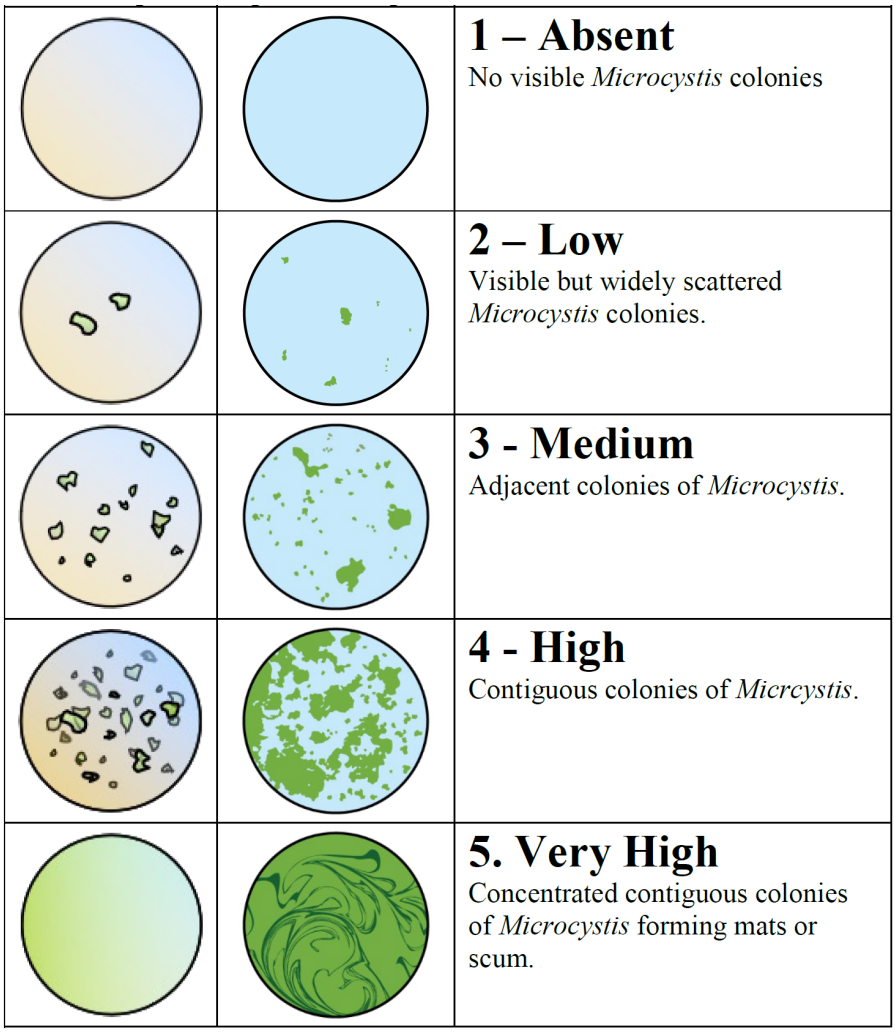


Figure 3
Scale for visual *Microcystis* index used by monitoring programs in the Delta.

Visual assessment data will be collated from five surveys, with additional surveys added if more become available. These data were subset to only include observations during the summer and fall, June-October, since this is the time frame when cyanoHABs usually occur. Total observations varied by region of the Delta and year, but ranged from 452-1246 data points per summer:

- The Environmental Monitoring Program (EMP) is conducted jointly by DWR, the California Department of Fish and Wildlife (CDFW), and Reclamation and collects water quality, phytoplankton, zooplankton, and benthic invertebrate data throughout the Delta, Suisun Bay, and San Pablo Bay. The EMP has recorded *Microcystis* observations at each of its discrete stations using the scale shown in Figure 3 since fall 2015. EMP also collects data on phytoplankton

community composition via microscopic enumeration of grab samples, allowing an evaluation of which species are contributing to phytoplankton blooms. These data are collected at 24 fixed stations and up to four floating stations each month throughout the year (IEP 2020). These data are published annually on the Environmental Data Initiative repository, and advanced copies of the data will be requested from the PI's if necessary.

- The CDFW Summer Townet Survey samples fixed locations from eastern San Pablo Bay to Rio Vista on the Sacramento River, and to Stockton on the San Joaquin River and a single station in the lower Napa River. The survey runs twice per month during June, July, and August and samples at 40 stations. The survey primarily monitors young-of-the-year fishes, but also measures zooplankton and environmental variables including water temperature (°C), water clarity (Secchi Depth and nephelometric turbidity units [NTU]), and specific conductance (microSiemens per centimeter [µS/cm]). Visual observations of *Microcystis* have been collected since 2007. Data are available via the CDFW website, and advanced copies of the data will be requested from the PI's if necessary.

- The CDFW Fall Midwater Trawl survey samples at fixed locations from eastern San Pablo Bay to the Cache Slough complex and Sacramento Deep Water Ship Channel, on the Sacramento River, and to Stockton on the San Joaquin River. This survey runs once per month during September, October, and November at 122 stations. The survey primarily monitors young-of-the-year fishes, but also measures zooplankton and environmental variables including water temperature (°C), water clarity (Secchi Depth and NTU), and specific conductance (µS/cm). Visual observations of *Microcystis* have been collected since 2007. Data are available via the CDFW website, and advanced copies of the data will be requested from the PI's if necessary.

- DWR's North Central Region Office conducts water quality and cyanoHAB sampling at stations throughout the South Delta. These samples include chlorophyll, nutrients, bromide, and organic carbon. When collecting water samples, the study also measures environmental variables including water temperature (°C), water clarity (Secchi Depth and NTU), specific conductance (µS/cm), and visual *Microcystis* index. Data are available from DWR's Water Data Library platform.

- Reclamation's Directed Outflow Project samples at randomly selected stations throughout Suisun Bay, Suisun Marsh, and the

Delta in coordination with the U.S. Fish and Wildlife Service Enhanced Delta Smelt Monitoring Program. This program primarily collects zooplankton and water quality samples, as well as environmental variables including water temperature (°C), water clarity (Secchi Depth and NTU), specific conductance (µS/cm), and visual *Microcystis* index.

- USGS California Water Science Center began collecting visual *Microcystis* observations during their water quality cruises in the fall of 2020. These cruises conduct both continuous, high-speed water quality mapping as well as discrete grab samples for nutrients. Provisional Data will be obtained from the PI. DWR has contracted with USGS for additional water quality cruises in support of monitoring the Emergency Drought Barrier and the potential for installing additional drought barriers in future years (Appendix C).

The visual *Microcystis* scale goes from 1 (absent) to 5 (very high). However, because the scale is somewhat subjective and varies between observers, these data will be categorized for this analysis using a three-point scale. Values of 1 were recoded as "absent," values of 2 or 3 as "low," and values of 4 or 5 as "high." First, the difference between incidence of cyanoHABs across the entire Delta will be assessed, to determine any Delta-wide impacts of the TUCP. Then, the data will be broken up into subregions to see whether any subregion has a disproportionately large change in HABs. Regions where HABs were particularly high will receive additional analysis.

An ordered logistic regression (the 'polr' function from the MASS package in R (Ripley et al. 2021)) will be used to test for differences between regions and between years. This regression will be followed by a pairwise post-hoc test using the function 'emmeans' in the emmeans package (Lenth et al. 2021) to evaluate whether drought years had an increased probability of cyanoHAB presence or increased probability of high cyanoHAB presence compared to wet years, and whether there are significant differences between years with a drought barrier (2015, 2021, 2022) and drought years without a barrier (2014, 2016, 2020).

Community Composition

The EMP also provides data on phytoplankton community composition via microscopy from subsurface grab samples, allowing a determination of which species are contributing to phytoplankton blooms. These data are collected at 24 fixed stations and two stations that track the location of the salinity field each month throughout the

year. Phytoplankton samples are collected with a submersible pump from a water depth of 1 meter below the water surface. Samples are stored in 50-milliliter (mL) glass bottles with 2 mL of Lugol's solution to act as a stain and preservative. Samples are analyzed by BSA Environmental Services, Inc. (Beachwood, Ohio). Phytoplankton are identified to the lowest taxonomic level possible using the Utermöhl method and American Public Health Association standard methods (APHA 2017; Utermöhl 1958). Additional data on community composition of harmful algae were collected at Banks Pumping plant and Clifton Court Forebay, associated with cyanotoxin sampling. We will subset these data to show only cyanoHABs species, defined as species in the genera *Anabaeopsis, Aphanizomenon, Cylindrospermopsis, Dolichospermum*, and *Microcystis*. While *Microcystis* is occasionally collected by these grab samples at one meter depth, it is better assessed by surface tows. We include these data to provide an idea of which taxa were present in the community but should not be taken as a quantitative assessment of *Microcystis* abundance.

Nutrients and discrete chlorophyll

Nutrient data (ammonium, nitrate + nitrite, and ortho-phosphate) will be collected from three sources:

1. The EMP, which collects discrete water quality grab samples at all stations where samples for phytoplankton community composition are collected. Water is collected using a flow-through system whereby it is pumped into the ship-board laboratory from a fixed intake located one meter below the water's surface or from a Van Dorn water sampler or via a submersible pump (IEP 2020). Analyses are performed for dissolved ammonia, dissolved nitrate + nitrite, total Kjeldahl nitrogen, total phosphorus, and dissolved orthophosphate by CDWR's Bryte Laboratory using EPA methods or Department-approved modifications of these methods (IEP 2020).

2. DWR's North Central Region Office (NCRO) collects discrete nutrient and chlorophyll-a data at six locations in the Central Delta surrounding Franks Tract. Chlorophyll-a samples were collected routinely from 2014-2021, while nutrient samples were only collected in 2014-2016 and 2021. Water is collected from a Van Dorn water sampler at a depth of one meter (DWR 2022). Samples were analyzed by DWR's Bryte Laboratory using EPA methods or Department-approved modifications of these methods (IEP 2020).

3. USGS has two programs that routinely collect discrete nutrient and chlorophyll-a data in the Delta: the California Water Science Center (CAWSC) and the San Francisco Bay Water Quality Survey (SFBS). CAWSC collects samples at numerous locations throughout the Delta, while the SFBS collects most of their samples downstream of the Delta with a few locations extending into the Delta. The SFBS has been collecting discrete water quality samples from 1969 to present, while the CAWSC began collecting samples more recently.

Data from 2022 will be plotted across the Delta separated by region to show trends across the summer. Data will then be subset to include stations in the Lower Sacramento, Lower San Joaquin, and South Delta (where cyanoHABs are most frequent) and summarized by month and year. We will run a generalized linear mixed model on each constituent using the formula Concentration ~ Year + Season + Error(Month) + Error(Station) to see whether nutrients or chlorophyll in 2022 were different from previous years using the lme4 package. We will perform a tukey post-hoc test on all pairwise comparisons and visualized significant differences between years using the estimated marginal means for the 'emmeans' package.

Nutrients are frequently identified as a driver for cyanoHABs, but nutrients are seldom limiting for phytoplankton production in the Delta. It is instructive to compare actual measured chlorophyll concentrations with potential chlorophyll concentrations that could be expected if all the available nitrogen in the water (i.e. the residual nitrogen) were converted to chlorophyll biomass to assess the phytoplankton biomass accumulation (i.e. bloom development) potential of a particular region. To perform this comparison, residual nitrogen concentration will be converted to chlorophyll using the ratio 1 µmol N: 1 µg chlorophyll a (Gowen 1992, Cloern and Jassby 2012). Residual nitrogen will be calculated by summing all the dissolved inorganic nitrogen species (nitrate + nitrite + ammonium) in units of molar mass N. Potential chlorophyll will be compared with measured chlorophyll for each region of the Delta for the summers of 2014-2020, and for the summers of 2021 and 2022.

Cyanotoxin Data

Cyanotoxin data will be assembled from multiple sources. These studies all use either ELISA or LCMS to analyze toxin concentrations. There is generally very high agreement between these two methods,

though ELISA may produce higher concentrations ((Preece et al. 2021)Table 3). Across most of the national HAB research community, data from either method are compared to thresholds and there is no conversion factor applied, nor is one method disregarded.

- The State Water Board's freshwater HAB program collects samples for cyanotoxins when large blooms are reported (https://www.waterboards.ca.gov/water_issues/programs/swamp/freshwater_cyanobacteria.html). Samples are lysed and analyzed for total microcystins/nodularins using the enzyme-linked immunosorbent assay (ELISA) method and using qPCR to detect the number of microcystin-producing cells present. Analyses are conducted by Bend Genetics, LLC, Sacramento, CA. The Water Board's HAB program also provides a platform for storage and display of other HAB occurrences collected by other programs. We will work with Karen Atkinson and other data managers to access all relevant cyanotoxin and cyanobacteria data collected over the time period of the TUCP.

- DWR collects cyanotoxin samples at Clifton Court Forebay and the Harvey O. Banks Pumping Plant (Banks Pumping Plant) to ensure that the water exported from the Delta is safe for use. Samples are collected every two weeks in April–October and analyzed by GreenWater Laboratories (Palatka, Florida), using a tiered approach. Samples are first assessed via microscopy to identify whether potentially toxic algae or cyanobacteria are present. If potentially toxic algae are detected, cells are lysed and samples are then tested for probable toxins using either ELISA or liquid chromatography–mass spectrometry (LC-MS), as appropriate (Foss and Aubel 2015).

- Through a special study conducted collaboratively by USGS and DWR with funding from the Delta Regional Monitoring Program, samples are collected at several stations throughout the Delta: Jersey Point (JPT), Decker (DEC), Middle River (MDM), Liberty Island (LIB), Rough and Ready Island (P8, DWR-EMP), and Vernalis (C10; DWR-EMP). For these efforts, cyanotoxins are being measured in whole water discrete samples as well as using Solid Phase Adsorption Toxin Tracking (SPATT) samplers every two to four weeks. All (100 percent) of these cyanotoxin samples will be analyzed using LC-MS, and—upon review of LC-MS data—a subset (approximately 20 percent) will be selected for analysis using ELISA. All analyses will be conducted by Lumigen Instrument Center, Wayne State University, Detroit, MI.

Preliminary data from water quality samples will be requested from the PIs.

- Under a Proposition 1 Grant, principal investigators (PIs) David Senn (SFEI), Janis Cooke (CVRWQCB), Ellen Preece (Robertson-Bryan, Inc), and Timothy Otten (Bend Genetics), are conducting a study of bioaccumulation of cyanotoxins in invertebrates at ten stations throughout the Delta. The study, "Identifying cyanobacterial harmful algal bloom toxins in Delta invertebrates: implications for native species and human health", includes analysis of Asian clams (*Corbicula fluminea*), crayfish, and whole water samples. Samples are collected monthly in the winter and every two weeks during the summer and analyzed for microcystins by Bend Genetics using ELISA. Preliminary data from water quality samples will be requested from the PIs.

- East Bay Regional Parks conducts sampling at Big Break Regional Shoreline where they visually inspect the water for signs of cyanobacteria twice per month. If signs of cyanobacteria are detected, they conduct microscopy and toxin analysis using Abraxis CAAS ELISA. Preliminary data from water quality samples will be requested from the PIs.

- DWR is also conducting additional cyanotoxin sampling in the vicinity of the Emergency Drought Barrier and South Delta Temporary Ag Barriers to assess the impacts of the Barriers and TUCP on cyanotoxins. All toxin analyses will be conducted by GreenWater. See attached study plans (Appendix A and B) for more information.

- Restore the Delta, a local community group, is currently working with the Central Valley Regional Water Board to implement a new citizen science program to monitor cyanotoxins near Stockton and other areas of high recreational use. They will be posting testing results to their website starting in May of 2022, and any additional data will be obtained from their science coordinator, Spencer Fern (spencer@restorethedelta.org).

None of the cyanotoxin data presented here are part of a comprehensive monitoring program. The USGS/DWR SPATT study and the Prop 1 Senn/Preece/Cooke/Otten studies were designed as special studies to better understand toxin dynamics rather than to establish a baseline. The Regional Board data is designed as a response to severe blooms, not a comprehensive monitoring program. The DWR Banks/CCF monitoring is designed specifically to assess water quality

for water export, so is not necessarily applicable to the rest of the Delta. While there may be some variation between testing laboratories and field collection procedures, all methods are considered comparable and can be used for health advisories. Combining these data sets does provide a relatively wide spatial and temporal scope of cyanotoxin monitoring, though it may miss small-scale or short-lived toxin events, particularly in smaller, backwater sloughs in the Delta.

FluoroProbe Data

The EMP and USGS both employ vessels equipped with high-resolution sensors that collect data continuously on both water quality and phytoplankton community composition while underway. During these surveys, the EMP monitors water quality using a YSI EXO2 water quality sonde (Xylem, Inc.) to measure pH, turbidity, specific conductance, chlorophyll a (with the Total Algae™ sensor), dissolved oxygen (DO), and water temperature. Both surveys monitor the phytoplankton community's composition using a FluoroProbe instrument (bbe moldaenke GmbH, Schwentinental, Germany) that differentiates cyanobacteria, diatoms, green algae, and chlorophytes based on the wavelength of the fluorescence given off by each taxonomic group's characteristic photopigments.

DWR has contracted with USGS to provide additional mapping cruises in the vicinity of Franks Tract and the North Delta (see task order attached, Appendix C)

FluoroProbe data collected by both the EMP and USGS are processed following the methodology described in the Methods PDF of the USGS data release at www.doi.org/10.5066/P9FQEUAL (Bergamaschi et al. 2020). Briefly, data are spatially aligned to equally spaced polygons spaced at approximately 150 meters. Interpolated values are calculated in ArcGIS using the Spline with Barriers tool (Terzopoulos and Witkin 1988) and used to create a continuous map of values (e.g., the concentration of chlorophyll a from blue-green algae) across the mapped domain.

Satellite Data

Satellite data, available from the San Francisco Estuary Institute's HAB Satellite Analysis Tool (SFEI 2021), can provide estimates of CyanoHAB abundance with broader spatial scale and higher temporal resolution than grab samples and visual observations. Satellite imagery is collected by the Copernicus Sentinel-3 mission and provides images of the Delta every 1-2 days. The HAB Satellite Analysis Tool

provides estimates of CyanoHAB abundance in the upper 1 meter of the water column by measuring the absorption of light by chlorophyll and phycocyanin, an accessory pigment in photosynthesis specific to cyanobacteria. Estimates of CyanoHAB abundance are reported in an exponential, satellite-specific, unitless metric called the Cyanobacteria Index (CI) for pixels with dimensions of 300 meters by 300 meters, each approximately an area of 22 acres. The Cyanobacteria Index is derived from post-processing methods established by the National Oceanic and Atmospheric Administration's National Ocean Service (Wynne et al. 2018). Because of the limitations of the satellite-based sensor in distinguishing subtle differences in absorption from cyanobacteria at levels that are very low (CI of 6.310×10^{-05} is near natural background levels of cyanobacteria) or very high (CI of 6.327×10^{-02} in extremely dense scums), minimum and maximum detectable levels have a smaller range than are possible using traditional water grab samples. Because the smallest pixel available is 22 acres, only larger areas of open water, such as Franks Tract, can be analyzed. Smaller sloughs are not large enough for accurate classification. Further information on these methods are detailed on the National Ocean Service website: https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-monitoring-system/more-information/

Satellite mosaics of rasterized CI data across the Central Delta for June–October in 2020-2022 will be downloaded from the San Francisco Estuary Institute's HAB Satellite Analysis Tool (SFEI 2021). Raster pixels for four open water regions in the Delta (Franks Tract, Clifton Court Forebay, Liberty Island, and Mildred Island) will be extracted from each file using the 'exactextract' function in the 'exactextractr' R package version 0.7.1 (Baston 2021). The four open water regions were defined using polygons from CDFW expanded by 200 meters around their perimeters to account for the large raster pixels. Pixels will be categorized into four CI categories (Low, Moderate, High, and Very High) based on WHO recreational guidance level thresholds (WHO 2021).

Continuous Water Quality Data

DWR and USGS maintain a network of water quality sondes that collect data continuously (i.e., every 15 minutes) across the Delta. These sondes collect data on water temperature, specific conductance, flow, dissolved oxygen, chlorophyll fluorescence, turbidity, and pH (though not all stations contain all sensors). To assess how HABs impact water

quality parameters, we will plot the daily mean of data collected at stations where harmful algal blooms occurred versus day of the year for the past eight years (2015-2022).

To see how extended periods of high temperatures may drive harmful algal blooms, we will calculate the number of degree-days over 19 degrees C by averaging the daily maximum and minimum water temperature at seven stations in the South Delta. This was converted to degree-days using the formula:

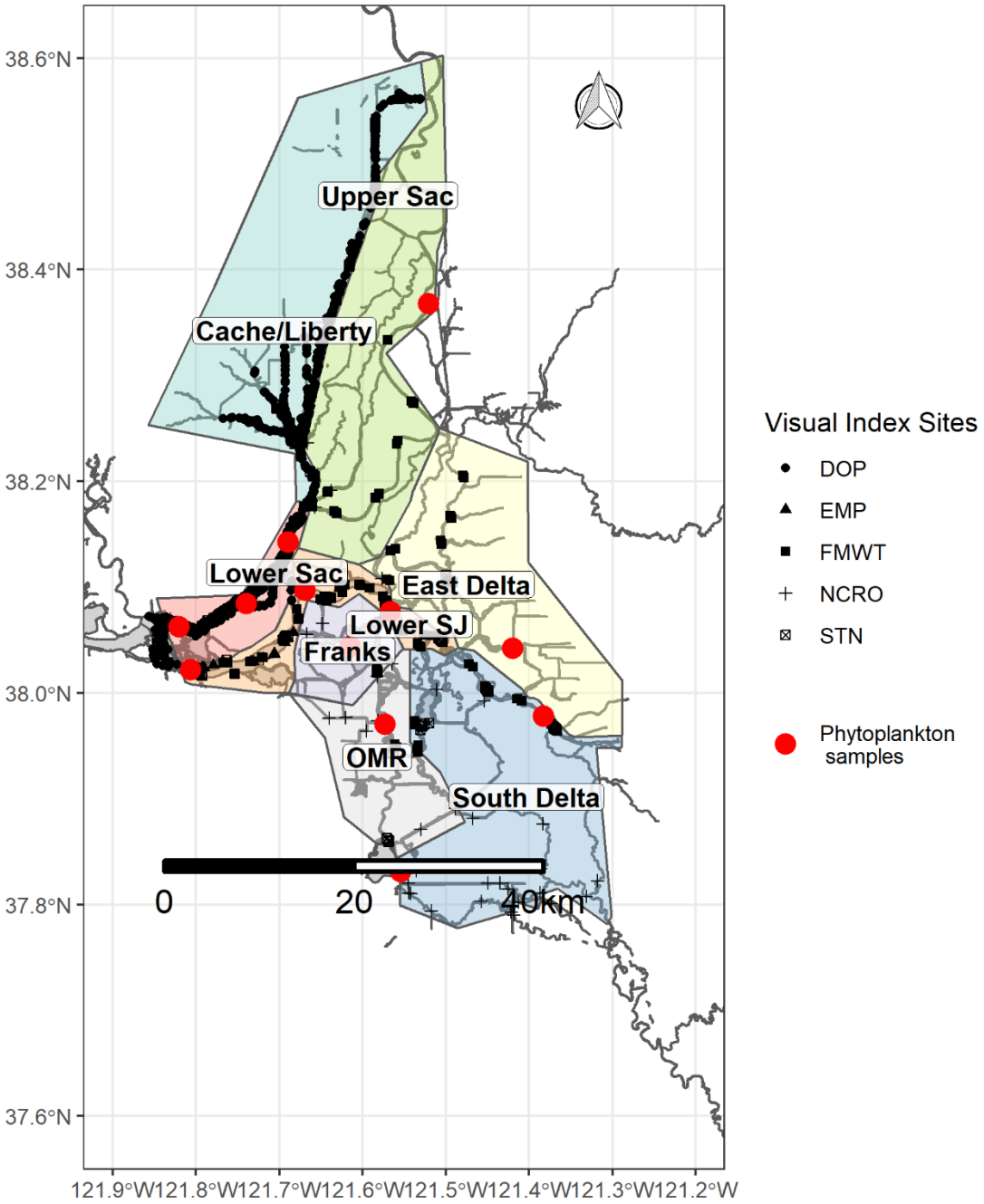
Degree Days = (Daily Max Temp – Daily Min Temp)/2 – 19

We will conduct the degree-day analysis using both water temperature and air temperature, to see whether air temperature patterns were similar to water temperature patterns.

Table 1. Stations used for continuous water quality and air temperature analyses.

Station Code	Station Name	Latitude	Longitude	Sensors
FAL	False River near Oakley	38.05547	-121.667	Chlorophyll, DO, Specific Conductance, Water Temperature, Turbidity
HOL	Holland Cut Near Bethel Island	38.01582	-121.582	DO, Specific Conductance, Water Temperature, Turbidity
HLT	Middle River near Holt	38.00308	-121.511	Chlorophyll, Specific Conductance, Water Temperature, Turbidity
ORQ	Old River at Quimbly	38.02712	-121.565	Specific Conductance, Temperature, Turbidity
OSJ	Old River at Franks Tract near Terminous	38.07125	-121.578	Chlorophyll, DO, Specific Conductance, Water Temperature, Turbidity
FRK	Franks Tract Mid Tract	38.04642	-121.598	Chlorophyll, DO, Specific Conductance, Water Temperature, Turbidity, pH
MDM	Middle River at Middle River	37.9430	-121.534	Chlorophyll, Flow, Specific Conductance, Water Temperature, Turbidity
SJR	San Joaquin R Mccune Station	37.6789	-121.265	Air Temperature
HBP	Harvey O Banks Pumping Plant	37.8019	-121.6203	Air Temperature

MSD	San Joaquin River at Mossdale	37.7860	-121.3060	Air Temperature



NOTE: Analysis to assess the impact of the 2021 Emergency Drought Barrier will focus on the Lower Sacramento, Lower San Joaquin, and Southern Delta. Analysis to assess the impact of the TUCP will encompass the entire area.

