Note to Reader: Chris Foe wrote this to help stimulate the information gap discussion. It is intended to be a "*straw man*" to start the discussion and lead to a more robust final product. The hope is that the final document will be something that the entire Science Work Group can agree upon. Points of agreement and knowledge gaps were taken from the white paper and oral and written comments by science work group members. This document and the white paper would be used by Water Board staff to inform the Nutrient Research Plan. The group might consider packaging the white paper and this document as chapter 1 and 2 of a joint report for review by the STAG, State Board Independent Nutrient Review Panel and the Water Board.



## CyanoHAB Knowledge Gaps

In 2013 the Delta Stewardship Council adopted the Delta Plan. The Plan identified a number of water quality impairments that might be the result of excessive nutrient levels in the Delta. One of these was the increase in magnitude and frequency of cyanobacterial (cyanoHAB) blooms in summer. The Plan recommended that the Central Valley Regional Water Board develop and implement a research plan to determine whether nutrient management might reduce these impairments. The Regional Water Board commissioned a white paper to:

- Review the biological and ecological factors that influence the prevalence of cyanobacteria and cyanotoxin production.
- Summarize observations of cyanobacterial blooms and associated toxin levels in the Delta.
- Synthesize the literature to provide an understanding of the factors, including nutrients, promoting cyanobacterial blooms in the Delta.

The Regional Water Board also assembled a Science Work Group composed of cyanobacteria experts (Appendix A) to review and comment on the white paper. The comments and white paper discussions were used to identify areas of agreement, disagreement and information gaps about factors promoting blooms in the Delta. An emphasis in these discussions was whether nutrient reductions might reduce the severity of blooms and toxin production. The areas of agreement, disagreement and information gaps have been assembled into a series of tables to inform a Nutrient Research Plan. The Research Plan will be presented to the Regional Water Board and, if requested, the Delta Stewardship Council. The white paper and Nutrient Research Plan are intended to provide the rationale and roadmap for future research to resolve outstanding issues about controls on the magnitude and frequency of cyanobacteria blooms and toxin formation.

Table 1 lists areas of agreement among Science Work Group members about CyanoHABs in the Delta. The consensus of the group is that CyanoHABs represent an emerging problem warranting additional research. There was general agreement about four areas of uncertainty. These are: (1) whether all ecologically important cyanoHAB hotspots have been identified, (2) whether the risk to human health and aquatic life has been robustly evaluated, (3) what drivers control the maximum size of cyanoHAB blooms and, (4) whether nutrient concentration could be used to constrain bloom biomass below a probability of causing human and wildlife impacts. The first area of uncertainty is particularly important as this information is needed to develop a holistic assessment of the risk of cyanoHAB exposure to people and wildlife, determine the drivers that typically control bloom initiation and maximum biomass, and determine the frequency that ambient nutrient concentrations control bloom biomass and toxin production.

The Science Work Group developed a list of important knowledge gaps in Table 2. The knowledge gaps are divided into two categories—those that will require a spatially broad monitoring program to answer and those that might best be addressed with a one-time special study. Nutrient management questions are emphasized in Table 2 as the impetus for this work is to help the Regional Water Board answer questions about whether future water quality objectives might alleviate the severity of the CyanoHAB impairment in the delta.

Table 1. The areas of agreement for cyanoHAB impairment in the Delta were developed by the Science Work Group after review and discussion of the white paper.

| Issue # | Topic | Agreement | Comments |
|---|---|---|---|
| 1 | *Microcystis* | *Microcystis* is the most common cyanoHAB genus in the Delta although *Aphanizomenon* and *Anabaena* have also be detected. | |
| 2 | Toxicity | CyanoHAB blooms can cause multiple water quality impairments including decreasing light penetration, reduced dissolved oxygen and toxicity to people, livestock and wildlife. The primary concern about cyanoHAB blooms in the Delta at present is the production of metabolic byproducts which can be toxic to people and wildlife. | |
| 3 | Toxins | Microcystin is the only toxic cyanoHAB byproduct repeatedly detected in the Delta. | |
| 4 | Risk | The risk of microcystin exposure to people and wildlife has not been well quantified in the Delta although potentially toxic concentrations to both people and wildlife have been detected. Additional monitoring will be needed to ascertain the extent, magnitude, duration and frequency of these episodes. | |
| 5 | Toxicological guidelines | The California Office of Health Hazard Assessment, World Health Organization and the U.S. EPA have published human health guidelines for microcystin. No toxicological guidelines are available for wildlife making a robust aquatic life risk analysis impossible. | Is this too simplistic? Should we break into separate statements for humans and wildlife? Talk about no and low effect levels for wildlife? |
| 6 | Hot Spots | The San Joaquin River in the Central Delta has experienced reoccurring cyanoHAB blooms although high concentrations may also have occurred in other unmonitored locations in the Delta. | |
| 7 | Trends | The magnitude and frequency of cyanoHAB blooms have increased since the mid-1990s in the Delta. | |
| 8 | Drivers | Six water quality drivers have been identified that control the production of cyanoHAB biomass in the Delta. These are temperatures above $19^{0}$C, high irradiance and water clarity, long residence time, a stratified water column, salinity less than 10ppt, and nutrients. | Not included herbicides and trace metals as more speculative. Should these be added? |
| 9 | Delta Heterogeneity | The absolute magnitude of the 6 drivers may change independently of each other in different areas of the delta resulting in changes in their relative importance and in the probability of cyanoHAB blooms. | |
| 10 | NH4 | CyanoHAB species preferentially take up NH4. The NH4 pool must be depleted before other N species are assimilated | |
| 11 | Bloom initiation | The initiation of a cyanoHAB bloom is not controlled by nutrient concentrations, forms or ratios. Bloom initiation may be triggered by higher water temperatures, increased residence time and/or increased water clarity in the Central Delta. | |
| 12 | Maximum Bloom size | No information exists on what drivers limit maximum CyanoHAB bloom biomass and toxin concentration in the Central Delta. | Is this true? I can find no information on this in literature or white paper |
| 13 | Bloom size | If the magnitude of other drivers remains favorable, then the final biomass and duration of a bloom will be directly proportional to the available nutrient pool. | |
| 14 | Nutrient Limitation | No data exists demonstrating that cyanoHAB bloom growth reduces ambient nutrient concentrations and whether final biomass is constrained by available nutrient concentrations. | Again, is this true? |
| | | | Is there consensus on the effect of N:P ratios on cyanoHAB growth at either limiting or non-limiting nutrient levels? |

