THOMAS H. KEELING (SBN 114979)
FREEMAN FIRM
1818 Grand Canal Boulevard, Suite 4
Stockton, CA 95207
Telephone: (209) 474-1818
Facsimile: (209) 474-1245
Email: tkeeling@freemanfirm.com

Attorneys for Protestants County of San Joaquin,
San Joaquin County Flood Control and Water Conservation District,
and Mokelumne River Water and Power Authority

OSHA R. MESERVE (SBN 204240)
SOLURI MESERVE, A LAW CORPORATION
510 8th Street
Sacramento, CA 95814
Telephone: (916) 455-7300
Facsimile: (916) 244-7300
Email: osha@semlawyers.com

Attorneys for Protestants Local Agencies of the North Delta,
Bogle Vineyards / Delta Watershed Landowner Coalition, Diablo Vineyards and
Brad Lange / Delta Watershed Landowner Coalition,
Stillwater Orchards / Delta Watershed Landowner Coalition

BEFORE THE

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

HEARING IN THE MATTER OF CALIFORNIA DEPARTMENT OF WATER RESOURCES AND UNITED STATES BUREAU OF RECLAMATION'S REQUEST FOR A CHANGE IN POINT OF DIVERSION FOR CALIFORNIA WATER FIX	**SUR-REBUTTAL TESTIMONY OF MICHAEL T. BRETT, Ph.D. CONCERNING HARMFUL ALGAL BLOOMS RESULTING FROM THE CALIFORNIA WATERFIX**

I, Michael Brett, do hereby declare:

I. INTRODUCTION

I have been a Professor in the Department of Civil and Environmental Engineering at the University of Washington since 1997. I received my doctorate from the Institute of Limnology at Uppsala University (Sweden) in 1990. I received my masters of science in Zoology from the University of Maine in 1985. I received my undergraduate bachelor's degree in Fisheries from Humboldt State University in 1983.

My research and teaching focuses on applied and biological Limnology, in particular the response of Lakes, Rivers and Estuaries to excessive nutrient inputs, especially eutrophication and regulation of phytoplankton biomass and secondary production in lakes. I also study the bioavailability of nitrogen and phosphorus in the effluents of advanced nutrient removal wastewater treatment plants. Much of my published research deals with planktonic dynamics of aquatic food webs. I have also directed several modeling projects that attempt to mechanistically represent the biological responses of lakes and reservoirs to eutrophication.

II. SUMMARY OF TESTIMONY

This testimony provides a sur-rebuttal to rebuttal testimony presented by Petitioner DWR in the above captioned hearing. (See DWR-81, DWR-653 and associated references.)

Testifying on behalf of the San Joaquin County Protestants, Local Agencies of the North Delta, et al., and South Delta Water Agency/Central Delta Water Agency, Erik Ringelberg ("Ringelberg") and other experts described the likely CWF-driven increases in the frequency and magnitude of Harmful Algal Blooms ("HABs") formation and *Microcystis*-related problems in the Delta. (SJC- 4 and SJC-68, SDWA-76 errata and SDWA-74, SDWA-257and associated exhibits referenced therein.) Ringelberg opined that the CWF would establish the equivalent of drought conditions, with their associated lower flows, by removing significant amounts of Sacramento River water from the Delta during seasonal periods critical for HABs formation. (SJC-4, p. 4:5-11.) The lower flows, and resulting longer water residence times, as well as likely localized increases in water temperatures, will all promote HABs formation, according to Ringelberg. He also observed that flow reduction directly affects water velocity, which scours sediments as well as maintains particles in suspension. Ringelberg explained that as a result of the CWF the nutrient concentrations will likely increase, thereby amplifying the conditions in which blue-green algae (cyanoabacteria) thrive. (SJC-4, pp. 12-13.)