Figure 4
Stations for long-term monitoring programs contributing *Microcystis* visual

observations (black), and phytoplankton grab samples (red) in 2021. Additional sampling by USGS will be integrated in the 2022 report

Hydrodynamic Modeling and Flow

To assess changes in residence time and temperature, three-dimensional simulations will be carried out using the Bay-Delta SCHISM three-dimensional circulation model (Ateljevich et al. 2014), which is an application of the Semi-implicit Cross-scale Hydroscience Integrated System Model (Zhang et al. 2016). Mean water age is used as a surrogate for residence time, evaluated using the Constituent oriented Age and Residence Time theory or CART (Deleersnijder et al. 2001) and the formulation described by Delhez et al. (2014). This method uses pairs of supplementary tracer transport equations to evolve the mean age of water at each point in the domain; the method naturally incorporates multiple pathways of travel and dispersion and is an economical tool for evaluating spatial patterns. "Age" in this case is defined as the time of last contact with the San Joaquin River. Quantitative results within Franks Tract are sensitive to assumptions concerning the vegetation field. Vegetation will be included using the method of Zhang et al. (2020), which was originally tested in Franks Tract using spatial patterns of vegetation inferred from hyperspectral imagery from 2015 (Ustin et al. 2016).

Data limitations

The datasets assembled as part of this monitoring effort will broadly document cyanobacteria and other potentially harmful algal blooms in the Delta during 2021 and 2022 by virtue of the wide range of different data sets. However, each of these data sets has certain limitations.

Uses and limitations of each data set are as follows:

- Visual index data provides a spatial and temporal scope, and a good indicator of Microcystis presence, but cannot provide a quantitative measure of Microcystis concentration and is not appropriate for other CyanoHAB taxa.

- Chlorophyll fluorescence data collected with a sonde provides continuous data on chlorophyll concentrations, but cannot distinguish between cyanobacteria and other phytoplankton. It also does not accurately quantify

chlorophyll in surface films or cyanobacteria that forms colonies or clumps.

- Chlorophyll-a data collected with grab samples and analyzed in a laboratory is more accurate than sonde data but may also miss surface-oriented cyanobacteria and cannot distinguish between cyanobacteria and other phytoplankton. Grab samples may also miss the peak of the bloom.

- Grab samples collected and analyzed with microscopy provide the best taxonomic resolution. However, samples collected by EMP are collected at 1-meter depth, so may miss surface-oriented cyanobacteria, such as *Microcystis*. While these samples identify taxa that are present, they do not indicate whether the taxa present are made of strains capable of producing toxins, nor whether they were producing toxins at the time of collection.

- Chlorophyll and phycocyanin data collected during high-speed mapping cruises using the Fluoroprobe provide data on a broad spatial scale and can distinguish between cyanobacteria and other algae but are limited in temporal scope. The Fluoroprobe also cannot distinguish between types of cyanobacteria (not all cyanobacteria are harmful).

- Satellite data provides broad spatial scope, however it cannot quantify low concentrations of cyanobacteria, nor can it distinguish between types of cyanobacteria (not all cyanobacteria are harmful). This data also cannot quantify cyanobacteria in small channels.

- The incident data reported to the State Board's Cyano-HAB portal relies on agencies and members of the public submitting reports, which may not be consistent over space and time. Many of these reports are based on visual observations rather than cyanotoxin data. However, these reports provide better coverage of marinas, boat ramps, and other places where the public regularly comes in contact with the water than other areas.

- Toxin data provides the most accurate assessment of potential harm caused by an algal bloom. However, unless sampling occurs on a daily basis, it may not characterize the toxicity over the entire time period. Furthermore, the

ecological and human health impacts of some cyanobacterial metabolites (such as anabaenopeptins) are still unknown.

AQUATIC WEEDS

Background

Ecology and Impacts

Aquatic vegetation provides important structure and function for aquatic organisms and waterfowl and greatly influences nutrient cycling, water quality, and the stability of sediments (Caraco and Cole 2002; Miranda et al. 2000). Diversity of fish and invertebrate species tends to be greater in native aquatic plant beds, and water quality conditions are generally more favorable for native fish and invertebrates (Boyer et al. 2013; Kuehne et al. 2016; Toft et al. 2003). Alternatively, non-native aquatic plants can have dramatic spatial and temporal effects on DO, temperature, and pH (Caraco and Cole 2002; Frodge et al. 1990) and can affect fish and macroinvertebrates (Brown 2003; Nobriga et al. 2005; Schultz and Dibble 2012).

Aquatic vegetation is commonly discussed in terms of their growth forms: submerged aquatic vegetation (SAV), emergent aquatic vegetation (EAV), and (3) floating aquatic vegetation (FAV) (Boyer and Sutula 2015). SAV grows predominantly below the water's surface and may or may not be rooted in the sediment. Examples of SAV found in the Delta include Brazilian waterweed (*Egeria densa*), coontail (*Ceratophyllum demersum*), and Canadian waterweed (*Elodea canadensis*). EAV is rooted in shallow water, with the majority of its growth occurring above the water's surface. Examples include cattail (*Typha* spp.), tules (*Schoenoplectus spp*.), and common reed (*Phragmites australis*). FAV floats on the water's surface and is not rooted in the sediment. An example of FAV in the Delta is water hyacinth (*Eichhornia crassipes*), though creeping emergents such as water primrose (*Ludwiggia spp*.) and alligatorweed (*Alternanthera philoxeroides*) are also frequently categorized as "FAV".

Weeds in the Delta

Coverage by FAV and SAV in the Delta has increased over the past 20 years (Ta et al. 2017), with particularly high increases seen during the last drought (Kimmerer et al. 2019). From 2008 to 2019, aquatic

vegetation increased in coverage by 2.4 times (7,100 acres to 17,300 acres), occupying nearly one-third of the area of Delta waterways (Ta et al. 2017; Ustin et al. 2020). This expansion of SAV has caused a suite of problems for use of the Delta, including clogging of water infrastructure, navigation hazards, and difficulty conducting scientific surveys (Caudill et al. 2021; Khanna et al. 2019). There have also been major changes to ecosystem functions, including increased water clarity (Hestir et al. 2016), changes to nutrient cycling (Boyer and Sutula 2015), reduction in sediment supply for tidal marshes (Drexler et al. 2020), increased invasive fish habitat (Conrad et al. 2016), changes to primary production (Cloern et al. 2016), and changes to invertebrate community composition (Young et al. 2018) .

Impacts of submerged vegetation in the Delta have become severe enough that management has intervened to mitigate the impacts on human use of the waterways. The Aquatic Invasive Plant Control Program of the California Department of Parks and Recreation, Division of Boating and Waterways (DBW) is chiefly responsible for aquatic vegetation control in the Delta and employs primarily chemical control tools. DBW is permitted to treat up to 15,000 acres per year of aquatic vegetation, but typically treats only about 40 percent of that limit (DBW 2020).

Drivers

Factors contributing the biomass of aquatic vegetation include parameters that impact growth and photosynthetic rate, parameters that impact establishment, and top-town effects of grazers and herbicides, which we have organized into a conceptual model (Figure 5). Photosynthetic rate is controlled by, light, sediment nutrient availability, and water temperature (Barko and Smart 1981; Chambers et al. 1991; Riis et al. 2012). In general, photosynthesis rates are largely driven by light levels; they increase from sunrise, peak at midday, then slowly decline in a fairly predictable manner. Light levels are also highest during mid-summer and decline during the fall. However, light available to an individual plant will vary with water depth, and water clarity. The maximum depth of plant growth is typically driven by the maximum depth to which light penetrates the water column to support photosynthesis and can vary greatly between species (Chambers and Kalff 1987). Increased water clarity allows for greater light penetration for photosynthesis to occur. In many cases, this can cause a feedback loop whereby the presence of SAV lowers water velocity and increases sediment deposition which increases water clarity and promotes further growth (Hestir et al. 2016; Petticrew and Kalff 1992). Increased water clarity in the Delta has

been implicated in the increased spread of Brazilian waterweed (Durand et al. 2016), and the increase in Brazilian waterweed has been implicated in increasing water clarity and the reduction in sediment transport to tidal wetlands (Drexler et al. 2020; Hestir et al. 2016).

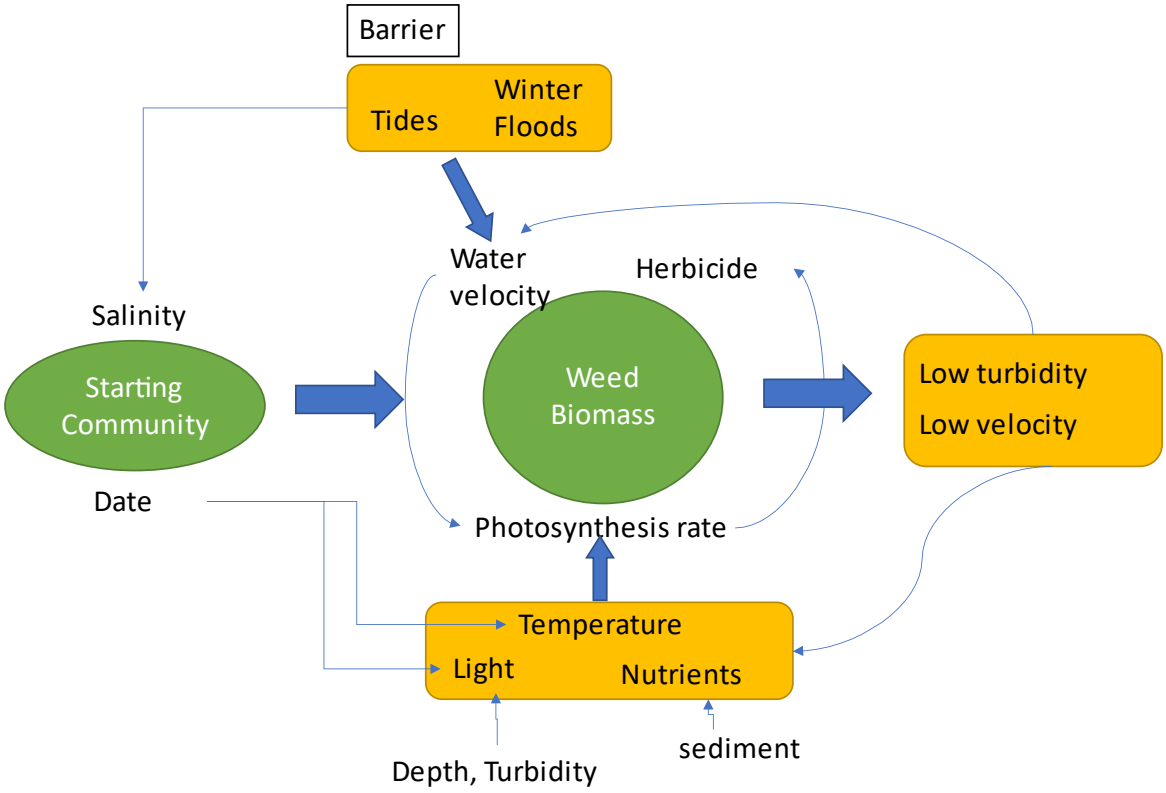


Figure 5. Conceptual model of aquatic weed biomass in the Delta.

Higher temperatures, in general, increase photosynthetic rate and therefore vegetation growth rate. The combination of high water temperatures with high light availability in the summer means that this is when most plants experience their highest growth, with peak biomass occurring in the fall. However, temperature tolerances will vary by species, and extremely high temperatures will lead to reduced growth or senescence.

Nutrients are also key for driving photosynthetic rate, and, unlike cyanoHABs, vegetation may acquire nutrients from the water or the sediment. Rooted SAV and EAV obtain the majority of their nutrients from the sediment, particularly nitrogen and phosphorus (Barko et al. 1991), but many submerged plants can also acquire nutrients directly

from the water column. During plant decomposition, this interface provides a mechanism for nutrient recycling between the sediment and the overlying water column. Factors that can affect rates of decomposition, and hence nutrient cycling, include the diversity of the plant community (Banks and Frost 2017) and water temperature (Carvalho et al. 2005). True FAV that is not rooted in the sediment must acquire all their nutrients form the water column. Increases in nutrients, such as those seen during 2013–2014, may facilitate the expansion of aquatic vegetation, although this effect is less conclusive (Boyer and Sutula 2015; Dahm et al. 2016).

Both SAV and EAV establish more readily in slower-moving water, so low-flow conditions that occur during droughts have been linked to increases in coverage of invasive vegetation. During the winter, high velocities that occur during floods may prevent vegetation from establishing or flush established vegetation out of the system. Also, water temperatures are cooler, turbidity is higher, and water is deeper, limiting vegetation regrowth immediately after floods. During the summer, velocity patterns are dominated by tides, so changes to outflow play a smaller role in control of SAV. However, changes to the physical structure of the Delta, such as installation of barriers and growth of vegetation itself, will have a large role in impacting local velocity patterns. For example, changes to flow patterns caused by the 2015 emergency drought barrier were implicated in the expansion of submerged vegetation in Franks Tract (Kimmerer et al. 2019).

Top-down control of vegetation occurs as grazing by invertebrates and treatment with herbicides. A variety of herbivorous insects occur on FAV and SAV (Marineau et al. 2019; Young et al. 2018), and several biocontrol agents have been released in the Delta to help control invasive vegetation (Caudill et al. 2021; Reddy et al. 2019). However, none of these herbivores appears to be limiting growth of vegetation in the Delta.

Human control efforts have had mixed success. For control of FAV, DBW most commonly uses glyphosate but also uses some imazamox and 2,4-D. For SAV control, fluridone is by far the most commonly applied herbicide in the Delta. However, recent studies have shown the use of fluridone on SAV in tidal environments such as the Delta to be generally ineffective (Khanna et al. in review; Rasmussen et al. in press). Therefore, this treatment program may increase the loading of herbicides into the system without significantly affecting weed abundance. Treatment of FAV with herbicides is thought to be somewhat more effective, although there are noticeable changes in

water quality post-treatment (Portilla and Lawler 2020; Tobias et al. 2019).

When growth conditions favor SAV in general, the community composition of an SAV patch will depend on salinity, starting community, transport of propagules, and light availability. Some invasive SAV species, such as Brazilian waterweed, are adapted to low-light conditions, which enables rapid elongation of shoots and subsequent canopy formation that further blocks light to other native SAV species. Different species of SAV also have varying temperature tolerances that factor into their life history patterns. For example, curlyleaf pondweed (*Potamogeton crispus*) commonly sprouts early in the growing season and can outcompete native SAV species that are not tolerant of lower water temperatures (Stuckey 1979). Species also vary in their salinity tolerances, with the native *Stukenia pectinata* having a higher salinity tolerance than the invasive *Egeria densa* (Borgnis and Boyer 2015). There are also species-specific sensitivities to different herbicides, leading to altered community composition in areas that receive herbicide treatment (Caudill et al. 2019).

Drought Barrier and TUCP

Drought conditions are predicted to cause an increase in invasive FAV and SAV due to the lack of winter floods. The April-June TUCP, which reduces spring outflow, is not expected to significantly impact vegetation establishment or growth because water velocities, and thus establishment of weeds, is dominated by tides during this time period.

While the TUCP is expected to have minimal impact on weeds, installation of the EDB is expected to cause a local increase in aquatic weeds in Franks Tract. With the Barrier in place, tidal velocities on the western side of the tract decrease while velocities in Fisherman's Cut and the eastern side of the tract increase. In 2021, installation of the Barrier may have caused an increase in weeds in the western side of the tract and a decrease in weeds in the high flow region on the eastern side (Hartman et al. in prep). Similarly, in 2015, weeds spread across the middle of Franks Tract, and the area was not cleared when high flows returned (Kimmerer et al. 2019). This was attributed to the decrease in water velocity through the center of the tract. A similar response to the 2022 EDB is expected, although the high coverage by weeds within Franks Tract over the past several years will make detecting a response difficult.

Methods

Three sources of data will be used to evaluate whether the 2022 TUCP and the 2021-2022 EDB contributed to changes in the abundance and/or species composition of aquatic weeds. The first two data sets are from the Center for Spatial Technologies and Remote Sensing (CSTARS) at the University of California, Davis. These data sets consist of (1) hyperspectral imagery that classifies the types of aquatic vegetation growing across the Bay-Delta landscape and (2) the vegetation field surveys used to ground-truth this hyperspectral imagery. (3) The third data set, collected by SePRO Corporation (SePRO), consists of annual field surveys of SAV in Franks Tract and is used to assess the efficacy of herbicide treatments at this site.

Hyperspectral Imagery

Since 2004, hyperspectral airborne imagery has been collected by fixed-wing aircraft over the Delta in many years, although the time of year and spatial extent of these surveys has varied. Franks Tract has been included in all surveyed years (2004-2008, 2014–2021). DWR will contract for additional years of imagery in the summer of 2022 and 2023.

It is difficult to differentiate potential impacts of the Barrier and TUCP on the abundance and composition of aquatic vegetation from impacts simply caused by drought. However, it is useful to compare changes in Franks Tract to those at similar sites not influenced by the Barrier (Figure 6). Previous studies have used Big Break as a reference site for Franks Tract because it is near Franks Tract but not influenced by the barriers (Kimmerer et al. 2019). Clifton Court Forebay was also chosen because it shares some similarities to Franks Tract in size, bathymetry, and hydrology and is far from the influence of the 2021-2022 EDB. Imagery for this site is available for ten of the 13 years for which there is Franks Tract imagery: 2004-2008, 2014, 2015, and 2019–2021. Mildred Island was also considered as a candidate reference site but was ultimately rejected because this site is too turbid to produce accurate classification maps of SAV using hyperspectral imagery.

Another challenge to isolating impacts of the Barrier and TUCP on aquatic vegetation is the use of herbicides for vegetation management. Herbicide treatments have been conducted at Franks Tract and Clifton Court Forebay, and the timing, type, and amounts of chemicals used in these treatments have varied among sites and years.

Survey and analysis methods for the hyperspectral imagery have varied somewhat among years, but the approach generally proceeds as described here for the 2018 survey. During this survey, HyVista Corporation (Sydney, Australia) used the HyMap sensor (126 bands: 450–2,500 nanometers, bandwidth: 10–15 nanometers) to collect imagery at a resolution of 1.7 meters by 1.7 meters. A diverse suite of inputs was derived from these images to capture reflectance properties across different regions of the electromagnetic spectrum, which track biophysiological characteristics useful for distinguishing types of plants. These intermediate inputs were generated using IDL scripts (IDL 8.01, ITT Visual Information Solutions) in ENVI (ENVI 4.8, ITT Visual Information Solutions).

Concurrent with imagery collection, ground-truthing surveys will be conducted to determine species composition at points across the Delta region (e.g., 2018: 950 points; see the *Hyperspectral Imagery Ground-Truthing* section for details). Field data will be divided into training and validation subsets for image classification and independent validation of class maps. Training and validation polygons will be overlaid on the raster images with generated inputs, and corresponding pixels within the raster images will be extracted using the R statistical computing language (version 4.0.2, R Core Team 2021) and packages 'sp' (version 1.4.5) (Pebesma and Bivand 2021), 'rgdal' (version 0.5.5) (Bivand et al. 2021), and 'rgeos' (version 1.5.23).

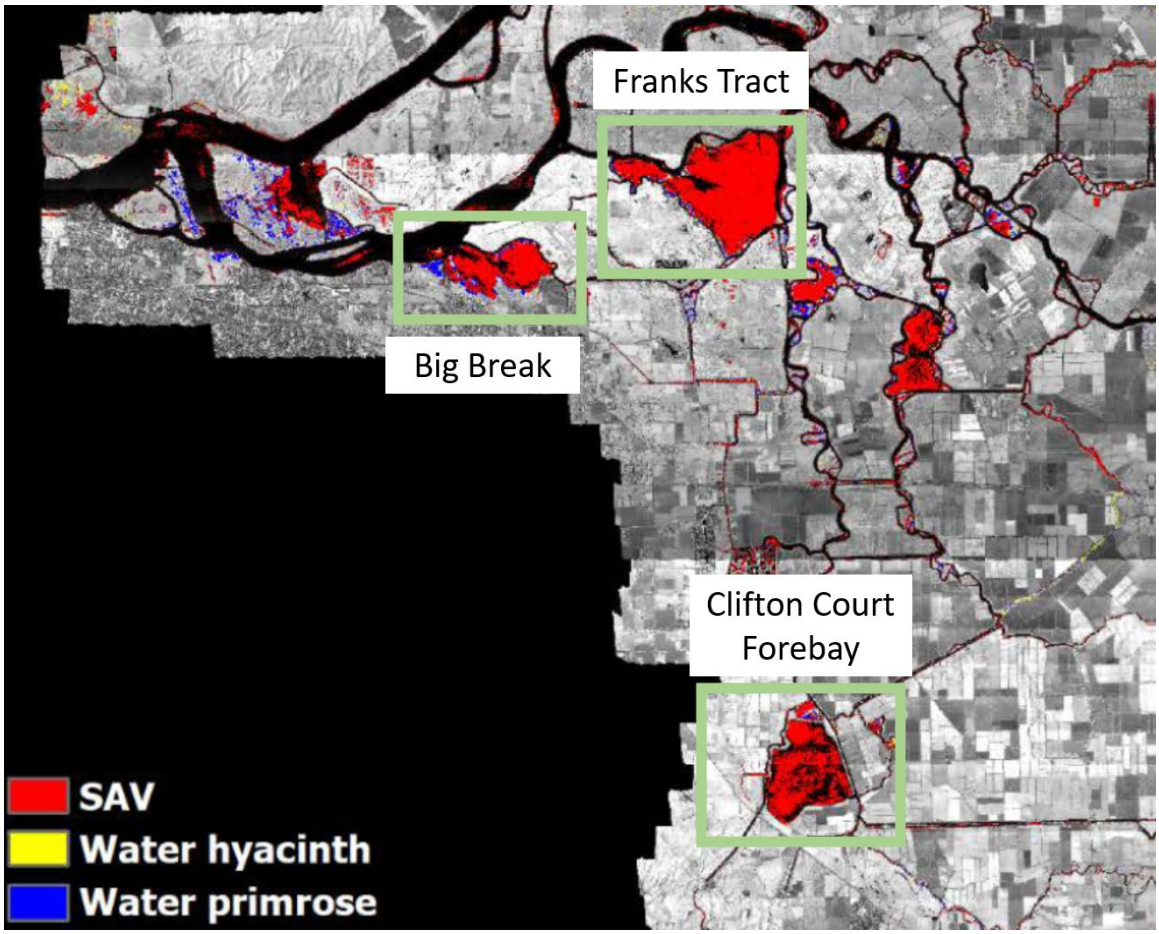


Figure 6
Map of the central and south regions of the Delta for 2019 showing the locations of Franks Tract and the two reference sites, Big Break and Clifton Court Forebay.

Training data will be fed into a Random Forests classifier (packages 'raster': version 3.4.5 (Hijmans 2021) and 'randomforest': version 4.6.14 (Breiman 2001). The best-fit class type (e.g., open water, SAV, water hyacinth, water primrose) for each pixel will be chosen based on consistency across tree predictions. The accuracy of the final maps will be assessed using confusion matrices and Kappa coefficients. The area of SAV will be calculated per site as the number of pixels classified as SAV multiplied by the area of a single pixel. These area calculations will be then used to make comparisons among sites and years. For additional details about the imagery analysis methodology, see Khanna et al. (2018).

Hyperspectral Imagery Ground-Truthing

Around the time that hyperspectral imagery is collected each year, the CSTARS staff collects ground-truthing field data on the community

composition of aquatic vegetation across the Delta, including areas in and around Franks Tract. For SAV sampling, they collect data on the species present at the water's surface and the fraction of surface area covered, Secchi depth, depth of the plant below the water surface, species, and fractional cover using a standard rake sample for vegetation. At sites where FAV and EAV are present, they record the species present, the fraction of surface area covered, the state of the plant (in a flowering or vegetative state versus senescent), and the mat density (classified as sparse, medium, or thick).

SePRO Vegetation Survey

Since 2006, DBW has collaborated with SePRO Corporation to manage SAV in Franks Tract using the herbicide fluoridone (Caudill et al. 2019). SePRO monitors changes in SAV community composition using point-intercept surveys (Madsen and Wersal 2018) conducted on one date annually in the fall. Sampling points are chosen by generating a grid of evenly spaced points projected over the full area of Franks Tract (Figure 7). The number of sampling points varies among years but is usually 100 (range: 50–200 samples). Most surveys have been conducted in mid-October (range: October 1–October 13). To sample each point, SePRO uses a weighted, double-headed, 0.33-meter-wide rake attached to a rope, which is dragged for approximately 3 meters along the bottom and then pulled up to the boat for analysis. All SAV present on the rake is identified to species and species-specific abundances are estimated based on the percentage of the rake each covers. Abundances are recorded using ordinal scores (1 = 1–19 percent, 2 = 20–39 percent, 3 = 40–59 percent, 4 = 60–79 percent, 5 = 80–100 percent). Monitoring data for 2022 will be requested from SePRO as soon as possible after collection.

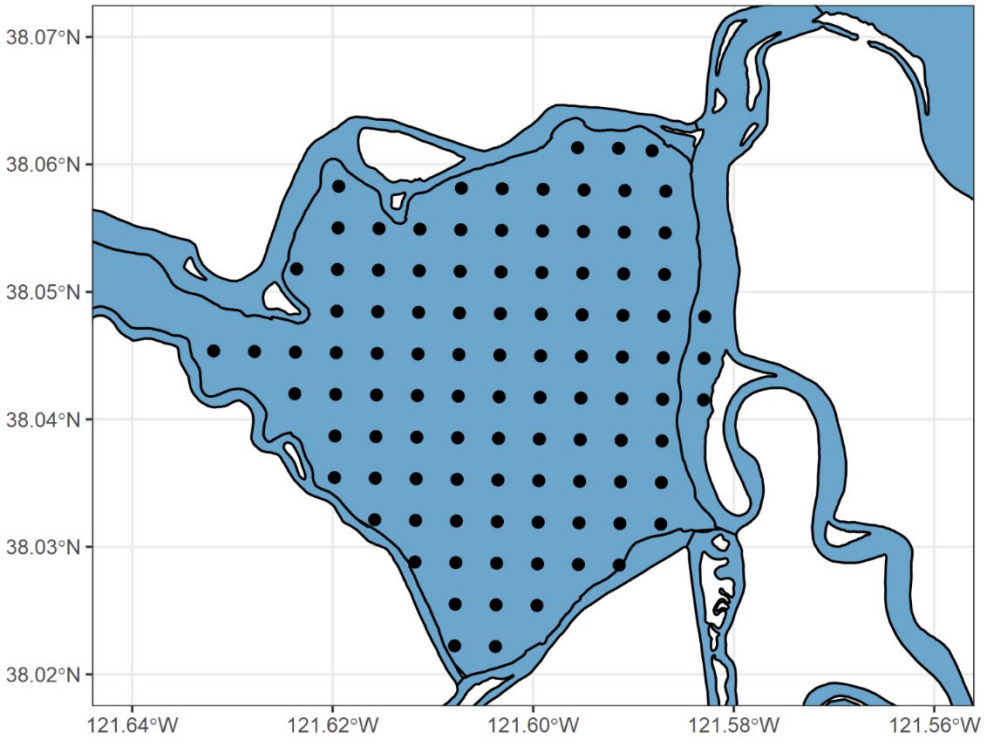


Figure 7
Sampling design for SePRO's annual long-term monitoring of submerged aquatic vegetation in Franks Tract, conducted in conjunction with herbicide treatments.