Table 2. Knowledge gaps that need resolution before it can be concluded that nutrient management might reduce the magnitude and frequency of cyanoHAB blooms in the Delta.

| **Topic #** | **Knowledge gap** | **Management Question** | **Experimental Design** |
|---|---|---|---|
| 1 | The location and magnitude of hotspots may vary both seasonally and annually in the Delta. Identify hotspots and determine whether they reoccur or are one-time events. | Have all hotspots where people and wildlife are at risk from exposure to toxins been identified? | Issues #1 to 5 may be answered by a combined monitoring and special studies program. |
| 2 | The drinking water and contact recreation human health risk for local residents may not have been adequately characterized in the Delta. | What risk do toxin levels pose for drinking water and human contact recreation? | |
| 3 | The risk to aquatic wildlife may not have been adequately characterized. Are additional acute & chronic bioassays needed? Should tissue bioaccumulation studies be conducted? What are the most sensitive species? | What risk do toxin levels pose for aquatic wildlife? | |
| 4 | What drivers control the maximum biomass and toxin concentration of blooms at hotspots? | Are the factors that determine the maximum size of blooms and toxin levels at hotspots controllable? | |
| 5 | What evidence exist that nutrient management might reduce maximum bloom size & toxin concentration at hotspots? | Can nutrient management reduce the risk of toxin formation at hotspots? | |
| 6 | CyanoHab models are not available for the Delta. | Robust models are useful for an number of reasons including a better understanding of the relative importance of different drivers, to test management scenarios, design & interpret experiments. | Assist in the development of models by collecting information requested by modelers using a combination of monitoring and special studies. |
| 8 | Is cyanoHAB growth in the Delta a function of increasing NH4 levels, even if DIN not limiting?<br><br>White paper documented that some strains of cyanoHAB species grow faster on NH4 than other DIN forms but no consistent pattern found for the phyla. In contrast, Dr. Parker documented a 50% increase in the relative growth rate of cyanoHAB species collected from the Delta and grown in laboratory bioassays amended with NH4 (personal communication). . | Can cyanoHAB growth rates and the possibility of bloom formation be decreased by NH4 control?<br><br>NH4 concentrations in many locations in the Delta are expected to decline by about 90% over the next decade as a result of POTW upgrades. | Special study. |
| 9 | Is cyanoHAB growth in the Delta a function of increasing DIN, even if DIN not limiting?<br><br>White paper documents that N concentrations, above non limiting levels, do not increase CyanoHAB growth rates. In contrast, Dr. Parker found an increased growth of CyanoHAB species collected from the Delta in lab bioassays amended with increasing levels of all forms of DIN. DIN concentrations were not limiting in control bioassays. | Can cyanoHAB growth rates and the possibility of bloom formation be decreased by DIN control?<br><br>DIN concentrations in the Delta should decrease by about 20-30 % with upgrades to local POTWs. | Special study |

Appendix A

Table 1. List of Cyanobacteria Science Work Group members and their affiliation

| Individual | Affiliation |
|---|---|
| David Senn | San Francisco Estuary Institute |
| Lisa Thompson | Sacramento Regional Combined Sanitation District |
| Tim Mussen | Sacramento Regional Combined Sanitation District |
| Alex Parker | California Maritime Academy |
| Stephanie Fong | State and Federal Contractors Water Authority |
| Peggy Lehman | Department of Water Resources |
| Raphael Kudela | U.C. Santa Cruz |
| Mine Berg (White Paper Author) | Applied Marine Sciences |
| Martha Sutula (Facilitator) | Southern California Coastal Water Research Project |
| Karen Taberski | San Francisco Regional Water Quality Control Board |
| Kim Ward | State Water Resources Control Board |
| Daniel Orr | California Department of Fish and Wildlife |