Environmental drivers and responses

Aquatic weed data will be compared with water quality, flow, and herbicide application data to determine drivers of variation in abundance and composition of aquatic weeds. Variables hypothesized to affect aquatic weeds include measures of flow, turbidity, salinity, temperature, and herbicide applications. Variables hypothesized to be affected by aquatic weeds will also be included in analyses, including dissolved oxygen and pH. Net Delta Outflow data will be obtained from DWR's CDEC station DTO. For water quality, monthly data will be obtained from DWR's EMP station D19 (Franks Tract) and DFW's Bay Study station 853 (San Joaquin River just W of Big Break). Discrete water quality stations were chosen over continuous stations for these two sites because the discrete stations covered most of the parameters of interest for all years of aquatic vegetation monitoring (hyperspectral imagery started in 2004) whereas most continuous station parameters did not. In addition, continuous sonde data will be obtained from DWR station FRK (Franks Tract). For flow and water quality, annual means based on the main growing season for aquatic weeds (March-October) will be used. Herbicide application data for Franks Tract and Clifton Court in 2022 will be obtained from DBW and DWR, respectively.

Data Analysis

For this report, total coverage by aquatic weeds in each region (Sacramento, San Joaquin, and Central) was calculated for 2014–2021, along with the change in coverage between years using hyperspectral imagery as described above. The change in community composition over time from DBW/SePro sample data was assessed via graphs of changes in the relative abundance of each species collected in rake samples.

Hyperspectral Imagery

Vegetation cover changes in Franks Tract and reference sites

To examine changes in coverage of SAV and FAV at the focal sites, the area of each type of vegetation is calculated from the annual classification maps (i.e, pixel size × number of pixels). FAV comprise the combined area of water hyacinth and water primrose, the two most dominant FAV taxa. SAV species cannot be differentiated from the imagery, so SAV is already a combined class. To calculate proportion of each site occupied by SAV and FAV, we will divide the area of each vegetation type by the DBW waterways area for each site. With these data, we will produce time series graphs showing cover for each vegetation type for each site. In addition, we will conduct correlation analyses comparing Franks Tract with each of the reference sites for each of the two types of vegetation. If landscape scale environmental changes, such as droughts, are more important in driving patterns of vegetation cover through time, then Franks Tract and the reference sites should change in similar ways across years (i.e, they should be correlated). If drought barriers affect aquatic vegetation in Franks Tract, then changes in aquatic vegetation cover in Franks Tract may differ from that of the refences sites (i.e, points for drought barrier years stray from the correlation line).

Relationships with environmental drivers and responses

For Franks Tract and the reference site Big Break, we will conduct a series of correlation analyses to determine which environmental drivers and responses (see 3.2.4 Environmental drivers) exhibit a statistically significant relationship with SAV and FAV coverage.

Vegetation cover changes in the broader Delta region

To examine landscape scale changes in aquatic vegetation cover, we will calculate the area for SAV and FAV using the same approach described above for individual sites. We will make these calculations for the largest composite region that includes all years of hyperspectral imagery. This region includes large areas of the North and Central Delta (~one-third of the legal Delta), where aquatic weeds are considered most problematic. The region for the Central Delta ranges from the northernmost extent of Twitchell Island to the southern extent of Rhode Island in the north-south orientation and from the western extent of Sherman Island to eastern extent of Fourteen-Mile Slough in the east-west orientation. The region for the North Delta ranges from the northernmost extent of Liberty Island to the southern extent of Prospect Island in the north-south orientation and the western extents of Lindsey Slough to the eastern extent of Prospect Island.

SePRO Vegetation Surveys

Vegetation composition changes in Franks Tract

To examine changes in SAV community composition in Franks Tract, we will plot times series of data for the ten most common species. We will calculate annual means and standard errors from the ordinal abundance scores.

Relationships with environmental drivers and responses

For Franks Tract and the reference site Big Break, we will conduct a series of Spearman correlations to determine which environmental drivers and responses (see 3.2.4 Environmental drivers) exhibited a statistically significant relationship with the SAV species abundances.

VULNERABLE COMMUNITIES

Background

The issue of Harmful Algal Blooms in the Delta impacts all people who live, recreate, and work in the Delta, as well as people who source drinking water from the Delta. However, cyanoHABs may disproportionately impact vulnerable communities – low-income communities and communities of color - more than others. This report is limited in its scope – it only assesses increases in harmful algal blooms caused by or exacerbated by the TUCP and Emergency Drought Barrier in 2022. The ongoing and increasing cyanoHABs crisis in the Delta is out of scope, but in writing the 2021 report it became clear that a larger, multi-agency effort to fully assess the drivers, impacts, and mitigation methods of cyanoHABs is needed.

HABS and SAV are an existing problem throughout the Delta. The focus of the environmental justice analysis will be to use the HABs study findings and additional research to answer the following questions:

1) Did implementing the April-June TUCP and/or Barrier change HABS and weeds in a way that would worsen existing conditions or expected conditions (drought) without the TUCP and/or Barrier?

2) Would effects be worse for vulnerable communities than the general population (i.e., disproportionate), and how?

Methods

In the 2021 HABs/Weeds report, we completed an initial analysis of the impact of HABs and weeds on vulnerable communities using primarily existing data, including surveys of people living, working, and recreating in the Delta, and census data. In the 2022 report, this will be updated with new information on impacts of the April-June 2022 TUCP and will include additional outreach and surveys.

To assess the impacts to vulnerable communities living in the area, the areas influenced most by the TUCP (the Lower Sacramento, Lower San

Joaquin, Franks Tract, and OMR) will be overlayed with census tracts showing population of minority and low-income populations.

To supplement existing data, DWR and Reclamation will reach out to local community organizations and Tribal organizations and hold listening sessions to hear how people have been impacted by HABs and Weeds.

COLLABORATION

This study plan could not be completed without close collaboration with multiple outside entities. The leaders of this project have already developed close relationships with leaders in cyanoHABs research in the Delta and elsewhere, including the Delta RMP, California CyanoHAB network, the USGS, the Interagency Ecological Program, and the Water Board's freshwater cyanoHABs program. In the report on the 2021 TUCO, we worked closely with Water Board staff to leverage their excellent cyanoHABs database to identify other stakeholders with information to share on HABs.

Activities for monitoring and assessing the impact of DWR and Reclamation's drought actions are being done in coordination with larger, multi-agency efforts to address Harmful Algal Blooms. DWR is participating in a workshop being planned by the Delta Science Program on HABs in the Delta. The workshop, planned for fall of 2022, will discuss the major issues in monitoring and managing HABs, with the goal of producing a multi-agency framework for monitoring HABs in the Delta.

DWR and Reclamation shared this study plan with the Interagency Ecological Program's Water Quality and Phytoplankton Project Work Team (PWT) at the April 29th, 2022, meeting and via email for review and comment from an audience including the coordinating entities identified in the TUCO condition. The goals of this team are to encourage sharing of data and methods to benefit development of formal synthesis and strategy documents, discuss changes to monitoring to inform management priorities, share new research on water quality and phytoplankton, and coordinate phytoplankton sampling.

DWR and Reclamation will follow the conditions of the TUCO and submit and present on the multiple draft reports with the coordinating entities identified in the Condition for review and comment. Specifically, regular updates and coordination will occur during the IEP Drought Synthesis team meetings.

REFERENCES

American Public Health Association (APHA). 2017. Standard methods for the examination of water and wastewater, 23 edition. American Public Health Association, American Water Works Association, and Water Environment Federation.

Ateljevich, E., K. Nam, Y. Zhang, R. Wang, and Q. Shu. 2014. Bay Delta Calibration Overview. In: Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 35th Annual Progress Report. California Department of Water Resources, Sacramento, CA.

Banks, L. K., and P. C. Frost. 2017. Biomass loss and nutrient release from decomposing aquatic macrophytes: effects of detrital mixing. Aquatic Sciences 79(4):881-890. doi:10.1007/s00027-017-0539-y

Barko, J. W., D. Gunnison, and S. R. Carpenter. 1991. Sediment interactions with submersed macrophyte growth and community dynamics. Aquatic Botany 41(1):41-65. doi:https://doi.org/10.1016/0304-3770(91)90038-7

Barko, J. W., and R. M. Smart. 1981. Sediment-based nutrition of submersed macrophytes. Aquatic Botany 10:339-352. doi:https://doi.org/10.1016/0304-3770(81)90032-2

Bashevkin, S. M., and B. Mahardja. 2022. Seasonally variable relationships between surface water temperature and inflow in the upper San Francisco Estuary. Limnology and Oceanography 67:684-702. doi:https://doi.org/10.1002/lno.12027

Bashevkin, S. M., B. Mahardja, and L. R. Brown. 2022. Warming in the upper San Francisco Estuary: Patterns of water temperature change from 5 decades of data. Limnology & Oceanography. doi:https://doi.org/10.1002/lno.12057

Baston, D. 2021. exactextractr: Fast Extraction from Raster Datasets using Polygons. Comprehensive R Archive Network (CRAN). https://cran.r-project.org/web/packages/exactextractr/index.html

Berg, M., and M. Sutula. 2015. Factors Affecting the Growth of Cyanobacteria with Special Emphasis on the Sacramento-San Joaquin Delta. Southern California Coastal Water Research Project. 100 pgs.,

Bergamaschi, B. A., T. E. Kraus, B. D. Downing, J. Soto Perez, K. O'Donnell, J. A. Hansen, A. M. Hansen, A. D. Gelber, and E. B. Stumpner. 2020. Assessing spatial variability of nutrients and related water quality constituents in the California Sacramento-San Joaquin Delta at the landscape scale: High resolution mapping surveys: U.S. Geological Survey data release, . doi:https://doi.org/10.5066/P9FQEUAL

Bever, A. J., M. L. MacWilliams, and D. K. Fullerton. 2018. Influence of an Observed Decadal Decline in Wind Speed on Turbidity in the San Francisco Estuary. Estuaries and Coasts 41(7):1943-1967. doi:10.1007/s12237-018-0403-x

Bivand, R., T. Keitt, and B. Rowlingson. 2021. Package 'rgdal': Bindings for the 'Geospatial' Data Abstraction Library. Comprehensive R Archive Network (CRAN), http://rgdal.r-forge.r-project.org/

Borgnis, E., and K. E. Boyer. 2015. Salinity tolerance and competition drive distributions of native and invasive submerged aquatic vegetation in the upper San Francisco Estuary. Estuaries and Coasts:1-11. doi:10.1007/s12237-015-0033-5

Boyer, K., E. Borgnis, J. Miller, J. Moderan, and M. Patten. 2013. Habitat Values of Native SAV (*Stukenia spp*.) in the Low Salinity Zone of San Francisco Estuary, Final Project Report. Delta Stewardship Council, Sacramento, CA.

Boyer, K., and M. Sutula. 2015. Factors controlling submersed and floating macrophytes in the Sacramento-San Joaquin Delta. Southern California Coastal Water Research Project.Technical Report 870, Costa Mesa, CA.,

Breiman, L. 2001. Random Forests. Machine Learning 45(1):5-32. doi:10.1023/A:1010933404324

Brooks, M. L., E. Fleishman, L. Brown, P. Lehman, I. Werner, N. L. Scholz, C. Mitchelmore, J. R. Lovvorn, M. L. Johnson, D. Schlenk, S. van Drunick, J. I. Derver, D. M. Stoms, A. E. Parker, and R. Dugdale. 2011. Life histories, salinity zones, and sublethal contributions of contaminants to pelagic fish declines illustrated with a case study of San Francisco Estuary, California, USA. Estuaries and Coasts 35(2):603-621.

Brown, L. R. 2003. Will tidal wetland restoration enhance populations of native fishes? San Francisco Estuary and Watershed Science 1(1):43 pages. doi:https://doi.org/10.15447/sfews.2003v1iss1art2

Caraco, N. F., and J. J. Cole. 2002. Contrasting impacts of a native and alien macrophyte on dissolved oxygen in a large river. Ecological Applications 12(5):1496-1509. doi:https://doi.org/10.1890/1051-0761(2002)012[1496:CIOANA]2.0.CO;2

Carmichael, W. 2008. A world overview — One-hundred-twenty-seven years of research on toxic cyanobacteria — Where do we go from here? Pages 105-125 *in* H. K. Hudnell, editor. Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs. Springer New York, New York, NY.

Carvalho, P., S. M. Thomaz, and L. M. Bini. 2005. Effects of temperature on decomposition of a potential nuisance species: the submerged aquatic macrophyte *Egeria najas* Planchon (Hydrocharitaceae). Brazilian Journal of Botany 65(1):51-60.

Caudill, J., A. R. Jones, L. Anderson, J. D. Madsen, P. Gilbert, S. Shuler, and M. A. Heilman. 2019. Aquatic plant community restoration following the long-term management of invasive *Egeria densa* with fluridone treatments. Management of Biological Invasions 10(3):473-485. doi:https://doi.org/10.3391/mbi.2019.10.3.05

Caudill, J., J. Madsen, and W. Pratt. 2021. Operational aquatic weed management in the California Sacramento–San Joaquin River Delta. J. Aquat. Plant Manage 59:112-122.

Chambers, P. A., and J. Kalff. 1987. Light and Nutrients in the Control of Aquatic Plant Community Structure. I. In Situ Experiments. Journal of Ecology 75(3):611-619. doi:10.2307/2260193

Chambers, P. A., E. E. Prepas, H. R. Hamilton, and M. L. Bothwell. 1991. Current Velocity and Its Effect on Aquatic Macrophytes in Flowing Waters. Ecological Applications 1(3):249-257. doi:https://doi.org/10.2307/1941754

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

Cloern, J. E., A. Robinson, A. Richey, L. Grenier, R. Grossinger, K. E. Boyer, J. Burau, E. A. Canuel, J. F. DeGeorge, J. Z. Drexler, C. Enright, E. R. Howe, R. Kneib, A. Mueller–Solger, R. J. Naiman, J. L. Pinckney, S. M. Safran, D. Schoellhamer, and C. Simenstad. 2016. Primary production in the Delta: then and now. San Francisco Estuary and Watershed Science 14(3). doi:http://dx.doi.org/10.15447/sfews.2016v14iss3art1

Conrad, J. L., A. J. Bibian, K. L. Weinersmith, D. De Carion, M. J. Young, P. Crain, E. L. Hestir, M. J. Santos, and A. Sih. 2016. Novel species ineractions in a highly modified estuary:

Association of Largemouth Bass with Brazilian waterweed *Egeria densa*. Transactions American Fisheries Society 145:249-263. doi:10.1080/00028487.2015.1114521
Dahm, C. N., A. E. Parker, A. E. Adelson, M. A. Christman, and B. A. Bergamaschi. 2016. Nutrient Dynamics of the Delta: Effects on Primary Producers. San Francisco Estuary and Watershed Science 14(4). http://www.escholarship.org/uc/item/1789c0mz
DBW. 2020. Aquatic Invasive Plant Control Program 2019 Annual Monitoring Report, Sacramento, CA. https://dbw.parks.ca.gov/?page_id=29469
Deleersnijder, E., J.-M. Campin, and E. J. M. Delhez. 2001. The concept of age in marine modelling: I. Theory and preliminary model results. Journal of Marine Systems 28(3):229-267. doi:https://doi.org/10.1016/S0924-7963(01)00026-4
Delhez, É. J. M., B. de Brye, A. de Brauwere, and É. Deleersnijder. 2014. Residence time vs influence time. Journal of Marine Systems 132:185-195. doi:https://doi.org/10.1016/j.jmarsys.2013.12.005
Drexler, J. Z., S. Khanna, and J. R. Lacy. 2020. Carbon storage and sediment trapping by Egeria desna Planch., a globally invasive, freshwater macrophyte. Science of the Total Environment. doi:10.1016/j.scitotenv.2020.142602
Durand, J., W. Fleenor, R. McElreath, M. J. Santos, and P. Moyle. 2016. Physical controls on the distribution of the submersed aquatic weed *Egeria densa* in the Sacramento–San Joaquin Delta and implications for habitat restoration. San Francisco Estuary and Watershed Science 14(1). http://www.escholarship.org/uc/item/85c9h479
DWR. 2022. Quality Assurance Project Plan: Central Delta and Emergency Drought Barrier Water Quality Monitoring Program. California Department of Water Resources, West Sacramento, CA,
Foss, A. J., and M. T. Aubel. 2015. Using the MMPB technique to confirm microcystin concentrations in water measured by ELISA and HPLC (UV, MS, MS/MS). Toxicon 104:91-101. doi:https://doi.org/10.1016/j.toxicon.2015.07.332
Frodge, J. D., G. L. Thomas, and G. B. Pauley. 1990. Effects of canopy formation by floating and submergent aquatic macrophytes on the water quality of two shallow Pacific Northwest lakes. Aquatic Botany 38(2):231-248. doi:https://doi.org/10.1016/0304-3770(90)90008-9
Glibert, P. M., R. Dugdale, F. P. Wilkerson, A. E. Parker, J. Alexander, E. Antell, S. Blaser, A. Johnson, J. Lee, T. Lee, S. Murasko, and S. Strong. 2014. Major–but rare–spring blooms in 2014 in San Francisco Bay Delta, California, a result of the long-term drought, increased residence time, and altered nutrient loads and forms. Journal of Experimental Marine Biology and Ecology 460:8-18.
Hestir, E. L., D. H. Schoellhamer, J. Greenberg, T. Morgan-King, and S. L. Ustin. 2016. The effect of submerged aquatic vegetation expansion on a declining turbidity trend in the Sacramento-San Joaquin River Delta. Estuaries and Coasts 39(4):1100-1112. doi:10.1007/s12237-015-0055-z
Hijmans, R. J. 2021. Package 'raster': Geographic Data Analysis and Modeling. Comprehensive R Archive Network (CRAN), https://rspatial.org/raster
Huber, V., C. Wagner, D. Gerten, and R. Adrian. 2012. To bloom or not to bloom: contrasting responses of cyanobacteria to recent heat waves explained by critical thresholds of abiotic drivers. Oecologia 169(1):245-256. doi:10.1007/s00442-011-2186-7
Hudnell, H., editor. 2008. Cyanobacterial harmful algal blooms: State of the science and research needs, volume 619. Springer, New York, NY, USA.
Hudnell, H. K. 2010. The state of U.S. freshwater harmful algal blooms assessments, policy and legislation. Toxicon 55(5):1024-1034. doi:https://doi.org/10.1016/j.toxicon.2009.07.021
Interagency Ecological Program (IEP), S. Lesmeister, and M. Martinez. 2020. Interagency Ecological Program: Discrete water quality monitoring in the Sacramento-San Joaquin Bay-Delta, collected by the Environmental Monitoring Program, 2000-2018. ver 2. .

Environmental Data Initiative. doi: https://doi.org/10.6073/pasta/a215752cb9ac47f9ed9bb0fdb7fc7c19

Khanna, S., S. Acuna, D. Contreras, W. K. Griffiths, S. Lesmeister, R. C. Reyes, B. Schreier, and B. J. Wu. 2019. Invasive Aquatic Vegetation Impacts on Delta Operations, Monitoring, and Ecosystem and Human Health. IEP Newsletter 36(1):8-19.

Khanna, S., M. J. Santos, J. D. Boyer, K. D. Shapiro, J. Bellvert, and S. L. Ustin. 2018. Water primrose invasion changes successional pathways in an estuarine ecosystem. Ecosphere 9(9):e02418. doi:10.1002/ecs2.2418

Kimmerer, W., T. R. Ignoffo, B. Bemowski, J. Modéran, A. Holmes, and B. Bergamaschi. 2018. Zooplankton Dynamics in the Cache Slough Complex of the Upper San Francisco Estuary. San Francisco Estuary and Watershed Science 16(3). doi: https://doi.org/10.15447/sfews.2018v16iss3art4

Kimmerer, W., F. Wilkerson, B. Downing, R. Dugdale, E. S. Gross, K. Kayfetz, S. Khanna, A. E. Parker, and J. K. Thompson. 2019. Effects of Drought and the Emergency Drought Barrier on the Ecosystem of the California Delta. San Francisco Estuary and Watershed Science 17(3). doi:https://doi.org/10.15447/sfews.2019v17iss3art2

Kuehne, L. M., J. D. Olden, and E. S. Rubenson. 2016. Multi-trophic impacts of an invasive aquatic plant. Freshwater Biology 61(11):1846-1861. doi:https://doi.org/10.1111/fwb.12820

Lehman, P., K. Marr, G. Boyer, S. Acuna, and S. Teh. 2013. Long-term trends and causal factors associated with *Microcystis* abundance and toxicity in San Francisco Estuary and implications for climate change impacts. Hydrobilogia 718:141-158.

Lehman, P., S. Teh, G. Boyer, M. Nobriga, E. Bass, and C. Hogle. 2010. Initial impacts of *Microcystis aeruginosa* blooms on the aquatic food web in the San Francisco Estuary. Hydrobiologia 637(1):229-248.

Lehman, P. W., G. Boyer, C. Hall, S. Waller, and K. Gehrts. 2005. Distribution and toxicity of a new colonial *Microcystis aeruginosa* bloom in the San Francisco Estuary, California. Hydrobilogia 541:87-99.

Lehman, P. W., G. Boyer, M. Satchwell, and S. Waller. 2008. The influence of environmental conditions on the seasonal variation of *Microcystis* cell density and microcystins concentration in San Francisco Estuary. Hydrobiologia 600(1):187-204. doi:10.1007/s10750-007-9231-x

Lehman, P. W., T. Kurobe, S. Lesmeister, C. Lam, A. Tung, M. Xiong, and S. J. Teh. 2018. Strong differences characterize *Microcystis* blooms between successive severe drought years in the San Francisco Estuary, California, USA. Aquatic Microbial Ecology 81(3):293-299. https://www.int-res.com/abstracts/ame/v81/n3/p293-299/

Lenth, R. V., P. Buerkner, M. Herve, J. Love, H. Riebl, and H. Singmann. 2021. Package 'emmeans': Estimated Marginal Means, aka Least-Squares Means. Version 1.6.2. Comprehensive R Archive Network, CRAN, https://cran.r-project.org/web/packages/emmeans/index.html

Liu, Y., P. Xie, and X.-P. Wu. 2009. Grazing on toxic and non-toxic Microcystis aeruginosa PCC7820 by Unio douglasiae and Corbicula fluminea. Limnology 10(1):1-5. doi:10.1007/s10201-008-0255-3

Madsen, J. D., and R. M. Wersal. 2018. Proper survey methods for research of aquatic plant ecology and management. Journal of aquatic plant management 56:90-96.

Marineau, E. D., M. J. Perryman, S. Lawler, R. Hartman, and P. D. Pratt. 2019. Management of invasive Water Hyacinth as Both a Nuisance Weed and Invertebrate Habitat. San Francisco Estuary and Watershed Science 17(2):1-19. doi:https://doi.org/10.15447/sfews.2019v17iss5

Mioni, C., R. Kudela, and D. Baxa. 2012. Harmful cyanobacteria blooms and their toxins in Clear Lake and the Sacramento-San Joaquin Delta (California). Surface Water Ambient Monitoring Program Report 10-058-150.

Miranda, L. E., M. P. Driscoll, and M. S. Allen. 2000. Transient physicochemical microhabitats facilitate fish survival in inhospitable aquatic plant stands. Freshwater Biology 44(4):617-628. doi:https://doi.org/10.1046/j.1365-2427.2000.00606.x

Nobriga, M., F. Feyrer, R. Baxter, and M. Chotkowski. 2005. Fish community ecology in an altered river delta: Spatial patterns in species composition, life history strategies, and biomass. Estuaries 28(5):776-785.

O'Neil, J. M., T. W. Davis, M. A. Burford, and C. J. Gobler. 2012. The rise of harmful cyanobacteria blooms: The potential roles of eutrophication and climate change. Harmful Algae 14:313-334. doi:https://doi.org/10.1016/j.hal.2011.10.027

Paerl, H. W., N. S. Hall, and E. S. Calandrino. 2011. Controlling harmful cyanobacterial blooms in a world experiencing anthropogenic and climatic-induced change. Science of the Total Environment 409(10):1739-1745. doi:https://doi.org/10.1016/j.scitotenv.2011.02.001

Paerl, H. W., and V. J. Paul. 2012. Climate change: Links to global expansion of harmful cyanobacteria. Water Research 46(5):1349-1363. doi:https://doi.org/10.1016/j.watres.2011.08.002

Pebesma, E., and R. Bivand. 2021. Package 'sp': Classes and Methods for Spatial Data. Version 1.4-6. Comprehensive R Archive Network (CRAN), https://github.com/edzer/sp/ https://edzer.github.io/sp/

Petticrew, E. L., and J. Kalff. 1992. Water Flow and Clay Retention in Submerged Macrophyte Beds. Canadian Journal of Fisheries and Aquatic Sciences 49(12):2483-2489. doi:10.1139/f92-274

Portilla, M. A., and S. P. Lawler. 2020. Herbicide treatment alters the effects of water hyacinth on larval mosquito abundance. Journal of Vector Ecology 45(1):69-81. doi:10.1111/jvec.12374

Preece, E. P., W. Hobbs, F. J. Hardy, L. O'Garro, E. Frame, and F. Sweeney. 2021. Prevalence and persistence of microcystin in shoreline lake sediments and porewater, and associated potential for human health risk. Chemosphere 272:129581. doi:https://doi.org/10.1016/j.chemosphere.2021.129581

Reddy, A. M., P. D. Pratt, J. V. Hopper, X. Cibils-Stewart, G. C. Walsh, and F. Mc Kay. 2019. Variation in cool temperature performance between populations of *Neochetina eichhorniae (*Coleoptera: Curculionidae) and implications for the biological control of water hyacinth, *Eichhornia crassipes*, in a temperate climate. Biological Control 128:85-93. doi:https://doi.org/10.1016/j.biocontrol.2018.09.016

Riis, T., B. Olesen, J. S. Clayton, C. Lambertini, H. Brix, and B. K. Sorrell. 2012. Growth and morphology in relation to temperature and light availability during the establishment of three invasive aquatic plant species. Aquatic Botany 102:56-64. doi:https://doi.org/10.1016/j.aquabot.2012.05.002

Ripley, B., B. Venables, D. M. Bates, K. Hornik, A. Gebhardt, and D. F. [ctb]. 2021. Package MASS, Support Functions and Datasets for Venables and Ripley's MASS. Version 7.3-54. R Project. CRAN, http://www.stats.ox.ac.uk/pub/MASS4/

Schoellhamer, D. H. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts 34(5):885-899. doi:DOI 10.1007/s12237-011-9382-x

Schultz, R., and E. Dibble. 2012. Effects of invasive macrophytes on freshwater fish and macroinvertebrate communities: the role of invasive plant traits. Hydrobiologia 684(1):1-14. doi:10.1007/s10750-011-0978-8

Senn, D., T. Kraus, A. Richey, B. Bergamaschi, L. Brown, L. Conrad, C. Francis, W. Kimmerer, R. Kudela, T. Otten, A. Parker, A. Robinson, A. Mueller-Solger, D. Stern, and J. Thompson. 2020. Changing nitrogen inputs to the northern San Francisco Estuary: Potential ecosystem responses and opportunities for investigation. SFEI Contribution #973. San Fransisco Estuary Institute, Richmond, CA.,

Silva, C., A. Anselmo, I. P. E. Macário, D. de Figueiredo, F. J. M. Gonçalves, and J. L. Pereira. 2020. The bad against the villain: Suitability of *Corbicula fluminea* as a bioremediation agent towards cyanobacterial blooms. Ecological Engineering 152:105881. doi:https://doi.org/10.1016/j.ecoleng.2020.105881

Spier, C., W. Stringfellow, J. Hanlon, M. Estiandan, T. Koski, and J. Kaaria. 2013. Unprecedented bloom of toxin-producing cyanobacteria in the Southern Bay-Delta Estuary and its potential negative impact on the aquatic food web. University of the Pacific Ecological Engineering Research Program Report 4.5.1.,

Stuckey, R. L. 1979. Distributional history of *Potamogeton crispu*s (curly pondweed) in North America. Bartonia (46):22-42. http://www.jstor.org/stable/41610371

Ta, J., L. W. J. Anderson, M. A. Christman, S. Khanna, D. Kratville, J. D. Madsen, P. J. Moran, and J. A. Viers. 2017. Invasive Aquatic Vegetation Management in the Sacramento–San Joaquin River Delta: Status and Recommendations. San Francisco Estuary and Watershed Science 15(4). doi:https://doi.org/10.15447/sfews.2017v15iss4art5

Terzopoulos, D., and A. Witkin. 1988. Physically based models with rigid and deformable components. IEEE Computer Graphics and Applications 8(6):41-51. doi:10.1109/38.20317

Tobias, V. D., J. L. Conrad, B. Mahardja, and S. Khanna. 2019. Impacts of water hyacinth treatment on water quality in a tidal estuarine environment. Biological Invasions 21(12):3479-3490. doi:10.1007/s10530-019-02061-2

Toft, J. D., C. A. Simenstad, J. R. Cordell, and L. F. Grimaldo. 2003. The effects of introduced water hyacinth on habitat structure, invertebrate assemblages, and fish diets. Estuaries 26(3):746-758.

Utermöhl, H. 1958. Methods of collecting plankton for various purposes are discussed. SIL Communications, 1953-1996 9(1):1-38. doi:10.1080/05384680.1958.11904091

Vroom, J., M. van der Wegen, R. Martyr-Koller, and L. Lucas. 2017. What Determines Water Temperature Dynamics in the San Francisco Bay-Delta System? Water Resources Research 53(11):9901-9921.

Wan, L., X. Chen, Q. Deng, L. Yang, X. Li, J. Zhang, C. Song, Y. Zhou, and X. Cao. 2019. Phosphorus strategy in bloom-forming cyanobacteria (Dolichospermum and Microcystis) and its role in their succession. Harmful Algae 84:46-55. doi:https://doi.org/10.1016/j.hal.2019.02.007

World Health, O. 2021. WHO guidelines on recreational water quality: volume 1: coastal and fresh waters. World Health Organization, Geneva.

Wynne, T., A. Meredith, T. Briggs, W. Litaker, and M. p. d. R. Stumpf 2018. Silver Spring. 2018. Harmful Algal Bloom Forecasting Branch Ocean Color Satellite Imagery Processing Guidelines. NOAA Technical Memorandum NOS NCCOS 252. National Oceanic and Atmospheric Administration, Silver Spring, MD. 48 pp. doi:10.25923/twc0-f025

Young, M. J., J. L. Conrad, A. J. Bibian, and A. Sih. 2018. The Effect of Submersed Aquatic Vegetation on Invertebrates Important in Diets of Juvenile Largemouth Bass, *Micropterus salmoides*. San Francisco Estuary and Watershed Science 16(2). doi:https://doi.org/10.15447/sfews.2018v16iss2art5

Zhang, Y., F. Ye, E. V. Stanev, and S. Grashorn. 2016. Seamless cross-scale modeling with SCHISM. Ocean Modelling 21(3):71-76.

Zhang, Y. J., N. Gerdts, E. Ateljevich, and K. Nam. 2020. Simulating vegetation effects on flows in 3D using an unstructured grid model: model development and validation. Ocean Dynamics 70(2):213-230. doi:10.1007/s10236-019-01333-8

APPENDIX A

Appendix A. TUCP and Emergency Drought Barrier Cyanotoxin Monitoring 2022 Work Plan

TUCP and Emergency Drought Barrier Cyanotoxin Monitoring 2022 Work Plan

Table of Contents

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Study Objectives/Questions

- What are the spatial and temporal trends in the relative abundance and cyanotoxin concentrations of cyanobacterial harmful algal blooms (cyanoHABs) in the central Delta, with specific interest in the areas around Franks Tract and Mildred Island before, during, and after the West False River Emergency Drought Barrier (EDB) is installed?
- Does the installation of the EDB promote an increase in the relative abundance and/or cyanotoxin concentrations from cyanoHABs in the Central Delta?
- Does the 2022 Temporary Urgency Change Petition (TUCP) promote an increase in the relative abundance and/or cyanotoxin concentrations from cyanoHABs in the Central Delta?
- How does the relative abundance of cyanotoxin concentrations compare annually and interannually with and without the EDB and TUCP?

Rationale/Need

California faces a multitude of environmental impacts due to climate change, one of which is the increased frequency and intensity of droughts. Current drought conditions (2018-2021) brought about the California Department of Water Resources' (DWR)requested emergency authorization for the installation of the 2021 – 2022 West False River Emergency Drought Salinity Barrier (EDB) in accordance with Governor Newsom's emergency proclamations issued on April 21 and May 10, 2021. The EDB would serve California water users by reducing the negative impacts of saltwater intrusion from the San Francisco Bay into the central and south Sacramento-San Joaquin Delta. Under drought conditions, reduced freshwater flows in the winter and spring result in the absence of flows to repel high salinity waters from the San Francisco Bay.

Installation of the EDB would allow California to conserve water by reducing the need for water releases from reservoirs used to push high salinity water downstream. Lastly, the barrier would also mitigate impacts on wildlife by maintaining important aquatic habitats for sensitive species. Low outflows in 2021 and 2022 also necessitated Temporary Urgency Change Petitions to Water Rights Decision D-1641 in June and July of 2021 and April-June of 2022. The 2022 TUCP seeks changes to permit and license conditions imposed pursuant to D-1641 that require the Projects to meet flow-dependent water quality objectives designed to protect fish and wildlife and agricultural beneficial uses in the Delta. These changes were requested because the Projects' storage and inflow may be insufficient to meet D-1641 requirements and additional operational flexibility is needed to support other Project priorities, including: minimum health and safety supplies (defined as minimum demands of water contractors for domestic supply, fire protection, or sanitation during the year); preservation of upstream storage for release later in the summer to control saltwater intrusion into the Delta; preservation of cold water to manage river temperatures for various runs of Chinook salmon and steelhead; maintenance of protections for State and federally endangered and threatened species and other fish and wildlife resources; and other critical water supply needs.

However, the installation of the drought barrier and the changes to outflow and exports associated with the TUCP will alter flows and increase residence times, promoting the growth of harmful algal blooms caused by cyanobacteria (cyanoHABs). CyanoHABs may impose threats to water quality and wildlife in several ways. This includes and is not limited to approximately 25 million Californians being affected by possible cyanotoxin releases by cyanoHABs into the water supply, potentially requiring costly water treatment options. CyanoHABs may also lead to the mortality of wildlife and domestic animals and the die-off of cyanoHABs can create anoxic conditions that may lead to substantial fish kills. Thus, the monitoring of cyanoHABs and cyanotoxins by DWR and USGS is critical to detecting and managing the potential impacts of the EDB and the TUCP.

In 2021, the Delta experienced a harmful algal bloom after the installation of the EDB, which triggered a request for additional cyanotoxin sampling for 2022 by the State Water Resources Control Board and the California Department of Fish and Wildlife. As one of the conditions of approval of the 2022 TUCO, DWR and Reclamation are required to continue a special study on the impact of the TUCP on harmful algal blooms in the Delta. Requirements for this report include measurements of cyanotoxin concentrations in areas where this TUCP Order may modify hydrodynamics to Delta waterways. This study describes the cyanotoxin monitoring being conducted in 2022 to fulfill this condition.

DWR's Division of Integrated Science and Engineering (DISE) and the North Central Region Office (NCRO) will share cyanotoxin sampling responsibilities during routine station maintenance and water quality monitoring from April through September 2022. Cyanotoxin monitoring at Franks Tract (FRK) will be conducted to assess the impact of the EDB specificatlly, while other sites in the central and south Delta (Middle River near Holt—Mildred Island (HLT), False River Near Oakley (FAL) and Holland Cut near Bethel Island (HOL)) will also be sampled for cyanotoxins to conduct a more thorough survey of HABs throughout the area most

hydrologically impacted by the TUCP. These samples will be combined with other studies of cyantoxins in the Delta being conducted by other researchers for a full assessment of HABs across the Delta and the potential impact of the drought actions.

Methods

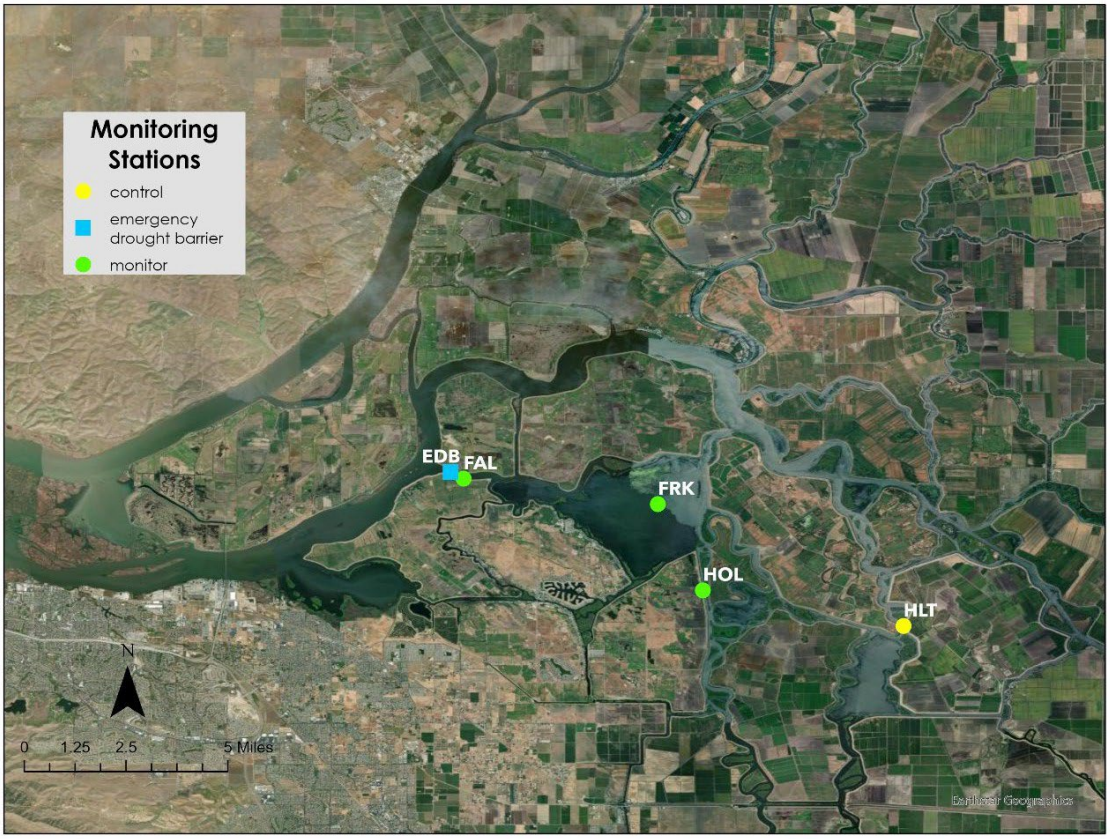

Figure 1. Station map of monitoring and control stations and the Emergency Drought Barrier.

Water Quality Monitoring

Routine continuous monitoring of water quality with YSI EXO2 sondes will be conducted at all stations with parameters as listed in Table 1. Field measurements will also be taken upon arrival at each station to document ambient conditions as cyanotoxin samples are collected. Maintenance of YSI EXO2 sondes will occur typically monthly (or every 3-5 weeks) following protocols from the NCRO Water Quality Evaluation Section Field Manual at False River near Oakley (FAL), Holland Cut near Bethel Island (HOL), and Middle River near Holt—Mildred Island (HLT) (DWR 2020). Additionally, discrete water samples will be collected at these same sites during monthly site visits for analysis by Bryte Lab for chlorophyll-a, total suspended solids, and standard nutrients (Table 1). Nutrients will be collected at FRK every 2 weeks. Measurements of turbidity with Secchi depth and visual *Microcystis* index values will also be taken alongside discrete samples. Sondes at FRK will be managed and maintained following DISE SOPs by the

Continuous Environmental Monitoring Program.

Table 1. Stations with continuous water quality sondes

StationCode	Station Name	Latitude	Longitude	Sensors
FAL	False River near Oakley	38.05547	-121.667	Chlorophyll, DO, Specific Conductance, Water Temperature, Turbidity
HOL	Holland Cut Near Bethel Island	38.01582	-121.582	DO, Specific Conductance, Water Temperature, Turbidity
HLT	Middle River near Holt	38.00308	-121.511	Chlorophyll, Specific Conductance, Water Temperature, Turbidity
FRK	Franks Tract Mid Tract	38.04642	-121.598	Chlorophyll, DO, Specific Conductance, Water Temperature, Turbidity, pH

Table 1. Discrete sampling constituents

Constituents
chlorophyll a (µg/L)
pheophytin a (µg/L)
dissolved chloride (mg/L)
dissolved bromide (mg/L)
dissolved ammonia (mg/L as Nitrogen)
dissolved nitrite + nitrate (mg/L as Nitrogen)
dissolved organic nitrogen (mg/L as Nitrogen)
total Kjeldahl nitrogen (mg/L as Nitrogen)
dissolved organic carbon (mg/L as Carbon)
total organic carbon (mg/L as Carbon)
dissolved orthophosphate (mg/L as Phosphorus)
total phosphorus (mg/L as Phosphorus)

SPATT Monitoring at Franks Tract (FRK)

Solid Phase Adsorption Toxin Tracking (SPATT) samplers will be deployed at Franks Tract station and swapped every 2 weeks. SPATT samplers are devices used to collect time-integrated data on toxin presence using resin beads that adsorb dissolved toxins in a body of water (Kudela 2020). SPATT samplers will be used in conjunction with discrete whole water sampling for cyanotoxins. USGS will construct SPATT samplers for deployment by DWR following the Standard Operating Procedures for SPATT assembly (Kudela 2020). SPATT samplers will be provided to DWR by USGS fully assembled with the resin mesh enclosed within its embroidery

hoop with each sampler individually stored in ultrapure water to prevent desiccation in zip lock bags (Fig 2a). USGS will also provide sample labels for retrieved SPATT samplers (Fig 3d). See field SOP for detailed procedures in Appendix A (DWR 2022).

SPATT Sampling

Samplers will be transported on wet ice to the field and deployed at FRK in a 6-inch PVC pipe and attached to a plastic-coated steel cable with a zip tie (Fig 2b). SPATT samplers will be submerged at approximately 1-meter below the surface (approximately the same depth as the stations continuous YSI EXO2 sonde) and oriented perpendicular to the flow of water. After the 2-week deployment period, samplers will be retrieved and swapped with a new SPATT sampler. The outgoing SPATT sampler will be rinsed in native water to remove any debris. To store the SPATT sampler, the resin bag will be removed from the embroidery hoop (Fig 3b) and stored completely flat in two plastic zip lock bags (Fig 3c), then placed on ice for transport back to the lab (Appendix A, DWR 2022).

SPATT Storage

SPATT samplers will be stored in the DISE EMP -20°C freezer until retrieved by USGS. Note the SPATT retrieval date and time on the SPATT log adjacent to the EMP freezer.

Figure 2. a) outgoing SPATT, b) attach outgoing SPATT to steel cable, c) outgoing SPATT ready for deployment.

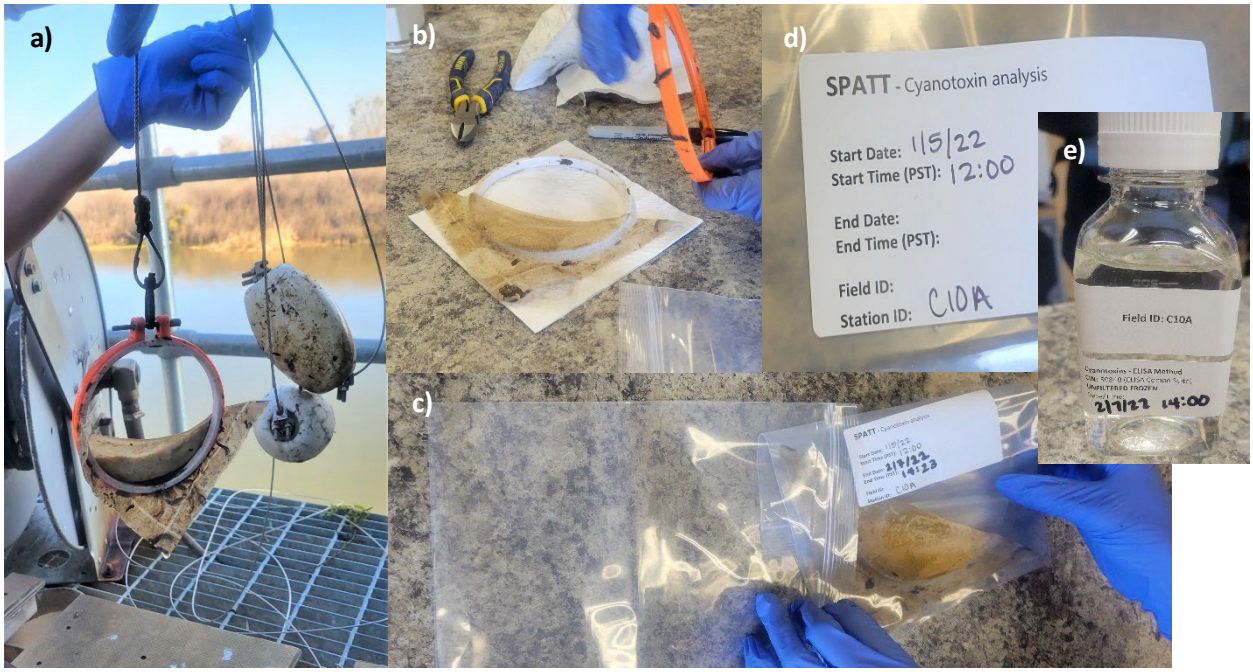

Figure 2. a) SPATT retrieval, b) SPATT bag removed from embroidery hoop, c) SPATT sampler double bagging, d) SPATT label, e) cyanotoxin water sample label.

Cyanotoxin Monitoring

Cyanotoxin will be sampled at FRK every 2 weeks concurrently with SPATT exchanges. FAL, HOL, and HLT will be sampled every 4 weeks. In the event of an algal bloom[1], cyanotoxin sampling will occur every 2 weeks at FAL, HOL and HLT. USGS will provide sample bottles for NCRO and DISE for cyanotoxin samples collected from FRK. Sample bottles for FRK will be pre-labeled with the field station, date, and time (Fig 3e).

A DWR subcontractor, GreenWater Laboratories, will analyze cyanotoxin samples from FAL, HOL and HLT. Sample bottles will be labeled directly on the bottles with a waterproof pen (e.g., Sharpie) with the date and time of collection, name of the water body, and station ID. Samples from FRK will be analyzed at Lumigen Instrument Center, a subcontractor of USGS and DSP.

Cyanotoxin Sample Collection

Cyanotoxin samples will be collected from the surface of the water using a sampling pole, bucket, or van dorn. Sample bottles will be triple rinsed with sample water then dispensed into 250 mL plastic sample bottles. Sample bottles will be filled to the 250 mL line to allow for enough headspace for expansion during freezing. Cyanotoxin samples will then be placed on ice for transport.

Cyanotoxin Sample Storage

Samples collected at FRK will be frozen in the EMP -20°C freezer until retrieved by USGS. Upon collection by USGS samples will be frozen at -80°C.

All other stations (FAL, HOL, HLT) will be refrigerated (not frozen) for up to 2-3 days prior to shipping to GreenWater. Note: samples will not be frozen as they cause cells to lyse and will not be viable for GreenWater's Potentially Toxicogenic Cyanobacteria (PTOX) screening.

Cyanotoxin Sample Shipping

Samples from FAL, HOL, HLT will be shipped to GreenWater Laboratories. A sampling schedule will be sent to GreenWater approximately two weeks prior to the start of cyanotoxin sampling (around mid-March) to allow GreenWater enough time to ship sampling kits prior to field sampling. Sampling kits will include a Styrofoam cooler with freeze packs and sample bottles. Bryte and Weck labs will be notified of sampling events and COCs will be provided to them via email.

Sample bottles will be placed in a plastic bag in the cooler. Bubble wrap and extra freeze packs will be used as needed to cushion the sample bottles and prevent samples from shifting during transport.

Coolers will be dropped off and shipped via FedEx standard overnight shipping (not priority or

[1] An algal bloom will be identified when the water temperature is greater than 19 C and a visual Microcystis index is 4 or 5. Or, when satellite data show a cyanobacterial index of 3.2 or greater, or when fluoroprobes read a cyanobacterial concentration of > 20 ug/L.

first overnight shipping, since they may arrive too early for GreenWater to receive). Shipping overnight will not occur on Fridays, as GreenWater will not receive samples on the weekends. When dropping off samples, GreenWater's FedEx account number and shipping address as well as the mailing address for the West Sacramento DWR office will be provided.

Samples from FRK will be shipped approximately monthly to Lumigen Instrument Center. Sample bottles will be packed to avoid breakage and shipped with dry ice to keep samples frozen. Samples will be shipped priority overnight.

Two different laboratories are being used for this study to provide continuity with existing data sets. All resulting toxins will be compared to thresholds for recreational use advisories, and any differences between the laboratories should be small in comparison with the advisory thresholds. Both Lumigen Instrument Center and GreenWater Laboratories are will respected and have provided high quality data for many years. Additional information on quality control procedures can be found in our QAPP.

Sample Analyses

GreenWater will conduct a Potentially Toxigenic Cyanobacterial (PTOX) screening of cyanotoxin samples to determine which cyanotoxins to test. Taxonomists at Greenwater will use an inverted microscope to inspect the sample for presence of cyanobacteria in the genera *Microcystis, Aphanizomenon, Cylindrospermum, Dolichospermum, Planktothrix*, and other potentially toxigenic taxa. Based on the taxa identified, Greenwater will use appropriate analytical chemistry techniques to determine whether any toxins are present (Table 2). Results from GreenWater's analyses will be emailed to DWR.

Table 2. Methods for analyzing samples for cyanotoxins used by GreenWater Laboratories.

Constituent	**Lab Method**
Microcystins/nodularins	Ada ELISA (Abraxis) EPA Method 546 & Ohio EPA Division of Environmental Services 701.0
Saxitoxin	Saxitoxin specific ELISA (Abraxis Procedure Number 52255B)
Anatoxin-a	Liquid Chromatography Mass Spectrometry
Cylindrospermopsin	Liquid Chromatography Mass Spectrometry

Samples from FRK will be analyzed by liquid chromatography and tandem mass spectrometry for different variants in the toxin classes: microcystins, anabaenopeptins, nodularin, anatoxins, saxitoxins (Table XX). A subset of approximately 20% of samples from FRK will also be analyzed by ELISA for microcystin/nodularin, saxitoxin, anatoxin, and cylindrospermopsin by BSA Environmental Labs.

Table 3. FRK cyanotoxin analyses

Toxin class	Variants / congeners
Microcystins	D-Asp3-Dhb7-RR, MC- RR, MC-YR, M C-HtyR, MC-LR, Dha-LR, D-Asp3-LR, Leu1 LR, MC-HilR, MC-WR, MC-LA, MC-LY, MC-LW, MC-LF
Anabaenopeptins	Anabaenopeptin A, Anabaenopeptin B, Anabaenopeptin F, Oscillamide Y
Nodularin	Nodularin R
Anatoxins	Anatoxin-a, Dihydroanatoxin, Homoanatoxin-a
Saxitoxins	Saxitoxin, Neosaxitoxin, Desamidoylneosaxitoxin
Cylindrospermopsin	Cylindrospermopsin, 7-epi-Cylindrospermopsin

Epiphytic CyanoHAB Monitoring

A subset of the 4 stations will be sampled to detect potential cyanoHABS on submerged aquatic vegetation (SAV). SAV samples will be collected within a 2-meter radius of the water quality station. Leaves of the SAV will be scraped and those scrapings will be collected in deionized water, see Appendix B (DWR 2022b). Samples will be transported back to the West Sacramento DWR office on ice.

Epiphytic cyanoHAB storage and shipping

Epiphytic HAB samples will be stored and shipped to GreenWater in an identical manner to cyanotoxin water samples collected at FAL, HOL and HLT (see Cyanotoxin Sample Shipping section above).

Data analyses

- Compare cyanotoxin levels between the control site (HLT) and monitoring sites (FRK, FAL and HOL) before, during, and after the EDB installation.
- Compare cyanotoxin levels over time during years with and without TUCPs.
- Time series visualizations of continuous water quality data (temperature, chlorophyll a, turbidity, specific conductance, flow, stage height) before, during, and after the EDB installation
- Investigate potential relationships between continuous water quality data and discrete cyanotoxin samples and time-integrated SPATT samples

Budget

SPATT samplers and laboratory analyses of whole water and SPATT samples will be covered by USGS for FRK. Discrete water samples (chlorophyll-a and total suspended solids) are covered under routine monitoring and nutrient samples are covered under EDB monitoring.

- Journal publication costs
- Additional supplies
    - Zip ties (to attach SPATT samplers)
    - Extra bubble wrap for shipping
    - Extra freeze packs for shipping

Table 4. GreenWater Whole Water Sample Processing Costs

Analytes and Analysis	**Cost per sample**	**Discounted cost (more than 1 sample)**
PTOX screening (waived if follow up analyses are performed)	$125	$125
Anatoxin-a-LC-MS/MS	$200	$150
Cylindrospermopsin ELISA	$200	$150
Microcystins ELISA	$125	$100
Saxitoxins ELISA, LC-MS/MS	$175	$150
BMAA LC-MS/MS (beta methylamino-L-alanine)	$325	$275

May 1 -Nov 30 = 31 weeks → 1 water sample/4 weeks ≈ 7 samples/station

HLT & HOL— 7 samples/station x 2 stations x $825/sample = **$11,550***

FAL—7 samples/station x 1 station x $1025/sample = **$7,175****

* This estimate assumes more than 1 sample will be submitted $825/sample (if all analytes are processed). Samples may range from $125-825 depending on the PTOX screening recommendations.
**Note for FAL, this will be the only station sampled on the Central Delta North run, so cost per sample won't be discounted and will range from $125-1,025.

Table 5. GreenWater Phytoplankton Identification & Enumeration Costs

Analysis	**Cost per sample**
Potentially Toxigenic (PTOX) Cyanobacteria Screen	$125
Qualitative Algal Identification	$150
Cyanobacteria ID & Enumeration	$250
Total Algal ID & Enumeration	$300
Algal ID, Enumeration & Biovolume	$375

7 samples/station x 3 stations x $300/sample = **$6,300**

Cyanotoxin and algal ID and enumeration grand total = 11,550 + 7,175 + 6,300 = **$25,025**

Resources

Estimated internal staff hours Oct 2021 - Nov 2022

Staff	Division/Section	Roles	Hours pre-barrier Oct 2021-Mar 2022	Hours during barrier/month Apr-Nov 2022	Total Hours
Rosemary Hartman	DISE/ Synthesis, Resiliency & Adaptive Management	Analysis, writing, planning			
Ted Flynn	DISE/Discrete Environmental Monitoring	Advise			
Morgan Martinez		Task support		8 -16	
Scott Waller	DISE/Continuous Environmental Monitoring	Advise			
Michelle Nelson		Task Support		8 - 16	
Andrew Tran	DISE/Continuous Environmental Monitoring	Task Support		8-16	
Daphne Gille	Estuarine Science & Monitoring				

Peggy Lehman	Estuarine Science & Synthesis	Microcystis/HABs expertise			
Shaun Philippart	Environmental Monitoring & Assessment	Advise			
Jared Frantzich	Regional Assistance/Water Quality Evaluation	Advise			
Tyler Salman		Task support		16	
Elena Huynh		Sample coordination & logistics, task support		32 * 8 = 256	2048

Timeline

Nov 2021—Feb 2022—Planning and drafting of study plan

April 2022 first week—Emergency Drought Barrier will be closed

April 2022—Nov 2022—Data collection

Nov 2022—Removal/opening of EDB

Dec 2022—Begin data visualization and analysis

2022 Timeline

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coordination and planning meetings	General coordination meeting												
	HAB control meetings												
Field Monitoring	Continuous SpCond, Temp, Turbidity, DO, Chlorophyll/phycocyanin,pH												
	SPATT samples												
	Discrete cyanotoxin grab samples												
	Epiphytic HAB samples												
	Discrete grab samples (Chlorophyll-a, TSS, nutrients, Secchi Depth)												

Deliverables	Final report special study of barrier effect and TUCP on HABs and aquatic weeds												
	Preliminary draft results of EDB monitoring and analysis												
	Status report covering monitoring period June – Dec 2021												
	Comprehensive report covering monitoring June 2021 – Dec 2022									Fall / Winter 2023			
Presentations	IEP Annual Meeting												
	Bay-Delta Science Conference 2023												
	IEP Directors Meeting												
	IEP Stakeholders Meeting												
	CAMT and CSAMP meetings												

Locations

Table 6. Station Information

Station Name	Station Code	Latitude	Longitude
Franks Tract	FRK	38.04642	-121.59810
Middle River near Holt--Mildred Island	HLT	38.00310	-121.51080
False River near Oakley	FAL	38.05580	-121.66690
Holland Cut near Bethel Island	HOL	38.01640	121.58190

References

DWR. 2022. Cyanotoxin and SPATT Sampling Field Standard Operating Procedures. California Department of Water Resources. North Central Region Office. State of California.

DWR. 2022b. Epiphytic HAB Sampling Field Standard Operating Procedures. California Department of Water Resources. North Central Region Office. State of California.

DWR. 2020. Resources Assessment Branch Water Quality Evaluation Section Field Manual. California Department of Water Resources. North Central Region Office. State of California.

Kudela, Raphael. 2020. Standard Operating Procedure for Solid Phase Adsorption Toxin Testing

(SPATT) Assemblage and Extraction for Freshwater and Brackish Harmful Algal Toxins.

Appendices

Appendix A. NCRO Cyanotoxin Sampling Field Standard Operating Procedures 2022

Sampling Plan (April – November 2022)

Franks Tract (FRK) SPATT and cyanotoxin sampling:

1st sampling event

- C-EMP swap out SPATT during sonde exchange visit
- C-EMP collect cyanotoxin water sample
- C-EMP process/filter nutrients at West Sac office

2nd sampling event

- NCRO swap out SPATT 2 weeks from the last swap
- NCRO collect cyanotoxin water sample
- NCRO process/filter nutrients at West Sac office

FAL, HOL, HLT cyanotoxin sampling:

- NCRO collect cyanotoxin water samples once a month
- NCRO process/filter nutrients at West Sac office

Sampling Equipment/Supplies

- Van Dorn
- 250 mL cyanotoxin PETG clear bottles (2 per station at FRK)—supplied by USGS
- 250 mL cyanotoxin plastic bottles (all other stations)
- Outgoing SPATT sampler—supplied by USGS
- Zip ties
- Clippers/cutters (to remove zip ties)
- Cooler with wet ice
- Zip lock bag for retrieved SPATT bag (2 per station)

Deployment of SPATTs

1. Always wear fresh (clean) gloves when handling SPATTs.
2. Transport outgoing SPATTs to the field on wet ice.
3. Fresh SPATT samplers supplied by USGS are stored in double zip lock bags with approximately 100 mL of ultrapure water to prevent resin from drying out (Fig 1a).
4. Visually inspect the SPATT to make sure there are no obvious holes in mesh bag that may allow resin to escape and to make sure it is securely fastened in the embroidery hoop.

5. SPATTs should be secured at the same depth as the continuous sonde where sensor measurements are taking place. The SPATT should be secured at a fixed depth and should not rise and fall with the tide. Secure the SPATT with a zip tie located at the top of the embroidery hoop (Fig 1b) and cut off any excess zip tie.
6. Lower the secured SPATT sampler (Fig 1c) into the PVC housing. The embroidery hoop should be kept upright in the water column – perpendicular to flow - so that water can move through the resin in the mesh bag. The resin will adsorb cyanotoxins present in the water.
7. Plumb bobs (small weights) can be secured to the embroidery hoop to prevent the SPATT from floating back up to the surface.
8. Note deployment date/time along with any relevant information on the SPATT label.

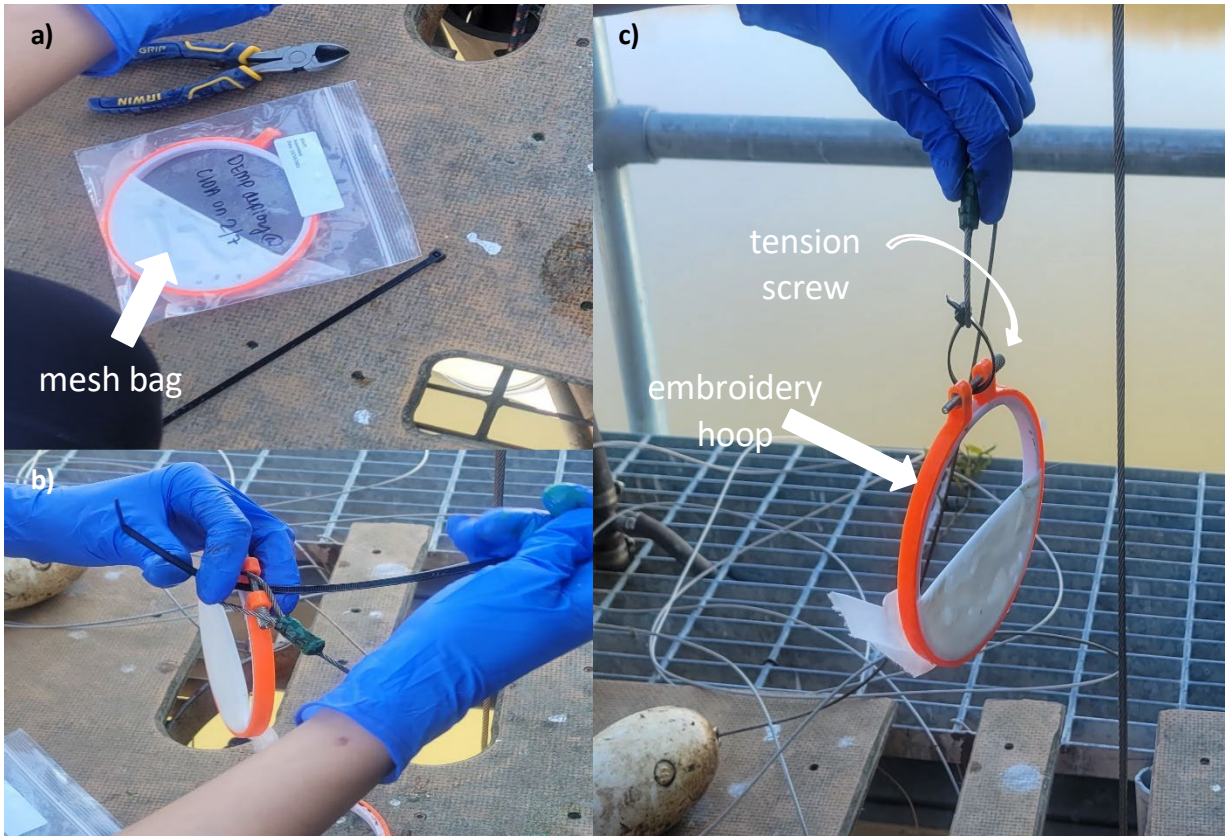

Figure 1. a) outgoing SPATT, b) attach outgoing SPATT to steel cable, c) outgoing SPATT ready for deployment.

Retrieval of SPATTs

1. Always wear fresh (clean) gloves when handling SPATTs.
2. Collect the SPATT sampler (Fig 2a) every two weeks.
3. Upon retrieval remove SPATT mesh bags from the embroidery hoop by loosening the metal tension screw (Fig 2b). Rinse the bags in native water to remove debris.
4. Shake off excess water and place the mesh bag into double zip lock bags. **Important:** Bags must be labeled with station name, date deployed, time deployed, date retrieved, and time retrieved (Fig 2d).
    a. SPATT resin bags must be stored lying completely flat (avoid folding corners of the SPATT bag) in the zip lock bags (Fig 2b).

5. Embroidery hoops can be discarded.
6. Transport bagged SPATTs on wet ice back to the office and store in the EMP lab freezer until they can be picked up by USGS.
7. Deploy a fresh SPATT according to instructions above.
8. At the West Sacramento EMP lab, note the date and time that the outgoing SPATT sampler was deployed as that information will be needed upon its retrieval label in 2 weeks.

Collection of Whole Water Samples for Cyanotoxins Analyses

1. Collect water with a Van Dorn water sampler.
    a. Triple rinse the Van Dorn by lowering the open Van Dorn to 1 meter, then pull the Van Dorn up to empty. Repeat 2 more times.
    b. Send the messenger to the Van Dorn at a 1-meter depth
2. Triple rinse the 250 mL sample bottles by dispensing a small quantity of water from the Van Dorn. Close the sample bottle top and shake the bottle. Pour out the rinse water and repeat two more times.
3. Dispense 250 mL of water from the Van Dorn into the triple rinsed sample bottle.
4. **FRK** samples (for USGS Analysis):
    a. Write the date and time of collection on the label of the 250 mL bottles (Fig 2e).
    b. Repeat steps 2-3 with the second sample bottle.
5. **FAL, HOL, HLT** samples (for GreenWater contractor):
    a. Record the time of collection on a datasheet.
6. Transport the 250 mL samples in a cooler on wet ice back to the office.
7. Store FRK samples in the EMP freezer until they can be picked up by USGS.
8. Store samples from all other sites in the refrigerator.

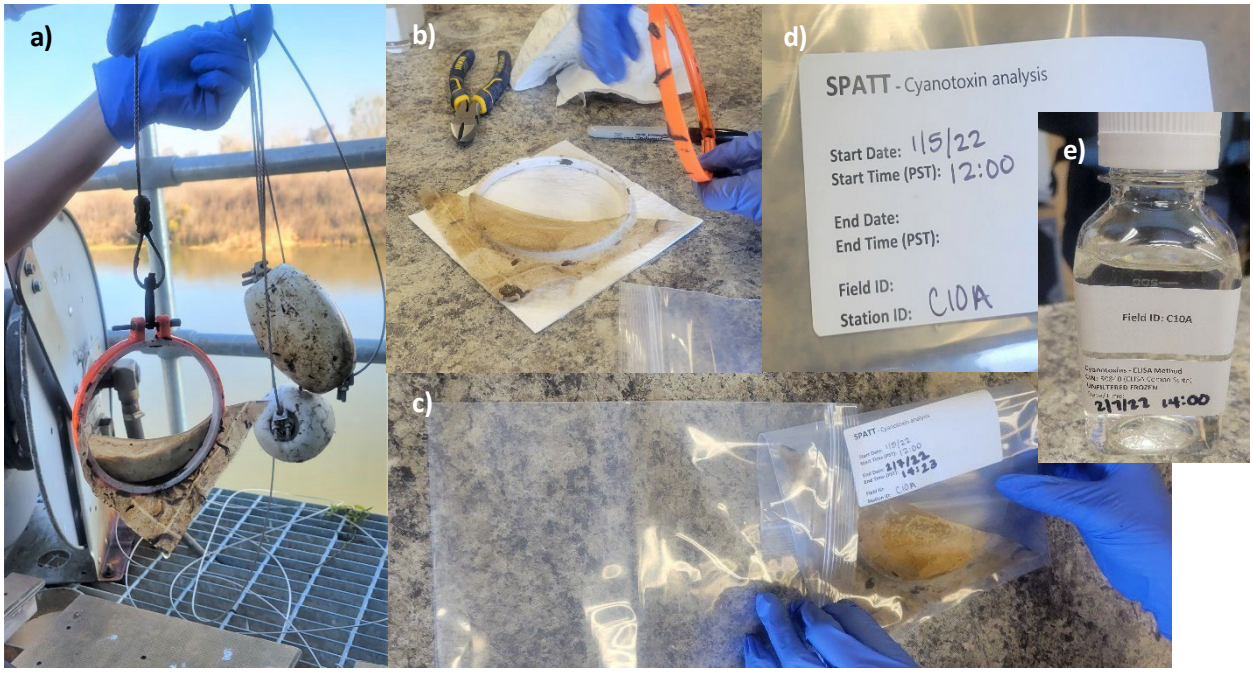

Figure. 2. a) SPATT retrieval, b) SPATT bag removed from embroidery hoop, c) SPATT sampler double bagging, d) SPATT label, e) cyanotoxin water sample label.

FRK Sample Pick-up

Once a month, USGS will pick up the retrieved SPATT samplers and 250 mL cyanotoxin samples from the West Sacramento office and will store samples in a -80 °C freezer.

FAL, HOL, HLT Samples

Samples will be stored for up to 2-3 days in the NCRO Water Quality Lab refrigerator prior to shipping to GreenWater via FedEx standard overnight shipping.

Appendix B. Epiphytic HAB Sampling Field Standard Operating Procedures

Equipment

- Sampling pole or rake
- Clippers
- Razor blades
- 250 mL sample bottles
- Squirt bottle with deionized water (DI)
- Ruler or measuring tape
- Plastic work surface (a plastic container lid or tray)
- ½ pint bottle or ~ 100 mL beaker
- Zip lock bags
- Cooler with wet ice

Methods

Pre-collection Preparation:

Label each (DI) triple rinsed bottle with a station identification code, sampling date and sample type ("epiphytic phyto") with a waterproof marker (e.g., Sharpie).

Field Collection:

1. Use a sampling pole or rake to grab submerged aquatic vegetation (SAV) found within a 10-meter radius of a water quality station. Clip vegetation from the sampling pole if needed.
2. Select the dominant plant species to sample for HABs and record sampling date, time, and species of vegetation.
3. Follow species-specific steps to standardize sampling of varying plant morphologies.

Egeria

1. Isolate a 4-cm segment of the plant to sample. Cut off the top 4 cm of the plant and discard in the appropriate receptacle (to prevent fragments from propagating). Cut a 4 cm segment of the stem with its associated leaves.
2. Triple rinse your plastic work surface and half pint bottle or beaker with deionized (DI) water.
3. Scrape the leaves from the 4-cm stem fragment on both sides with a razor blade, transferring any material from the blade into a half pint bottle or beaker. If needed, trim the leaves off the stem to make scraping easier.

4. Pour the scraped material into the sample bottle. Ensure that all the scraped material is transferred into the sample bottle by rinsing the razor blade, work surface, and sides of the half pint bottle or beaker with DI water into the sample bottle. Fill up the rest of the sample bottle with DI up to the 250 mL mark.
5. Store the sample bottle a zip lock bag and place on ice for transport back to the lab.

Storage and Shipping

Samples will be stored for up to 2-3 days in the NCRO Water Quality Lab refrigerator prior to shipping to GreenWater via FedEx standard overnight shipping.

APPENDIX B

Appendix B. NCRO WQES Proposed HAB Monitoring Workplan 2022

CVRWQCB – South Delta Temp. Barriers Project – Section 401 Water Quality Requirements
DWR (NCRO WQES) - Delta Regional Monitoring Program (RMP) Participation Plan
NCRO WQES Proposed HAB Monitoring Workplan 2022

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Introduction:

The collection of additional harmful algal bloom (HAB) data is part of additional requirements by the South Delta Temporary Barriers Project (TBP) Section 401 Water Quality Certification. DWR was required as part of the certification process to provide a revised Delta Regional Monitoring Program (RMP) participation plan that describes a list of proposed monitoring tasks to help the Central Valley Regional Water Quality Control Board (CVRWQCB) better understand the complex water quality questions related to the TBP monitoring program.

The list of additional HAB related Delta RMP monitoring tasks include:

1. Year-Round Visual Harmful Algal Bloom (HAB) Index Reporting – DWR DES Environmental Monitoring Program (EMP) 1-5 *Microcystis* Visual Index
2. Collection of Water Samples for Algal Bloom and/or Toxin Analyses
3. Phytoplankton Identification

Background and Purpose:

HABs are large overgrowths of algae in marine or freshwater ecosystems that have the potential to produce toxins that can harm other living organisms (Zegura et al. 2002). The Sacramento-San Joaquin Delta has observed an increasing number of HABs in the past few years, especially in the central and south Delta. These HABs have been composed primarily of the freshwater algae called cyanobacteria, or blue-green algae (BGA). Specifically, one of the most prevalent cyanobacteria in recent years is *Microcystis aeruginosa* (Lehman et al. 2017); a known producer of toxins called microcyst ins that negatively affect the health of aquatic organisms and can impact human health. In late 2017, as required by South Delta Temporary Barriers Projects CVWRCB Section 401 Water Quality Certification, DWR NCRO began implementing and recording a surface *Microcystis* bloom visual index value during standard water quality station visits.

Monitoring and Evaluation:

Time-period: Visual DWR EMP Visual Index Monitoring of HABs will occur year-round (Jan.-Dec.) in the South and Central Delta at all North Central Region Office (NCRO) Water Quality Evaluation Section continuous monitoring stations. Tow net samples for Microcystis and Van Dorn samples for phytoplankton analyses will occur during the months of known peak *Microcystis* presence (July-October) and coincide with Temporary Agricultural Barrier installation which is typically May-October, but sampling can occur outside of that window if the barrier installation timeline is altered and or visual index scores indicate earlier detection of HABs. Water samples for toxin analysis will be collected only during peak Visual Index periods (Visual Index >4) and will require consultation with CVWRCB before collection.

Location: The NCRO operates monitoring stations and monitors for Microcystis Visual Index from Miner Slough near Sacramento River in the northern Delta south to stations in Old River near Mountain House Creek (Figure 1). The primary study area for the TBP monitoring efforts is in the south Delta channels of Old River and Grant Line Canal near Tracy, CA. The four primary temporary barriers installed are Middle River TBP near MRX station, Grant Line Canal TBP near GLE station, lower Old River TBP near ODM, and Old River near Head TBP near OH1 station (Figure 1).

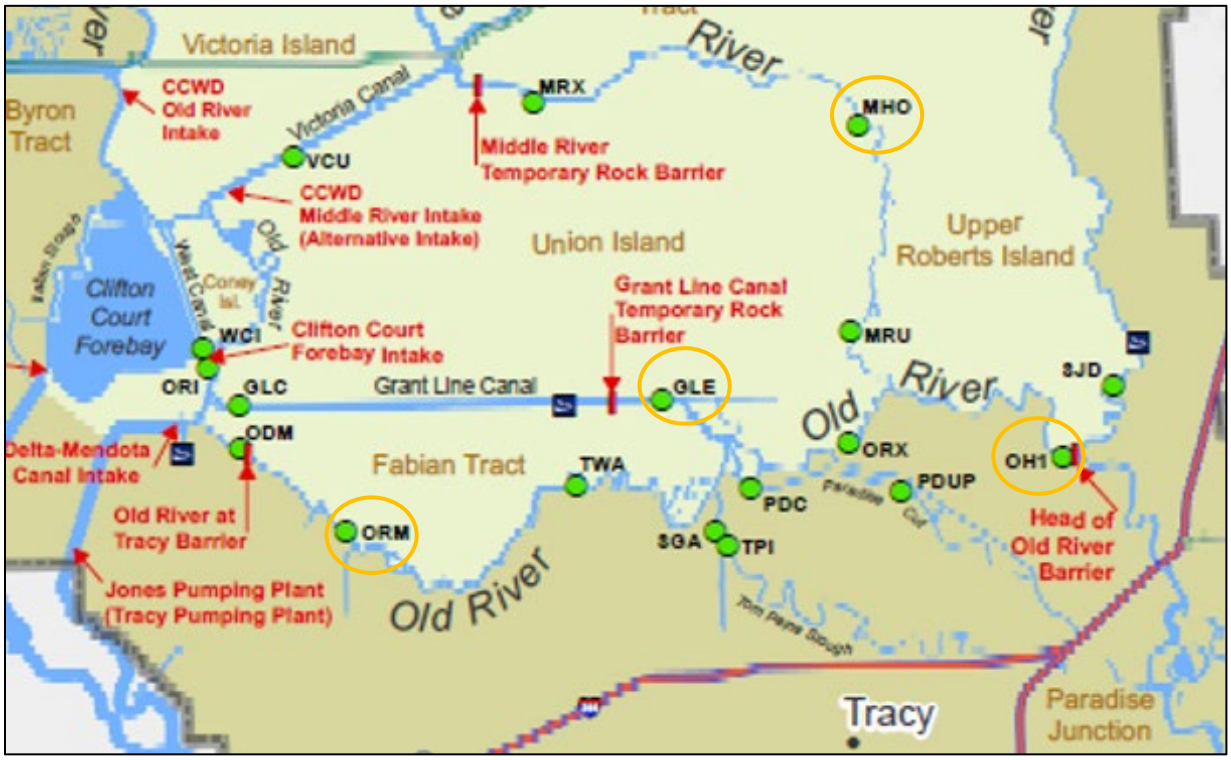


Figure 1. DWR NCRO WQES map of south Delta phytoplankton sampling locations. Four primary sampling locations MHO, GLE, ORM, and OH1 noted by orange circles.

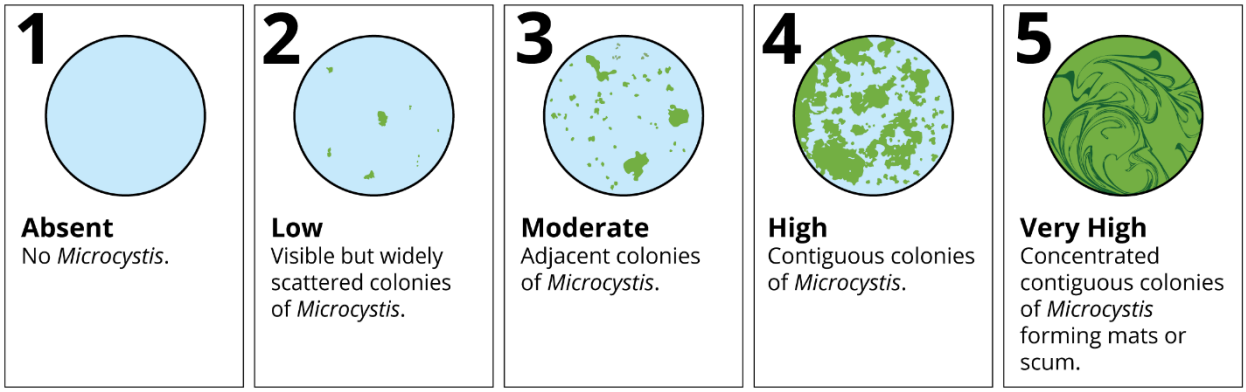
Monitoring Tasks: The following 3 tasks are the procedures which DWR staff accomplish to complete the above listed objectives to monitor HABs in the South Delta**.** Task 3 was drafted in the original workplan upon the creation of this project but has yet to be completed due to a lack

of funding from the CVWRCB. As funding allows, completion of task 3 objectives would be desired during events of high HAB concentrations.

Task 1. Year-Round Visual Harmful Algal Bloom (HAB) Index Reporting

DWR WQES will collect year-round visual analysis of HAB species (*Microcystis* and *Aphanizomenon*) using DWR EMP Visual Qualitative *Microcystis* Scoring Guide (1-5) while performing regular maintenance at continuous water quality stations (typically 1x per month). The primary regions of interest are the south and central Delta regions. These will be reported to the California Water Quality Monitoring Harmful Algal Bloom Portal (https://mywaterquality.ca.gov/habs/index.html). CVRWQCB will provide WQES staff with a modified spreadsheet for importing field data. Data will be reported to the portal monthly after typical continuous water quality station maintenance field runs. Additional photos will be taken and archived to provide visual evidence of index conditions.

Figure 3. DWR EMP Visual *Microcystis* Scoring Guide



Source: Ted Flynn, Environmental Monitoring Program

Task 2. Phytoplankton Sample Collection and Identification

DWR WQES will collect a similar sampling matrix to DWR EMP:

1. *Microcystis* sample will be collected by towing an 80-µm plankton net towed horizontally just below the surface for 1-3 min or using bucket if thick biomass. Sample will then be placed in 50mL Amber glass bottle and preserved w/ Lugol's solution for ID and enumeration of *Microcystis* only using DWR FlowCAM and/or contracted taxonomist (See Appendix for attached protocol).
2. Ambient water sample will be collected at 1m with Van Dorn water sampler and placed in 50 mL amber glass bottle and preserved w/ Lugol's solution for ID and enumeration of all phytoplankton taxa by contracted taxonomist (i.e., BSA Environmental). This sample will correspond with regular chlorophyll-a grab sample completed at each station for corroboration with continuous sonde data.

DWR WQES plans to collect net tow samples at 4 stations (MHO, ORM, GLE, and OH1 – See Figure 1 and 2) during planned water quality station maintenance field runs. These stations are known sites of high (3-4) Visual Qualitative Scoring and cover primary South Delta flow channel corridors potentially effected by temporary barrier installation and/or water project operations. Samples will be collected at these 4 stations 4x each year, 1x per month starting July-Oct (total

net tow samples = 16 for FlowCAM or contracted taxonomist *Microcystis* ID and enumeration and 16 ambient water sample for BSA taxonomist identification).

This task will utilize DWR EMP's standard methods for phytoplankton identification, quantification, biomass estimation, and quality assurance. Samples will be analyzed with the DWR-owned FlowCAM. Samples will typically all be run through FlowCAM within 1-2 months of collection (not exceeding 3-months). Sample biovolume estimates will be completed at the end of the collection period typically by February of the following year.

Task 3. Collection of Water Samples for Algal Bloom and/or Toxin Analyses

DWR WQES will collect a water sample at sites for toxin analysis **only** when Visual Qualitative Scoring is high (4 - 5) and only when CVWRCB provides directive and funding. DWR WQES will contact CVRWQCB to make final decision on whether to collect samples for toxicity (Contacts: Janis Cooke (CVWQCB) 916-464-4672). Samples will be collected in 250 mL amber glass bottles provided by CVWQCB. DWR WQES will contact CVWQCB to coordinate sample drop-off and/or pick-up from laboratory facilities. Samples will typically be held overnight in the WQES laboratory refrigerator or in cooler on ice and picked up the next morning (hold time ~24hours).

Data Management and Analysis:

Data Management and Accessibility

Collected data is stored both physical field datasheets and electronic form. Electronic data is stored on DWR shared drives, cloud-based drives, and external hard drives all of which are housed in DWR facilities on secure servers which experience daily data back-ups. Datasets are maintained by DWR staff and available upon request from Technical Lead and/or Project Manager.

Deliverables

1. Monthly Visual Harmful Algal Bloom (HAB) Index Reporting
2. Phytoplankton Identification and Enumeration Data
3. Annual summary report of years visual scores and HAB biovolume calculations as well as dataset will be delivered in the first quarter of the following year
4. Final Report at end of 401 Certification (every 5 years) summarizing and analyzing the projects visual scoring and biovolume calculations.

Data Analysis

Annual analysis of collected data would consists of 3 main analyses.

1. A monthly average of the HAB visual index over the 12-month periods collected at all the TBP stations.
2. A biovolume estimation of *Microcystis* collected during task 2 at our 4 target stations. Estimation would be completed by one of the following procedures:
    a. FlowCAM processing and classification by DWR staff utilizing EMP's protocols (see Appendix IV for analysis computations)
    b. By outside contracted taxonomic expert in identifying *Microcystis* and other HAB causing phytoplankton
3. A percentage summary of total phytoplankton identified from ambient water samples collected at our 4 target stations over the 4-month sampling period

Further investigation would occur during the final report which could include but is not limited to:

1. Investigation into correlation or causation of HAB abundance in relation to Water Quality and Flow Data collected by NCRO office
2. Statistical analysis of potential trends seen over the project's lifespan
3. Comparing results with other HAB related data collected from throughout the Delta

Funding

All labor and equipment associated with this HAB monitoring project will be funded by Department of Water Resources Operations and Maintenance (O&M) Temporary Barriers Project and Lower San Joaquin South Delta Branch. The primary program manager contacts on the resource agreements for this work are Karen Tolentino (Karen.Tolentino@water.ca.gov 916-902-9897), Bill McLaughlin (William.Mclaughlin@water.ca.gov 916-902-9899), and Jacob McQuirk (Jacob.McQuirk@water.ca.gov (916) 902-9905).

Stakeholder and Agency Coordination

DWR commits to working alongside CVWRCB as well as partners throughout the Interagency Ecological Program to coordinate HAB monitoring efforts and sharing of knowledge to provide the best available results in monitoring the Sacramento San-Joaquin Delta.

References:

Lehman, P. W., Kurobe, T., Lesmeister, S., Baxa, D, Tung, A.., Teh, S. J. 2017. Impacts of the 2014 severe drought on the Microcystis bloom in San Francisco Estuary. Harmful Algae 63:94-108.

Zegura B, Sedmak B, and Filipi M. 2002. "Microcystin-LR induces oxidative DNA damage in human hepatoma cell line HepG2." Toxicon, 41, 41-48.

Appendix:

I. 2019 *Microcystis* Field Sampling SOP

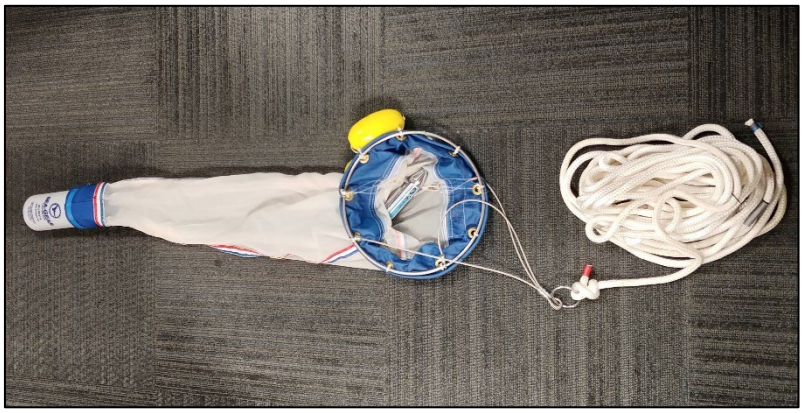
Purpose:

NCRO sampling for Microcystis biovolume and toxins (when appropriate) as part of the 401c permit for temporary barriers in the South Delta.

A. Microcystis net setup

Equipment:

- *Microcystis* net - 0.3 m wide, 80 µm mesh plankton net
- 1 L Plastic Cod End
- 40 ft rope
- General Oceanic 2030R6 Mechanical Flow meter (w/ Low Velocity Rotor)
- Floatation Buoy
- Zip-ties



1. Prepare the flow meter for use by adding water to the body of the meter as directed by manufacture. Attach flow meter to the mouth of the *Microcystis* net using zip-ties. Be sure to attach the flow meter to the net's ring so that it sits in the center of the net and the propeller falls inside of the net.
2. Attach flotation buoys to the top of the *Microcystis* net ring using zip-ties. Attach enough flotations to allow the top of the net's ring to sit at the surface of the water when launched.
3. Attach a plastic wide mouth bottle to the end of the *Microcystis* net. Be sure to tighten any loose bolts that are holding down the hose clamp ring.
4. Tie one end of the 40 ft rope to the steel wires at the mouth of the net. Prepare rope for launch by securely attaching rope to vessel used for towing.

B. *Microcystis* Net Tow samples

Equipment:

- *Microcystis* net - 0.3 m, 80 µm mesh plankton net, flow meter, line, cod end, floats
- 1L amber glass bottle
- 1 Labeled 60ml amber glass bottle with 0.5 mL Lugol's Iodine solution
- 2000 mL graduated cylinder
- 100 mL graduated cylinder
- *Microcystis* tow and toxin data sheet, pencil
- Funnel
- Bucket
- DI water refill and wash bottle

Procedure:

1. Bottle Preparation: Label the bottle before collecting samples with station name, date (mm/dd/yy), sampling method ('net tow'). Add in 0.5 mL of Lugol's Iodine Solution to 60 mL phytoplankton bottle.
2. Read the flow meter value and write down the start value.
3. With the *Microcystis* net, flow meter, line, and cod end attached and ready, drop the net in the water just below the surface of the water without spinning the fin on the flow meter and let the current take it out 50 feet away. If current is slack, slowly spool out line into the water as boat operator drives forward. There should be tape or a visible marker on the line indicating when you are 50 feet away.
4. Once the net reaches 50 feet, gently pull the net in. Try not to break any *Microcystis* colonies
5. Repeat steps 3 and 4
6. Record the ending flow meter reading.
7. Gently rinse the net from the outside using the DI wash bottle to rinse any big colonies into the cod end.
8. Remove the cod end from the net. Pour the cod end water into a 2000 mL graduated cylinder and record the volume.
9. Pour the water from the graduated cylinder into the 1L glass amber bottle if collecting additional sample during high HAB concentration events.
10. At all times, be gentle with the sample. Gently swirl the 1L amber bottle containing net tow water. Using the 100 mL graduated cylinder, measure out 50 mL of the Microcystis Net Tow sample. Be careful not to spill any sample. Use a small funnel for sample transfers if needed.
11. Tightly cap the Net tow 60 mL bottle and invert several times to ensure the mixture of Lugol's Solution. Place in a Ziploc bag. Store the samples in a safe place that will avoid damage to the bottles and keep out of direct sunlight. **Do NOT ice or freeze samples.**
12. Once finished, tightly screw on the lid of the 1L glass amber bottle, and place on wet ice in the cooler.

NOTE: Bucket – If the *Microcystis* is thick, then the flow meter will not function well, and bucket sampling might be necessary. Try to get a representative sample of the surface water and scum – don't scrape the scum to get more *Microcystis*. Place the *Microcystis* sample in a 1L amber glass bottle and place on ice.

C. *Microcystis* Net Tow samples for phytoplankton bottles

Equipment:

- *Microcystis* tow and toxin data sheet, pencil
- Van Dorn water sampler
- 2000 mL graduated cylinder
- 100 mL graduated cylinder
- 1 Labeled 60ml amber glass bottle with 0.5 mL Lugol's Iodine solution
- Small funnel for sample transfers

Procedure:

1. Bottle Preparation: Label the bottle before collecting samples with station name, date (mm/dd/yy), sampling method ('van dorn'). Add in 0.5 mL of Lugol's Iodine Solution to 60 mL phytoplankton bottle.
2. Rinse the van Dorn 3x by dropping it into the water and pulling it back up just above the surface of the water to empty.
3. Using a Van Dorn, collect a water sample 1 meter below the surface of the water.
4. Measure out 50 mL of sample using a 100 mL graduated cylinder and place in 60 mL bottle.
5. Tightly cap the phytoplankton bottle and invert several times to ensure the mixture of Lugol's Solution. Place in a Ziploc bag. Store samples in a safe place that will avoid damage to the bottles and keep out of direct sunlight. **Do NOT ice or freeze phytoplankton samples.**
6. Record data by adding a checkmark to the assigned box on the datasheet. Rinse the graduated cylinder 3x with DI water for the next site.

D. Ambient Water –Toxin samples

Equipment

- 0 - 0.3 m Van Dorn water sampler
- 1 L amber glass bottle

Important: inspect the van Dorn rope for frays or other weak points at the beginning of each sampling day. You do not want to lose the sampler due to rope break.

Procedure:

1. Bottle Preparation: Label the bottle before collecting samples with station name, date (mm/dd/yy), sampling method ('van dorn').
2. Rinse the van Dorn 3x by dropping it into the water and pulling it back up just above the surface of the water to empty.

3. Lower the van Dorn right below the surface of the water column and collect water sample by dropping the messenger to release the rubber end covers. Do not try to collect *Microcystis*, just the water below the surface.
4. Pull up the van Dorn and triple-rinse a 1-L amber glass bottle before filling it all the way up. Place the bottle on wet ice in the cooler.
5. Record data by adding a checkmark to the assigned box on the datasheet and prep the van Dorn for the next site.

E. Sonde readings and additional notes

Note: This step is not required by the Central Valley Regional Water Quality Control Board, but is additional information being collected by WQES staff.

1. Using a calibrated EXO field sonde, take a field reading 1 meter below the surface while collecting the *Ambient water – Toxin Samples*. Record the following parameters: Temperature, Dissolved Oxygen percent and concentration, Specific Conductivity, pH, Turbidity (FNU), Blue Green Algae (ug/L), and Chlorophyll (RFU and ug/L).
2. Record HAB visibility based on WQES' HAB visibility scale (1=not visible, 2= low, 3= medium, 4= high, 5= extreme)

F. Sample Processing

1. The 60 mL **Van Dorn** samples are to be stored in a dimly lit place until it can be processed for phytoplankton analysis. WQES is working with DISE to conduct phytoplankton analysis. Lugol's Iodine solution allows for storage of the sample up to four months after collection.
2. The 1 L Microcystis tow net samples can be discarded after the 60 mL subsample is taken. Please be aware that staff at UC Davis may want to conduct additional analysis on these samples. It is important that you communicate with all stakeholders, assuring the sample is no longer needed before discarding collection. The 60 mL **Net Tow** bottles must be stored in a dimly lit place until it can be processed through the FlowCAM for analysis through LT300 and GT300 lens or analyzed via microscopy by outside taxonomist. Lugol's Iodine solution allows for storage of the sample up to four months after collection. See FlowCAM protocol for procedure or contract language for taxonomist.
3. Enter all data collected from field run into an excel sheet including: Date, Time of collection, Site, Net Tow volume, Flow Meter reading of 100 ft tow, Sonde readings, and any additional notes. This file should be shared with all stakeholders.

II. *Microcystis* Sampling Gear Checklist

Microcystis NCRO Sampling 2019

Boat Check List	Date	Date	Date	Date
Field sheets and pencils				
Clip board				
Van Dorn sampler				
Microcystis net, float, flow meter, line, cod end				
Large funnel (optional)				
2000mL graduated cylinder				
Small transferring funnel				
One Ziploc bag for phyto bottles				
Ice chest with sample bottles (below)				
Two 1L amber glass bottle per station				
Two 60mL phytoplankton bottle per station				

III. 2019 *Microcystis* Field Data Sheet

Microcystis Tow & Toxin Sheet

Site	Date	Time	Net Tow Volume (1-2 L glass amber bottle)	Phytoplankton		Ambient Water (0.3m van dorn; 1-2L glass amber bottle)	HAB visual score (1 – 5)	Microcystis Flow Meter 100 ft tow		Notes
				Net Tow	Van Dorn			Start	Stop	

HAB visual Scoring index: 1=not visible, 2= low, 3= medium, 4= high, 5= extreme

Additional Notes:

_____

_____

DWR: Water Quality Evaluation Section

Updated 08 August 2019

IV. FlowCAM Analysis Computations

***Microcystis* Net Tow**

Microcystis was sampled using an 80 µm mesh plankton net with a General Oceanics' mechanical flow meter attached to the opening of the net (0.3 m in diameter). The following formulae were used to calculate the water volume that passed through the *Microcystis* net (from "General Oceanics Digital Flowmeter Mechanical and Electronic Operators Manual").

Values needed	Description
Start and end of flow meter values	Before casting the net and flow meter into the water, the starting flow meter value is recorded. Once the net is pulled out of the water, the ending flow meter value is recorded.
Net diameter = 0.3 meter	Measurement from opening of the net
Standard Speed Rotor Constant = 26,873	Given value from manufacturer
Formulae:	
$$\text{DISTANCE in meters} = \frac{\text{Difference in COUNTS} * \text{Rotor Constant}}{999999}$$	
$$\text{VOLUME cubic meters} = \frac{3.14 * (\text{Net Diameter})^2 * \text{Distance}}{4}$$	
MA net water VOLUME in Liters = Volume cubic meters * 1000	Convert VOLUME cubic meters to VOLUME Liter for easier computation when calculating Final Chlorophyll Value (below)

Calculating Default Values for Sites with No Difference Values

Updated 08 August 2019

To calculate the water volume that passes through the *Microcystis* net, both START and ENDING flow reading are necessary; however, error in reading can occur due to flowmeter not spinning or getting stuck. When this occur for a site, a default value is calculated for the net volume difference (ENDING – START). Below is the calculation on how to obtain the default value if a site is missing a difference value.

Refer to **Field data Microcystis net comps 02182016.xlsx** for example.

File location: F:_Microcystis 2015\Analysis\Bryte data

Site BI on 10/14/15 did not have a difference value because the flowmeter got stuck. A default value was generated by averaging the difference values for BI from all sampling events.

$$mean\ difference = \frac{(sum\ of\ difference\ value\ for\ BI\ from\ all\ sampling\ events)}{\#\ of\ sampling\ event\ with\ actual\ difference\ value}$$

$$1449 = \frac{(1059 + 1392 + 1363 + 1707 + 2030 + 1145)}{6}$$

Updated 08 August 2019

Final Chlorophyll a Volume

The following calculations were performed to determine the final chlorophyll [µg/L] volume in the *Microcystis* net tow sample. Chlorophyll a from here on is abbreviated as chla.

Values needed	Description
Bryte chla [µg/L]	Value from water quality chlorophyll sampling
Cod volume [mL]	Total Microcystis net tow sample volume that was collected in the brown square sampling bottle
$\text{Cod volume [L]} = \frac{\text{Cod volume [mL]}}{1000}$	total sample volume converted from mL to L for easier calculation
MA net water volume [L]	obtain this MA net water volume from the Microcystis net tow computations (see formulae above for method)

Formulae	Description
$\text{Net chla [µg]} = \text{Bryte chla } \left[\frac{\text{µg}}{\text{L}}\right] * \text{sample vol from cod [L]}$	obtain the net chla by multiplying the Bryte chla and cod volume values together
$\text{Final chla } \left[\frac{\text{µg}}{\text{L}}\right] \text{in net tow } = \frac{\text{Net chla [µg]}}{\text{MA net water volume [L]}}$	Calculate final chla in the net tow sample by dividing the net chla into the MA net tow water volume

Updated 08 August 2019

FlowCAM Total Microcystis Biovolume

Microcystis water samples were collected in phytoplankton bottles and preserved with 0.5 mL of Lugol's solution. The samples were processed with the FlowCAM using two size fractions: greater than 300-micron particles and less than 300-micron particles (See FlowCAM Standard Operating Procedure for more details). Each sample was processed 2 to 3 times. Microcystis spp. were then identified and enumerated for total biovolume. The following calculations were performed to determine the total Microcystis biovolume for each site per sampling event.

Values needed	Description
Cod volume [L]	Total Microcystis net tow sample volume that was collected in the brown square sampling bottle
MA net water volume [L]	MA net water volume from the Microcystis net tow computations (see formulae above for method)
Sample vol from cod (L)	Total Microcystis net tow sample volume that was collected in the brown square sampling bottle
Dilution factor 1 to X	The dilution value from when processing the Microcystis sample with the FlowCAM
Count (Microcystis aeruginosa, Microcystis flos-aquaes, Microcystis wesenbergii)	Obtain the count of Microcystis species after classification and QA/QC processing. Each species is counted separately and added together later for the final count
Particles per ml, summary	Obtain this value after classification and QA/QC processing. The value can be found when exporting the classification summary into an excel file
Average biovolume, ABD (Area Based Diameter) (Biovolume → BV)	Obtain this value by exporting the Microcystis classification summary from FlowCAM

Calculations	Unit
Total mass = count * avg BV	$\mu m^3 = \text{count} * \mu m^3$

Updated 08 August 2019

$Correction\ factor = \frac{particles\ per\ mL}{count}$	$\frac{\text{Particles}}{\text{mL}} = \frac{\text{Particles}}{\text{mL} * \text{count}}$
BV/mL = total mass * correction factor	$\frac{\mu m^3}{\text{mL}} = \mu m^3 * \frac{\text{Particles}}{\text{mL}}$
Dilution correction = BV/ml * dilution factor	$\frac{\mu m^3}{\text{mL}} = \frac{\mu m^3}{\text{mL}} * \text{dilution factor}$
Total BV in brown bottle = dilution correction * sample vol from cod * 1000	$\mu m^3 = \frac{\mu m^3}{\text{mL}} * \text{L} * 1000$
Final BV/L = total BV/L / MA net water volume	$\frac{\mu m^3}{L} = \frac{\mu m^3}{L}$
Repeat all steps to calculate the biovolume/L for all runs and *Microcystis* spp.	

If a replication has more than one *Microcystis* spp. (ex: *Microcystis aeruginosa* and *Microcystis flos aquae*s), add the biovolume together. Obtain the mean value for each sampling event by averaging the biovolume from all the replications. Obtain the total *Microcystis* BV/L by adding the GT300 and LT300 BV/L together. Example below.

1	Date	Site	Station	Rep	size fraction	Microcystis aeruginosa final BV/L	Microcystis flos aquae final BV/L	Microcystis wesenbergii final BV/L		Microcystis LT / GT300 BV/L
2	8/14/15	MI	7	a	gt300	4.38E+08	5.52E+06	0.00E+00		4.43E+08
3	8/14/15	MI	7	b	gt300	7.72E+07	2.40E+06	0.00E+00		7.96E+07
4	8/14/15	MI	7	c	gt300	4.68E+07	1.35E+07	0.00E+00		6.03E+07
5	8/14/2015	MI	7	b	lt300	6.34E+05	0.00E+00	0.00E+00		6.34E+05
6	8/14/2015	MI	7	a	lt300	5.95E+07	7.66E+06	0.00E+00		6.72E+07

Updated 08 August 2019

	Collection Date	Station	Site	Rep	MC GT300 bv/L		meanGT300			
2	8/14/2015	7	MI	a	4.43E+08		1.94E+08			
3	8/14/2015	7	MI	b	7.96E+07					
4	8/14/2015	7	MI	c	6.03E+07		+			Total MC BV/L
5								=		2.28E+08
6	Collection Date	Station	Site	Rep	MC LT300 bv/L		meanLT300			
7	8/14/2015	7	MI	b	6.34E+05		3.39E+07			
8	8/14/2015	7	MI	a	6.72E+07					
9										

APPENDIX C

Appendix C. Task order for additional HABs work by USGS

California Water Science Center Proposal 2022-09
Southwest Region, WMA, USGS
Principal Investigator: Keith Bouma-Gregson
Cooperator: CA Department of Water Resources

INTERAGENCY AGREEMENT
WORK ORDER

Work Order No.:	HABDSB-01
Contractor:	United States Geological Survey (USGS)
Request for Services:	Under Standard Agreement No. 4600014088
Dated:	March 7, 2022

As stated in Agreement 4600014088 hereinafter referred to as "the agreement" (Exhibit A-Section III), the "USGS is a federal entity, a bureau of the Department of the Interior, and not a contractor". All references to "Contractor" shall mean USGS, a U.S. Government agency. The following text uses the term DWR Project Manager and Work Order (WO) Manager equivalently.

The Department of Water Resources (DWR) is implementing activities needed to construct and operate Emergency Drought Barriers (EDBs) in response to the Governor's Emergency Drought Proclamation on May 10, 2021 which extends the drought emergency to include the Sacramento-San Joaquin Delta. Currently, an EDB is installed in West False River (Figure 1).

The field work, analysis, and reporting described in this WO is intended to document the effects of the Temporary Urgency Change Petitions (TUCP) and the West False River on the abundance and distribution of toxic cyanobacterial harmful algal blooms (cyanoHABs) in the Sacramento/San Joaquin Delta.

BACKGROUND

This WO provides detailed scopes of work, budgets, timelines, and deliverables associated with USGS' ongoing participation in field work related to the impact of EDBs on water quality and algal toxins in the Delta. The total period of performance of this WO is from the date of WO execution through February 28, 2024. This period of performance allows for data collection one year from the date of the WO being executed and additional months to conclude analysis and report writing after all data have been collected from the field. This period of performance could change if drought conditions continue.

DESCRIPTION OF TASKS

OVERVIEW

The tasks involved in this WO include: Project Management (Task 1); High-resolution mapping surveys in Miner Slough, Steamboat Slough, Lindsey Slough, Cache Slough Complex, and the Sacramento River (Task 2, Figure 2); High-resolution mapping surveys around Franks Tract and Mildred Island (Task 3, Figure 3); Cyanotoxin monitoring at DWR's Franks Tract (FRK) station (Task 4); Water Quality, Phytoplankton, and cyanoHABs data analysis and interpretation (Task 5); Field-validation of remote sensing cyanoHAB algorithm (Task 6); Analysis and Reporting (Task 7).

Task 1 – Project Management

Period of performance: **Date of WO execution through February 28, 2024.**

Description

Contractor shall manage this work order including coordinating with DWR, providing progress reports, participating in coordination calls, and reviewing/approving deliverables.

Contractor shall attend monthly drought monitoring coordination teleconferences with DWR WO Manager and core team members (as directed by DWR WO Manager) and provide updates and monthly progress documentation of WO tasks, discuss progress/status such as risks, performance issues, completed task(s), and anticipated completion dates of task(s). Contractor and DWR WO manager will collaborate, develop, and adopt the monthly progress report template prior to the first monthly coordination and status meeting. DWR may request additional coordination and briefing teleconferences as the drought proceeds including monitoring design, logistics, implementation, data analysis/reporting, explanation of the methods and results, and presentations at interagency meetings, conferences, and/or agency executives. Contractor shall coordinate and communicate (via email or phone) with DWR WO Manager for approval prior to implementing a change in scope.

Deliverables

1.1 Monthly progress reports on status of tasks

Task 2 – High-resolution mapping surveys Miner Slough, Steamboat Slough, Lindsey Slough, Cache Slough Complex, and Sacramento River

Period of performance: **Date of WO execution through October 31, 2022**

Description

Contractor will be conducting 3 high-resolution mapping surveys in spring, summer and fall (~May, July and October) of 2022 (see Table 1 for high-resolution and discrete parameters). These are boat-based surveys that involve continuously measuring water quality parameters while underway and collecting water quality samples at ~30 samples across the Delta. The surveys during 2022 are being funded by an agreement between the USGS and the State Water contractors. However, Miner, Steamboat, Lindsey, and upper Cache Sloughs are not covered by these surveys. Under this task, the three 2022 surveys will be extended to cover these additional waterways that may be impacted by the EDBs. If hydrologic conditions do not warrant the installation of EDBs in Miner and Steamboat Sloughs in 2022, data will be collected to obtain baseline data of water quality conditions without the EDBs.

Under this task

- Contractor will extend the 2022 Spring, Summer and Fall mapping surveys to include Miner and Steamboat Sloughs. Contractor also will extend mapping surveys up Lindsey Slough to where it meets Barker Slough and feeds water to the North Bay Aqueduct Pumping Plant to assess potential drinking water impacts (e.g., salinity, dissolved organic carbon).

- Parameters indicative of water residence time (stable isotopes of water, d2H and d16O) will be added to 1 mapping surveys conducted in the Northern Delta and collected in Miner, Steamboat, and Lindsey, and Barker Sloughs. Water residence time parameters – including in situ continuous measurements made during the mapping survey and collection of discrete water samples collected at key locations (Table 1) – will be collected during the Summer (July/August) survey, when flows are lower and cyanoHABs most likely. These data will be compared to USGS residence time calculations from prior years without EDBs in place (Figure 2).

The timing of all data collection in Task 2 will be coordinated with DWR to ensure the collection of data best suits the study objectives.

Deliverables

DWR will be informed via email of updates to the sampling strategy, any data collection anomalies including equipment failure, sensor fouling, or other changes/concerns as the study progresses. Provisional data will be made available upon request from DWR WO manager.

2.1 Public data release (e.g. NWIS, ScienceBase) of USGS-approved data collected through this task by February 28, 2024. Working collaboratively, USGS and DWR staff will either, add a record in DWR DELVE database to link DELVE with the location of the data in a USGS data repository (e.g. NWIS or ScienceBase) or will add the data directly to the DWR DELVE database.

Task 3 – High-resolution mapping surveys around Franks Tract and Mildred Island

Period of performance: **Date of WO execution through October 31, 2022**

Description

To describe the phytoplankton species composition and bloom density around the False River Barrier, Contractor will conduct high-resolution mapping in and around Franks Tract, as well as in and around Mildred Island which will serve as a control (no EDB) site.

- Contractor will conduct 3 mapping surveys of Franks Tract and Mildred Island between approximately, May-October 2022. Exact timing of surveys will depend on observations of bloom formation. Continuous and discrete water quality and phytoplankton measurements will be collected during each survey. All parameters listed in Table 1 will be collected, except continuous ammonium data.

- Water residence time parameters – both in situ continuous measurements made during the mapping survey and collection of discrete water samples collected at key locations (stable isotopes listed in Table 1) – will be collected across both flooded islands. In Franks Tract, the boat path will cross the gradient of low-to-high residence time posited by DWR hydrodynamic modeling results (Figure 3).
    - Residence time measurements will be used to help validate and calibrate the DWR hydrodynamic models.

The timing of all data collection in Task 3 will be closely coordinated with DWR to ensure data collection efforts best suit the study objectives.

Deliverables

DWR will be informed via email of updates to the sampling strategy, any data collection anomalies including equipment failure, sensor fouling, or other changes/concerns as the study progresses. Provisional data will be made available upon request from DWR WO manager.

3.1 Public data release (e.g. NWIS, ScienceBase) of USGS-approved data collected through this task by February 28, 2024. Working collaboratively, USGS and DWR staff

will either, add a record in DWR DELVE database to link DELVE with the location of the data in a USGS data repository (e.g. NWIS or ScienceBase) or will add the data directly to the DWR DELVE database.

Task 4 – Cyanotoxin monitoring at Franks Tract (FRK) station

Period of performance: **Date of WO execution through March 31, 2023**

Description

- Contractor will assist DWR in monitoring for cyanotoxins at the DWR monitoring station in Franks Tract (FRK) for one year (~April 2022-April 2023).
- Sample collection, handling, and analyses will follow protocols used by USGS and DWR for cyanotoxin data collection efforts at other stations in the Delta.
    - Cyanotoxin samples (both discrete whole water and solid phase adsorption toxin tracking (SPATT) samplers) will be collected approximately monthly for the months of November to April and approximately twice a month for the months of May through October for a total of 18 samples per year.
    - All Samples will be analyzed by LC-MS/MS by Lumigen Instrument Center (http://chem.wayne.edu/lumigen/) and 20% subset of samples will be analyzed by ELISA method by BSA Environmental Services (https://www.bsaenv.com). Funding for cyanotoxin analysis is being provided by the Delta Science Program through a separate agreement with Lumigen Instrument Center and BSA Environmental Services and is not included in this work order.
    - An additional ~10% of samples will be collected for QA/QC (field duplicates, lab replicates, blanks, and spikes)
- Contractor will assemble solid phase adsorption toxin tracking (SPATT) samplers to monitor cyanotoxins in Franks Tract. After constructing SPATT samplers, Contractor will ship samplers to DWR who will deploy samplers in Franks Tract.
- DWR will collect discrete whole water samples and deploy SPATT samplers at FRK. These cyanotoxin samples will be delivered to Contractor, who will arrange shipment to analytical laboratories, and receive and manage results and data from the lab.
- Provisional data will be shared with DWR within 1 business days of receipt from laboratory.

Deliverables

DWR will be informed via email of updates to the sampling strategy and any anomalies including equipment failure, analytical issues, or other changes/concerns as the study progresses.

4.1 Assembled SPATT samplers will be supplied to DWR within 10 business days of a request from DWR.

4.2 DWR will be informed via email within 24 hours when samples are shipped to analytical labs.

4.3 Provisional cyanotoxin data will be shared with DWR within 1 business day of receipt from laboratory.

4.4 Public data release (e.g. NWIS, ScienceBase) of USGS-approved data collected through this task by February 28, 2024. Working collaboratively, USGS and DWR staff will either, add a record in DWR DELVE database to link DELVE with the location of the data in a USGS data repository (e.g. NWIS or ScienceBase) or will add the data directly to the DWR DELVE database. Data will also be made available to DWR to publish in Environmental Data Initiative (EDI).

Task 5 – Water Quality, phytoplankton, and cyanoHABs data analysis and interpretation.

Period of performance: **Date of WO execution through February 28, 2024**

Description

Hydrologic and climatic conditions influence the community composition, abundance, and spatial distribution of phytoplankton, including cyanoHABs. Water operations in the Delta are adjusted in response to weather and precipitation patterns. How water is managed in the Delta changes the water quality conditions phytoplankton experience and alter how the phytoplankton community develops over time. Through the Interagency Ecological Program (IEP) and other efforts, DWR analyzes water quality data to inform how the aquatic food-web responds to different environmental conditions, including drought, and water management.

When requested by DWR, Contractor will consider participating in DWR data analysis and interpretation projects relating to water quality, phytoplankton, and food-webs in the Delta. Participation in each project will depend on the availability of USGS scientists. DWR and Contractor will agree upon the scope of Contractor involvement at the outset of each project in this task.

Deliverables

5.1 USGS will contribute to data analysis projects coordinated or led by DWR and will help plan future data collection or analysis efforts. A written summary will be provided to DWR each quarter summarizing what was accomplished under this task.

Task 6 – Field-validation of remote sensing cyanoHAB algorithm

Period of performance: **Date of WO execution through October 31, 2023**

Description

Remotely sensed data is useful for tracking bloom dynamics on large water bodies that would be costly to sample frequently with field visits. Satellite algorithms to estimate cyanobacterial density in the top (about 1 Secchi depth) of surface waters have been developed by National Oceanographic and Atmospheric Administration (NOAA). The Cyanobacterial Index (CI) algorithm is applied to data from the Ocean Land Color Instrument OLCI sensor on the Sentinel-3 satellites for the continental United States (Wynne et al. 2018). These data are freely available from NOAA. The satellite sensor has a pixel size of 300 meters, so only larger channels in the Delta are resolvable with the CI algorithm.

While remote sensed data provides high spatial and temporal coverage (return time 2-3 days), certain water conditions can confound the algorithm and generate spurious results. However, ground-truthing of remote sensed data can be accomplished with handheld hyperspectral field measurements (Figure 4). By analyzing the reflectance spectra under different conditions, it is possible to generate custom “flags” to identify satellite pixels likely to be falsely indicating a cyanoHAB and minimize erroneous satellite detections of cyanoHABs in the Delta. This will improve the utility of satellite remote sensing data across all regions of the Delta.

- Contractor will collect handheld hyperspectral radiometer measurements to field validate the CI algorithm against confounding factors such as submerged aquatic vegetation, filamentous algae, and suspended sediments (Figure 4). Discrete samples for chlorophyll-a, phytoplankton enumeration, dissolved organic compounds, and suspended particles will also be collected during surveys.

- Contractor will conduct at least 3 survey days across a variety of seasons and water conditions. This will enable the creation of a hyperspectral library representing different environmental and water quality conditions in the Delta. Contractor will then run the CI algorithm on each of the collected spectra and identify which conditions triggered a false positive or false-negative from the algorithm.

- Contractor will develop a Delta-specific “flagging” algorithm to identify these confounding results and record the CI value as “questionable.”

Deliverables
DWR will be informed via email of updates to the sampling strategy and any anomalies including equipment failure, analytical issues, or other changes/concerns as the study progresses.

6.1 Public data release (e.g. NWIS, ScienceBase) of USGS-approved data collected through this task by February 28, 2024. Working collaboratively, USGS and DWR staff will either, add a record in DWR DELVE database to link DELVE with the location of the data in a USGS data repository (e.g. NWIS or ScienceBase) or will add the data directly to the DWR DELVE database.

Task 7 – Analysis and Reporting

Period of performance: **Date of WO execution through February 28, 2024**

Description
Analyses of data collected in Tasks 2 (mapping of North Delta Sloughs), will be conducted to assess the direct or potential influence of EDBs on the phytoplankton community and cyanoHABs in the North Delta. If EDBs are not placed in the North Delta in 2022, then analyses in Task 2 will describe baseline environmental conditions to enable future comparisons if EDBs are installed in Miner or Steamboat Sloughs.

Analyses of data collected in Tasks 3-4 (Mapping of Franks Tract and Mildred Island, Cyanotoxin Monitoring at Franks Tract) will be conducted to assess the influence of the False River EDB on water quality, the phytoplankton community and cyanoHABs in the Central Delta.

Analysis of data in Task 6 will be conducted to assess the effectiveness of satellite remote sensed data for monitoring of cyanobacterial blooms during drought conditions.

Deliverables
Contractor shall analyze the data collected in Task 2, 3, 4, and 6 and will contribute, in a collaborative process, text and graphics to the interim reports below based on the indicated timelines. Additional updates or presentations will be given upon request by DWR. If study findings warrant, USGS staff will lead or co-author a journal article(s) or USGS Scientific Investigations Report(s).

7.1 USGS will contribute to DWR-led comprehensive report covering monitoring period June 2021 to November 2022: Due in Fall 2023 / Winter 2024

TABLES

Table 1. Continuously and discretely measured parameters collected during high-resolution mapping surveys.

Continuously measured parameters	
Temperature	Chlorophyll-*a*
Specific conductivity	Fluorescence of dissolved organic matter (fDOM)
pH	Nitrate
Dissolved Oxygen	Ammonium
Turbidity	Phytoplankton taxonomy (Fluoroprobe)
Water Residence time: stable isotopes δ^2H and $\delta^{18}O$ **(Optional parameter)**	
Discretely sampled parameters	
Nitrate (NO3-N) and Nitrite (NO2-N) (µM)	Soluble reactive phosphate (SRP, PO4) (µM)
Ammonium (µM)	Chlorophyll-*a* & Phaeophytin (mg L^{-1})
Total Dissolved Nitrogen (TDN) (µM)	Phytoplankton Enumeration (cells L-1 and cm^3 L-1 by species)
Dissolved Organic Nitrogen (DON) (µM)	Picocyanobaceria (cells L^{-1} and cm^3 L^{-1})
Optical Properties of dissolved organic matter (absorbance, fluorescence) (intensity)	Water Residence time: stable isotopes δ^2H and $\delta^{18}O$ **(Optional parameter)**

FIGURES

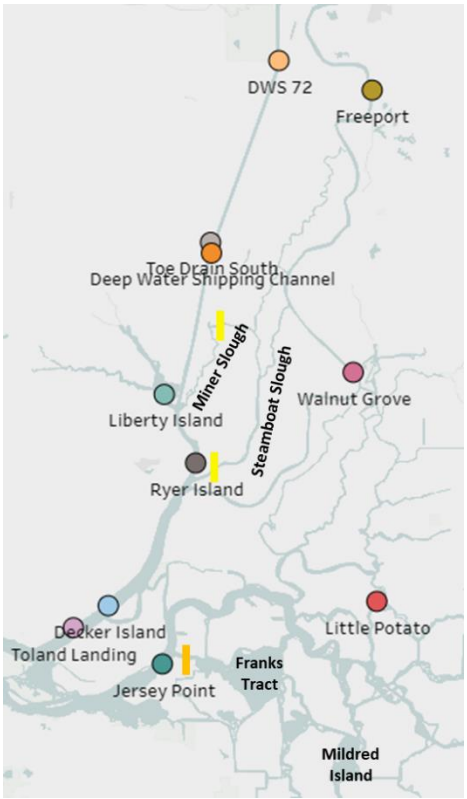


Figure 1. Map of the study region of the Sacramento San Joaquin Delta showing current False River Barrier (orange bar), proposed barriers in Miner and Steamboat Sloughs

(yellow bars), and current USGS continuous water quality monitoring stations (colored points).

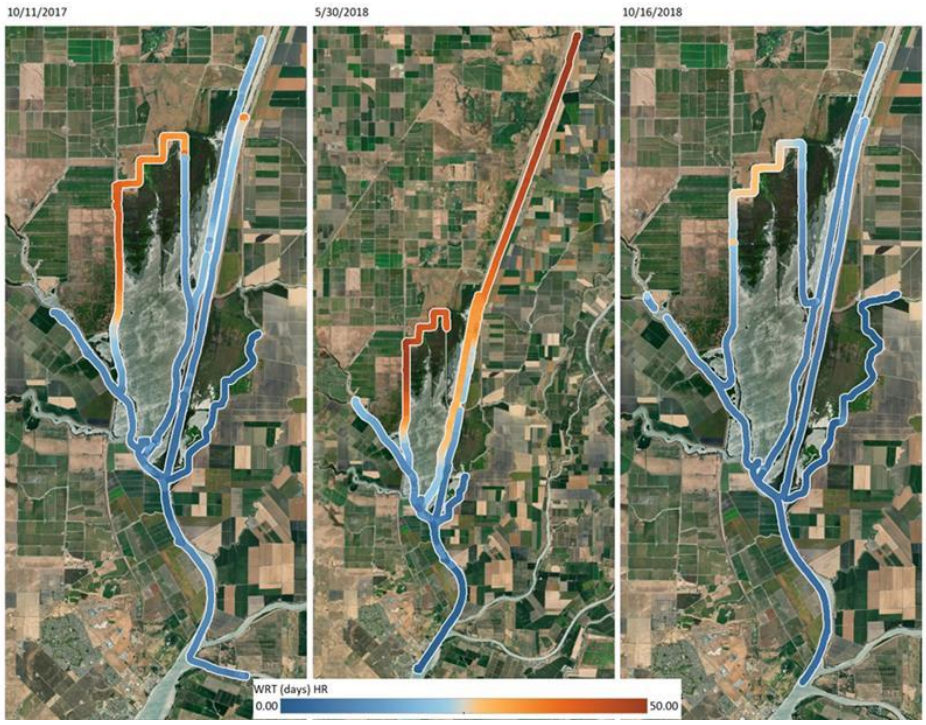


Figure 2. Water Residence Time (WRT) measurements from 2018 in Cache Slough Complex.

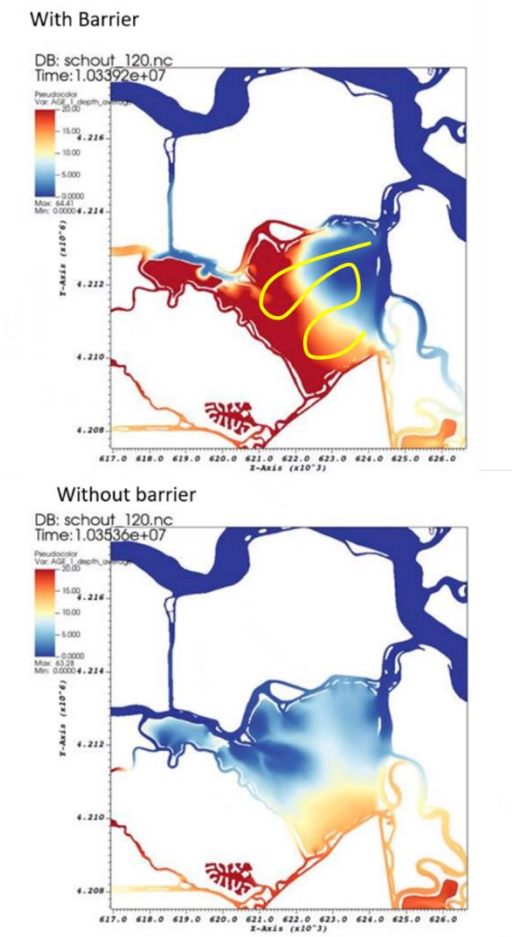


Figure 3. Water residence time (days) in Franks Tract with (top panel) and with the False River Barrier (middle panel). Yellow line shows potential mapping and sampling route across the gradient of young to old water moving from northeast to southwest. (Model output: Eli Ateljevich, DWR)

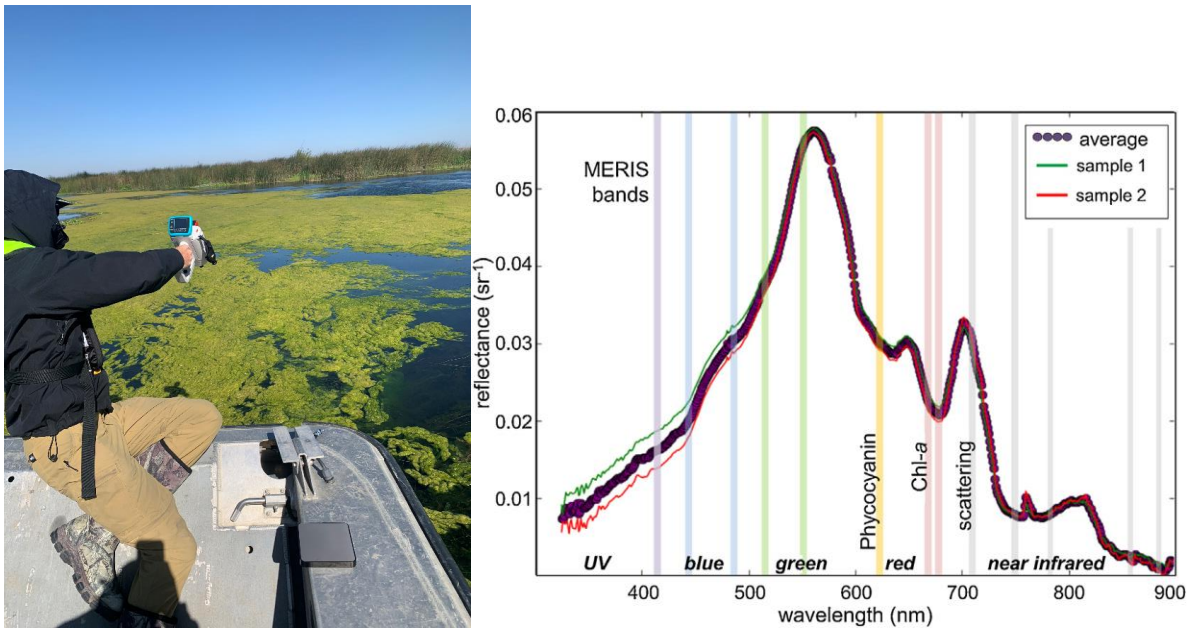


Figure 4. Left panel: Collecting hyperspectral data from a floating algal mat in Franks Tract. Right panel: Example hyperspectral reflectance from handheld radiometer. The absorbance of chlorophyll-a can be seen at 680-700 nanometers. The MERIS satellite bands are shown as vertical bars. (Image from Stumpf et al. 2016)

REFERENCES

Stumpf, R.P., Davis, T.W., Wynne, T.T., Graham, J.L., Loftin, K.A., Johengen, T.H., Gossiaux, D., Palladino, D., Burtner, A., 2016. Challenges for mapping cyanotoxin patterns from remote sensing of cyanobacteria. Harmful Algae 54, 160–173. https://doi.org/10.1016/j.hal.2016.01.005

Wynne, T.T., Meredith, A., Briggs, T., Litaker, W., Stumpf, R.P., 2018. Harmful Algal Bloom Forecasting Branch Ocean Color Satellite Imagery Processing Guidelines. NOAA Technical Memorandum NOS NCCOS ; 252. https://doi.org/10.25923/twc0-f025

SCHEDULE

Contractor will be prepared to begin work upon receipt of this signed Work Order by DWR through February 28, 2024. All deliverables will be provided to the DWR Work Order manager by the dates indicated below. Permission for deliverable time extensions not beyond the end date of this Work Order requires approval in writing from the DWR Work Order manager.

The projected schedule for completing the work follows:

Schedule of Deliverables - 1		
Task No.	**Deliverable**	**Deliverable Date**
Task 1 – Project Management	1.1 Monthly progress reports on status of tasks	Monthly and ongoing with WO manager. Within 30 days
Task 2 – High-resolution mapping surveys Miner Slough, Steamboat Slough, Lindsey Slough, Cache Slough Complex, and Sacramento River	2.1 Public data release (e.g. NWIS, ScienceBase) of USGS-approved data collected through this task. A record of the data release will be added to the DWR DELVE database.	February 28, 2024
Task 3 - High-resolution mapping surveys around Franks Tract and Mildred Island	3.1 Public data release (e.g. NWIS, ScienceBase) of USGS-approved data collected through this task by February 28, 2024. A record of the data release will be added to the DWR DELVE database or a link in DWR DELVE database to redirect DWR to USGS website for data access as appropriate.	February 28, 2024
Task 4 – Cyanotoxin monitoring at Franks Tract (FRK) station	4.1 Assembled SPATT samplers will be supplied to DWR within 10 business days of a request from DWR. 4.2 DWR will be informed via email within 24 hours when samples are shipped to analytical labs. 4.3 Provisional cyanotoxin data will be shared with DWR within 1 business days of receipt from laboratory.	4.1 10 business days of a request from DWR 4.2 Within 24 hours of shipment 4.3 Within 1 business days of receipt from laboratory

Schedule of Deliverables - 1		
Task No.	**Deliverable**	**Deliverable Date**
	4.4 Public data release (e.g. NWIS, ScienceBase) of USGS-approved data collected through this task by February 28, 2024. A record of the data release will be added to the DWR DELVE database or as a link in DELVE database to redirect DWR to EDI or USGS website for data access as appropriate. Data will also be made available to DWR to publish in Environmental Data Initiative (EDI).	4.4 February 28, 2024
Task 5 - Phytoplankton and cyanoHABs data analysis and interpretation.	5.1 USGS will contribute to data analysis projects coordinated or led by DWR and will help plan future data collection or analysis efforts. A written summary will be provided to DWR each quarter summarizing what was accomplished under this task.	Quarterly
Task 6 - Field-validation of remote sensing cyanoHAB algorithm	6.1 Public data release (e.g. NWIS, ScienceBase) of USGS-approved data collected through this task. A record of the data release will be added to the DWR DELVE database.	6.1 February 28, 2024
Task 7 – Analysis and Reporting	7.1 Contribute to DWR led comprehensive report covering monitoring period June 2021 to November 2022: Due in Fall 2023 / Winter 2024	7.1 Comprehensive report covering monitoring period June 2021 to November 2022: Due in Fall 2023 / Winter 2024

All deliverables listed above shall be packaged and delivered to DWR by email, in applicable Microsoft Office (word, excel, etc.), Adobe (pdf), or other file formats acceptable to the DWR WO Manager.

All deliverables shall be completed (including all required USGS review steps) and submitted to the DWR Work Order Manager on or before the indicated date. DWR staff shall provide comments and input to the deliverables in advance to the stated due dates as practicable and as requested by USGS staff.

DETAILED COSTS

Contractor shall invoice all services in accordance with Exhibit A, of the master contract. The total amount of this Work Order shall not exceed **$613,581**. See Attachment 1 for complete budget cost details.

WORK ORDER SUMMARY

SUMMARY BY TASK

Work Order HABDSB-01	
General Project Description	
Task	**Total by Task**
Task 1 – Project Management	$60,429.64
Task 2 – High-resolution mapping surveys Miner Slough, Steamboat Slough, Lindsey Slough, Cache Slough Complex, and Sacramento River	$96,670.93
Task 3 - High-resolution mapping surveys around Franks Tract and Mildred Island	$129,426.33
Task 4 – Cyanotoxin monitoring at Franks Tract (FRK) station	$28,169.15
Task 5 - Phytoplankton and cyanoHABs data analysis and interpretation.	$19,991.32
Task 6 - Field-validation of remote sensing cyanoHAB algorithm	$120,056.97
Task 7 – Analysis and Reporting	$158,836.13
Total	**$613,581**

CONTACT PERSONS

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AUTHORIZED SIGNATURES

Contractor and State agree that these services will be performed in accordance with the terms and conditions of Standard Agreement Number 4600014088.

State of California
Department of Water Resources

Behzad Soltanzadeh
Assistant Division Manager 2
Division of Operations and Maintenance

3/15/2022
Date

United States Geologic Survey

Michael Schmidt, Director
Western Fisheries Research Center

Date

ATTACHMENT 1 - PROJECT STAFFING

USGS personnel listed below are among the primary staff who may bill to this Work Order. Additional staff approved by DWR may be assigned to this Work Order (see Attachment 1 for more detail).

- Keith Bouma-Gregson
- Tamara Kraus
- Brian Bergamaschi
- Elizabeth Stumpner
- Angela Hansen
- Emily Richardson
- Brendan Wakefield
- Katy O'Donnell
- Crystal Sturgeon
- Tim Baxter
- Jeniffer Soto-Perez
- Dylan Burau
- Balthasar Von Hoyningen huene
- Ayelet Delascagigas
- Nathan Jumps
- Summer Burdick

ATTACHMENT 2 - DETAILED BUDGET SHEETS

Task 1 total: $60,429.64

CAWSC subtotal: $52,551.72

CRRL subtotal: $7,877.92

TASK 1 - Project Management

Employee Name	Tas	Task Name	Fiscal Y	Hour	Hourly Rat	Hourly Tot	Leave Dis	Total (Net)	Total (Gross)
Biologist	1.1	Project meeting	2022	21	$ 51.86	$ 1,089.11	$ 234.16	$ 1,323.27	$ 2,492.30
Soil Scientist	1.1	Project meeting	2022	14	$ 85.73	$ 1,200.28	$ 258.06	$ 1,458.34	$ 2,746.70
Chemist	1.1	Project meeting	2022	14	$ 111.17	$ 1,556.43	$ 334.63	$ 1,891.06	$ 3,561.72
Physical Scientist	1.1	Project meeting	2022	21	$ 38.81	$ 814.99	$ 175.22	$ 990.21	$ 1,865.01
Biologist	1.2	Progress report	2022	12	$ 51.86	$ 622.35	$ 133.80	$ 756.15	$ 1,424.17
Soil Scientist	1.2	Progress report	2022	4	$ 85.73	$ 342.94	$ 73.73	$ 416.67	$ 784.77
Chemist	1.2	Progress report	2022	4	$ 111.17	$ 444.69	$ 95.61	$ 540.30	$ 1,017.63
Physical Scientist	1.2	Progress report	2022	12	$ 38.81	$ 465.71	$ 100.13	$ 565.83	$ 1,065.72
Biologist	1.1	Project meeting	2023	36	$ 53.42	$ 1,923.05	$ 413.46	$ 2,336.51	$ 4,400.70
Soil Scientist	1.1	Project meeting	2023	24	$ 88.31	$ 2,119.34	$ 455.66	$ 2,575.00	$ 4,849.89
Chemist	1.1	Project meeting	2023	24	$ 114.51	$ 2,748.21	$ 590.86	$ 3,339.07	$ 6,288.97
Physical Scientist	1.1	Project meeting	2023	36	$ 39.97	$ 1,439.03	$ 309.39	$ 1,748.43	$ 3,293.07
Biologist	1.2	Progress report	2023	24	$ 53.42	$ 1,282.03	$ 275.64	$ 1,557.67	$ 2,933.80
Soil Scientist	1.2	Progress report	2023	8	$ 88.31	$ 706.45	$ 151.89	$ 858.33	$ 1,616.63
Chemist	1.2	Progress report	2023	8	$ 114.51	$ 916.07	$ 196.95	$ 1,113.02	$ 2,096.32
Physical Scientist	1.2	Progress report	2023	24	$ 39.97	$ 959.36	$ 206.26	$ 1,165.62	$ 2,195.38
Biologist	1.1	Project meeting	2024	15	$ 55.02	$ 825.31	$ 177.44	$ 1,002.75	$ 1,888.63
Soil Scientist	1.1	Project meeting	2024	10	$ 90.96	$ 909.55	$ 195.55	$ 1,105.11	$ 2,081.41
Chemist	1.1	Project meeting	2024	10	$ 117.94	$ 1,179.44	$ 253.58	$ 1,433.02	$ 2,699.02
Physical Scientist	1.1	Project meeting	2024	15	$ 41.17	$ 617.59	$ 132.78	$ 750.37	$ 1,413.28
Biologist	1.2	Progress report	2024	4	$ 55.02	$ 220.08	$ 47.32	$ 267.40	$ 503.64
Soil Scientist	1.2	Progress report	2024	2	$ 90.96	$ 181.91	$ 39.11	$ 221.02	$ 416.28
Chemist	1.2	Progress report	2024	2	$ 117.94	$ 235.89	$ 50.72	$ 286.60	$ 539.80
Physical Scientist	1.2	Progress report	2024	4	$ 41.17	$ 164.69	$ 35.41	$ 200.10	$ 376.87
								Task 1 CAWSC Total	**$ 52,551.72**

Task 1 - Project Management CRRL

Employee Name	Task	Activity	Fiscal Year	Hours	Hourly Rate	Hourly Total	Leave Dist	Total (Net)	Total (Gross)	Period	Total
Fisheries Biologist	1.0 (Period 1)	Contract and Work Order management	2022	80	62.84	5027.2	0	5027.2	7,877.92	1	$7,877.92
									Task 1 Total		**$7,877.92**

TASK 2 - High-resolution mapping surveys Miner S., Steamboat S., Lindsey S., Cache Slough Complex, and Sacramento R.

Personnel / Expense Category	Task	Fiscal Year	Hours	Expense	Hourly Rate	Hourly Total	Leave Dist	Total (Net)	Total (Gross)	Total
Field Work										
Chemist	2.1	2022	9		$ 111.17	$ 1,000.56	$ 215.12	$ 1,215.68	$ 2,289.67	
Hydrotech	2.1	2022	0		$ 29.02	$ -	$ -	$ -	$ -	
Physical Scientist	2.1	2022	30		$ 38.81	$ 1,164.27	$ 250.32	$ 1,414.58	$ 2,664.30	
Hydrotech	2.1	2022	39		$ 35.65	$ 1,390.42	$ 298.94	$ 1,689.36	$ 3,181.82	
Physical Scientist	2.1	2022	3		$ 31.65	$ 94.94	$ 20.41	$ 115.35	$ 217.25	
Soil Scientist	2.1	2022	12		$ 85.73	$ 1,028.81	$ 221.19	$ 1,250.00	$ 2,354.32	
Hydrotech	2.1	2022	110		$ 48.26	$ 5,308.99	$ 1,141.43	$ 6,450.42	$ 12,149.04	
Hydrotech	2.1	2022	36		$ 32.94	$ 1,185.66	$ 254.92	$ 1,440.58	$ 2,713.25	
Hydrotech	2.1	2022	24		$ 17.72	$ 425.26	$ 91.43	$ 516.69	$ 973.17	
Hydrotech	2.1	2022	0		$ 23.62	$ -	$ -	$ -	$ -	
Hydrologist	2.1	2022	24		$ 58.67	$ 1,407.97	$ 302.71	$ 1,710.68	$ 3,221.98	
Hydrotech	2.1	2022	40		$ 35.61	$ 1,424.59	$ 306.29	$ 1,730.88	$ 3,260.02	
Hydrotech	2.1	2022	15		$ 33.12	$ 496.78	$ 106.81	$ 603.58	$ 1,136.82	
Biologist	2.1	2022	60		$ 51.86	$ 3,111.74	$ 669.02	$ 3,780.76	$ 7,120.87	
Hydrologist	2.1	2022	0		$ 59.33	$ -	$ -	$ -	$ -	
										$ 41,282.51
Continuous ammonium										
Physical Scientist	2.1	2022	43		$ 39.97	$ 1,718.85	$ 369.55	$ 2,088.40	$ 3,933.39	
Physical Scientist	2.1	2022	39		$ 32.59	$ 1,271.18	$ 273.30	$ 1,544.48	$ 2,908.96	
Chemist	2.1	2022	3		$ 88.31	$ 264.92	$ 56.96	$ 321.88	$ 606.24	
Hydrotech	2.1	2022	12		$ 49.71	$ 596.54	$ 128.26	$ 724.79	$ 1,365.11	
										$ 8,813.69
Equipment and supplies										
Equipment	2.1	2022		$ 3,000.00				$ 3,000.00	$ 5,650.35	
Supplies	2.1	2022		$ 3,000.00				$ 3,000.00	$ 5,650.35	
Trucks	2.1	2022		$ 450.00				$ 450.00	$ 847.55	
Boats	2.1	2022		$ 1,350.00				$ 1,350.00	$ 2,542.66	
										$ 14,690.91
Laboratory Analyses										
Shipping	2.1	2022		$ 150.00				$ 150.00	$ 282.52	
NWQL Supplies (G&S)	2.1	2022		$ 1,608.47				$ 1,608.47	$ 1,801.49	
NWQL water quality samples	2.1	2022		$ 15,751.21				$ 15,751.21	$ 17,641.35	
NWQL stable isotope samples	2.1	2022		$ 9,273.60				$ 2,704.80	$ 3,029.38	
										$ 22,754.74
Data management and analysis										
Hydrotech	2.1	2022	30		$ 48.26	$ 1,447.91	$ 311.30	$ 1,759.20	$ 3,313.37	
Chemist	2.1	2022	10		$ 111.17	$ 1,111.73	$ 239.02	$ 1,350.76	$ 2,544.08	
Hydrotech	2.1	2022	16		$ 29.02	$ 464.39	$ 99.84	$ 564.24	$ 1,062.72	
Hydrotech	2.1	2023	20		$ 48.26	$ 965.27	$ 207.53	$ 1,172.80	$ 2,208.92	
										$ 9,129.09
									Task 2 total	**$ 96,670.93**

TASK 3 - High-resolution mapping surveys around Franks Tract and Mildred Island.										
Personnel / Expense Category	**Task**	**Fiscal Yea**	**Hours**	**Expense**	**Hourly Rate**	**Hourly Total**	**Leave Dist**	**Total (Net)**	**Total (Gross)**	**Total**
Field Work										
Chemist	3.1	2022	40		$ 111.17	$ 4,446.94	$ 956.09	$ 5,403.03	$ 10,176.33	
Hydrotech	3.1	2022	39		$ 35.65	$ 1,390.42	$ 298.94	$ 1,689.36	$ 3,181.82	
Hydrotech	3.1	2022	147		$ 48.26	$ 7,094.73	$ 1,525.37	$ 8,620.10	$ 16,235.53	
Hydrotech	3.1	2022	66		$ 32.94	$ 2,173.71	$ 467.35	$ 2,641.06	$ 4,974.30	
Hydrotech	3.1	2022	42		$ 17.72	$ 744.21	$ 160.01	$ 904.22	$ 1,703.05	
Hydrotech	3.1	2022	51		$ 58.67	$ 1,407.97	$ 302.71	$ 1,710.68	$ 3,221.98	
Hydrotech	3.1	2022	24		$ 35.61	$ 1,816.35	$ 390.52	$ 2,206.87	$ 4,156.53	
Biologist	3.1	2022	66		$ 33.12	$ 794.84	$ 170.89	$ 965.73	$ 1,818.91	
										$ 45,468.44
Equipment and supplies										
Equipment	3.1	2022		$ 3,000.00				$ 3,000.00	$ 5,650.35	
Supplies	3.1	2022		$ 3,000.00				$ 3,000.00	$ 5,650.35	
Trucks	3.1	2022		$ 450.00				$ 450.00	$ 847.55	
Boats	3.1	2022		$ 1,350.00				$ 1,350.00	$ 2,542.66	
										$ 14,690.91
Laboratory Analyses										
Shipping	3.1	2022		$ 150.00				$ 150.00	$ 282.52	
NWQL Supplies (G&S)	3.1	2022		$ 1,577.67				$ 1,577.67	$ 1,766.99	
NWQL water quality samples	3.1	2022		$ 21,356.70				$ 21,356.70	$ 23,919.50	
NWQL stable isotope samples	3.1	2022		$ 5,382.00				$ 5,709.76	$ 6,394.94	
										$ 32,363.95
Data management and analysis										
Hydrotech	3.1	2022	90		$ 51.20	$ 4,608.25	$ 990.77	$ 5,599.02	$ 10,545.47	
Chemist	3.1	2022	60		$ 117.94	$ 7,076.63	$ 1,521.48	$ 8,598.11	$ 16,194.10	
Hydrotech	3.1	2022	16		$ 29.02	$ 464.39	$ 99.84	$ 564.24	$ 1,062.72	
Hydrotech	3.1	2023	80		$ 49.71	$ 3,976.91	$ 855.04	$ 4,831.95	$ 9,100.73	
										$ 36,903.03
									Task 3 Total	**$ 129,426.33**

TASK 4 - Franks Tract Cyanotoxin Monitoring									
Employee Name/Expense Category	**Task**	**Task Name**	**Fiscal Year**	**Hours**	**Hourly Rate**	**Hourly Total**	**Leave Dist**	**Total (Net)**	**Total (Gross)**
Hydrologic technician	4.1	SPATT samplers	2022	21	$ 32.94	$ 691.64	$ 148.70	$ 840.34	$ 1,582.73
Hydrologic technician	4.1	SPATT samplers	2022	21	$ 17.72	$ 372.11	$ 80.00	$ 452.11	$ 851.52
Hydrologist	4.1	SPATT samplers	2022	14	$ 59.33	$ 830.63	$ 178.59	$ 1,009.22	$ 1,900.81
Hydrologic technician	4.2	Sample handling	2022	21	$ 32.94	$ 691.64	$ 148.70	$ 840.34	$ 1,582.73
Hydrologic technician	4.2	Sample handling	2022	21	$ 17.72	$ 372.11	$ 80.00	$ 452.11	$ 851.52
Hydrologist	4.2	Sample handling	2022	14	$ 59.33	$ 830.63	$ 178.59	$ 1,009.22	$ 1,900.81
Hydrologic technician	4.3	Data management	2022	21	$ 32.94	$ 691.64	$ 148.70	$ 840.34	$ 1,582.73
Hydrologist	4.3	Data management	2022	21	$ 59.33	$ 1,245.95	$ 267.88	$ 1,513.83	$ 2,851.22
Hydrologic technician	4.3	Data management	2022	21	$ 48.26	$ 1,013.53	$ 217.91	$ 1,231.44	$ 2,319.36
Hydrologic technician	4.1	SPATT samplers	2023	15	$ 33.92	$ 508.85	$ 109.40	$ 618.25	$ 1,164.44
Hydrologic technician	4.1	SPATT samplers	2023	15	$ 18.25	$ 273.76	$ 58.86	$ 332.62	$ 626.48
Hydrologist	4.1	SPATT samplers	2023	15	$ 61.11	$ 916.66	$ 197.08	$ 1,113.74	$ 2,097.68
Hydrologic technician	4.2	Sample handling	2023	15	$ 33.92	$ 508.85	$ 109.40	$ 618.25	$ 1,164.44
Hydrologic technician	4.2	Sample handling	2023	15	$ 18.25	$ 273.76	$ 58.86	$ 332.62	$ 626.48
Hydrologist	4.2	Sample handling	2023	15	$ 61.11	$ 916.66	$ 197.08	$ 1,113.74	$ 2,097.68
Hydrologic technician	4.3	Data management	2023	15	$ 33.92	$ 508.85	$ 109.40	$ 618.25	$ 1,164.44
Hydrologist	4.3	Data management	2023	15	$ 61.11	$ 916.66	$ 197.08	$ 1,113.74	$ 2,097.68
Hydrologic technician	4.3	Data management	2023	15	$ 49.71	$ 745.67	$ 160.32	$ 905.99	$ 1,706.39
								Task 4 total	**$ 28,169.15**

TASK 5 - Water Quality, phytoplankton and cyanoHABs data analysis and interpretation									
Employee Name/Expense Category	**Task**	**Task Name**	**Fiscal Year**	**Hours**	**Hourly Rate**	**Hourly Total**	**Leave Dist**	**Total (Net)**	**Total (Gross)**
Biologist	5.1	Data analysis	2022	100.0	$ 51.86	$ 5,186.23	$ 1,115.04	$ 6,301.26	$ 11,868.11
Physical Scientist	5.1	Data analysis	2022	50.0	$ 38.81	$ 1,940.44	$ 417.20	$ 2,357.64	$ 4,440.50
Hydrologic technician	5.1	Data analysis	2022	20.0	$ 29.02	$ 580.49	$ 124.81	$ 705.30	$ 1,328.39
Soil Scientist	5.1	Data analysis	2022	12.0	$ 85.73	$ 1,028.81	$ 221.19	$ 1,250.00	$ 2,354.32
								Task 5 total	**$ 19,991.32**

TASK 6 – Field-validation of remote sensing cyanoHAB algorithm

Employee Name/Expense Category	Task	Task Name	Fiscal Year	Hours	Hourly Rate	Hourly Total	Leave Dist	Total (Net)	Total (Gross)	
Chemist	6.1	Field work	2022	12	$ 111.17	$ 1,334.08	$ 286.83	$ 1,620.91	$ 3,052.90	
Hydrologic technician	6.1	Field work	2022	3	$ 29.02	$ 87.07	$ 18.72	$ 105.79	$ 199.26	
Physical scientist	6.1	Field work	2022	60	$ 38.81	$ 2,328.53	$ 500.63	$ 2,829.17	$ 5,328.59	
Hydrologic technician	6.1	Field work	2022	39	$ 35.65	$ 1,390.42	$ 298.94	$ 1,689.36	$ 3,181.82	
Physical scientist	6.1	Field work	2022	30	$ 31.65	$ 949.35	$ 204.11	$ 1,153.46	$ 2,172.48	
Soil Scientist	6.1	Field work	2022	12	$ 85.73	$ 1,028.81	$ 221.19	$ 1,250.00	$ 2,354.32	
Hydrologic technician	6.1	Field work	2022	99	$ 48.26	$ 4,778.09	$ 1,027.29	$ 5,805.38	$ 10,934.13	
Hydrologic technician	6.1	Field work	2022	48	$ 32.94	$ 1,580.88	$ 339.89	$ 1,920.77	$ 3,617.67	
Hydrologic technician	6.1	Field work	2022	24	$ 17.72	$ 425.26	$ 91.43	$ 516.69	$ 973.17	
Hydrologist	6.1	Field work	2022	12	$ 23.62	$ -	$ -	$ -	$ -	
Hydrologic technician	6.1	Field work	2022	9	$ 58.67	$ 703.98	$ 151.36	$ 855.34	$ 1,610.99	
Hydrologic technician	6.1	Field work	2022	9	$ 35.61	$ 320.53	$ 68.91	$ 389.45	$ 733.50	
Biologist	6.1	Field work	2022	84	$ 33.12	$ 298.07	$ 64.08	$ 362.15	$ 682.09	
										$ 34,840.94
Equipment and supplies										
Equipment	6.1		2022					$ 3,000.00	$ 5,650.35	
Supplies	6.1		2022					$ 3,000.00	$ 5,650.35	
Trucks	6.1		2022					$ 450.00	$ 847.55	
Boats	6.1		2022					$ 1,350.00	$ 2,542.66	
										$ 14,690.91
Laboratory Analyses										
Shipping	6.1		2022					$ 150.00	$ 282.52	
NWQL Supplies (G&S)	6.1		2022					$ 11,702.67	$ 13,106.99	
NWQL water quality samples	6.1		2022					$ 39,033.00	$ 43,716.96	
										$ 57,106.47
Data management and analysis										
Hydrotech	6.1		2023	80	$ 49.71	$ 3,976.91	$ 855.04	$ 4,831.95	$ 9,100.73	
Biologist	6.1		2023	20	$ 53.42	$ 1,068.36	$ 229.70	$ 1,298.06	$ 2,444.83	
Physical scientist	6.1		2023	20	$ 40.93	$ 818.52	$ 175.98	$ 994.50	$ 1,873.09	
										$ 13,418.66
									Task 6 Total	**$ 120,056.97**

TASK 7 - Report Writing									
Employee Name/Expense Categor	Task	Task Name	Fiscal Year	Hours	Hourly Rate	Hourly Total	Leave Dist	Total (Net)	Total (Gross)
Biologist	2	North Delta Mapping	2023	120	$ 53.42	$ 6,410.17	$ 1,378.19	$ 7,788.36	$ 14,668.99
Soil Scientist	2	North Delta Mapping	2023	40	$ 88.31	$ 3,532.24	$ 759.43	$ 4,291.67	$ 8,083.15
Chemist	2	North Delta Mapping	2023	40	$ 114.51	$ 4,580.34	$ 984.77	$ 5,565.12	$ 10,481.62
Physical Scientist	2	North Delta Mapping	2023	40	$ 39.97	$ 1,598.93	$ 343.77	$ 1,942.69	$ 3,658.97
Geologist	2	North Delta Mapping	2023	40	$ 60.43	$ 2,417.01	$ 519.66	$ 2,936.67	$ 5,531.07
Biologist	3	Franks Tract Mapping	2023	120	$ 88.31	$ 10,596.72	$ 2,278.30	$ 12,875.02	$ 24,249.45
Soil Scientist	3	Franks Tract Mapping	2023	40	$ 114.51	$ 4,580.34	$ 984.77	$ 5,565.12	$ 10,481.62
Chemist	3	Franks Tract Mapping	2023	40	$ 39.97	$ 1,598.93	$ 343.77	$ 1,942.69	$ 3,658.97
Physical Scientist	3	Franks Tract Mapping	2023	40	$ 60.43	$ 2,417.01	$ 519.66	$ 2,936.67	$ 5,531.07
Geologist	3	North Delta Mapping	2023	40	$ 53.42	$ 2,136.72	$ 459.40	$ 2,596.12	$ 4,889.66
Biologist	4	Franks Tract Cyanotoxins	2023	80	$ 114.51	$ 9,160.69	$ 1,969.55	$ 11,130.23	$ 20,963.24
Soil Scientist	4	Franks Tract Cyanotoxins	2023	20	$ 39.97	$ 799.46	$ 171.88	$ 971.35	$ 1,829.48
Biologist	6	Remote Sensing validatio	2023	120	$ 53.42	$ 6,410.17	$ 1,378.19	$ 7,788.36	$ 14,668.99
Soil Scientist	6	Remote Sensing validatio	2023	25	$ 88.31	$ 2,207.65	$ 474.64	$ 2,682.30	$ 5,051.97
Chemist	6	Remote Sensing validatio	2023	60	$ 114.51	$ 6,870.51	$ 1,477.16	$ 8,347.68	$ 15,722.43
Physical Scientist	6	Remote Sensing validatio	2023	100	$ 40.93	$ 4,092.59	$ 879.91	$ 4,972.50	$ 9,365.45
								Task 7 Total	**$ 158,836.13**

Annually established indirect rate applies. Salary rates and leave assessment amounts listed are estimates. Actual salary rates may fluctuate over the term of this Work Order as required by the Office of Personnel Management. https://www.opm.gov/policy-data-oversight/pay-leave/salaries-wages/.

ATTACHMENT 3 - GENERAL PROVISIONS APPLICABLE TO ALL DELIVERABLES AND WORK PRODUCTS:

G1: All provisional and USGS-approved (QA/QC'd) data, deliverables and work products developed by the Contractor under this Work Order will be transferred to DWR. As stated in Exhibit B; page 6 of 11 of the original agreement, signed by Department of General Services (DGS) on November 17, 2021, all data and information obtained and/or received under this agreement shall be in the public domain.

G2: Contractor shall maintain copies of all data and work products throughout the term of this Work Order and any subsequent Work Orders or extensions. Contractor is encouraged to maintain all files.

G3: A complete electronic copy of all final documents will be provided in both the associated Microsoft Office application format and as an indexed and searchable Adobe portable document format.

G4: Execution of this Work Order will require the Contractor to work closely with DWR and other agency staff (e.g. NMFS, USFWS, USBR, and CDFW) as well as other DWR contractors.

G5: Invoicing will provide adequate documentation to justify expenses allowed within the Work Order. DWR and the Contractor will come to an agreement about the template to be used for billing prior to the first invoice being issued.

G6: All written deliverables shall be provided to the DWR Work Order Manager as a draft with at least a one-week period for DWR review and comment before the DWR Work Order manager will approve the deliverable.