DWR provided rebuttal to Ringelberg with testimony from Dr. Michael Bryan ("Bryan"). He opined that the CWF would not alter channel velocities at various Delta locations to a degree that would make hydrodynamic conditions substantially more conducive to HABs than projected conditions under the No Action Alternative. (DWR-81, pp. 15:17 - 16:17.) Responding, in part, to testimony by Ringelberg concerning the deleterious effects of the increased residence time expected to result from the CWF, Bryan stated that increased residence time, in itself, does not necessarily lead to increased HABs formation and that the relationship between HABs formation (*Microcystis* in particular) and CWF-driven increases in residence time is uncertain. (DWR-81, pp. 16:18 -17:21.) Bryan testified that his qualitative review indicated that turbidity changes likely to result from the CWF would be "minor" and that they would not substantially affect HABs formation in the Delta. (DWR-81, pp. 18:18 – 19:14.) He similarly diminished the effects of CWF-driven temperature increases by opining that they would also be too minor, as modeled for the Delta locations he examined, to substantially worsen HABs formation. (DWR-81, pp. 17:26 – 18:12.) With respect to anticipated CWF-driven increases in nutrient concentrations, Bryan again opined that such increases would be relatively small and "would not be expected to increase the frequency, magnitude, or duration of cyanoHAB in the Delta, relative to that which would occur for the [No Action Alternative]." (DWR-81, pp. 19:16 – 20:10.)

Many of the main points made in DWR-81, DWR-651 and DWR-653 are consistent with evidence in the limnological literature and for the Delta ecosystem. In particular, Harmful Algal Blooms (HABs) dominated by cyanobacteria are typically associated with high phosphorus concentrations, high water temperatures, water column irradiance >50 µmoles/m2/s, and low salinity <10 ppt. Cyanobacteria blooms are also strongly associated with low flows, low turbulence and long water residence times (Visser et al. 2016). Also, at this time the limnological community's ability to predict when a particular taxa of cyanobacteria (e.g., *Microcystis, Aphanizomenon, Anabaena, Oscillatoria,* and *Cylindrospermopsis*) will bloom (or decline for that matter) is quite limited. What is known is that certain taxa tend to have annually recurring blooms within specific water bodies, e.g., *Microcystis aeruginosa* in the Delta, *Anabaena circinalis* in Clear Lake (California), *Aphanizomenon flos-aquae* in Upper Klamath Lake (Oregon), and *Nodularia spumigena* in Pyramid Lake (Nevada). That *Microcystis aeruginosa* forms HABs in the Delta, especially during low flow drought years, was also noted by Bryan. (DWR-653; see also Lehman et al. 2017 (DWR-720).)

However, as explained below, the emphasis of DWR-653 on the importance of flow velocity over water residence times for the development of cyanobacteria blooms is not consistent with evidence or the published literature. Specifically, both low turbulent mixing and long water residence times tend to favor cyanobacteria compared to non-buoyant eukaryotic phytoplankton (e.g., diatoms, chlorophytes, etc.) but for different reasons. Low turbulence allows cyanobacteria to utilize buoyancy regulation to optimize light and nutrient availability, while other non-buoyant algae tend to sink. Long water residence times favor cyanobacteria because they grow much more slowly than other phytoplankton and they are therefore more susceptible to hydraulic washout and advective depletion of their populations. This is consistent with much of the literature cited in DWR-653.

III. SUR-REBUTTAL TO OPINIONS 5-9 IN DWR-81 AND DWR-653

Rebuttal Opinion #5 - Flow Velocity (DWR-81, pp. 15-16, DWR-653, pp. 10-30.)

> *Petitioner DWR contended that channel velocities at several mid-channel Delta locations would not be altered enough by the CWF to be more conducive to Microcystis blooms relative to the no action scenario.*

Sur-Rebuttal

> *There is insufficient basis for the Petitioner DWR to conclude that mid-channel Delta locations would not be altered enough by the CWF to be more conducive to Microcystis blooms relative to the no action scenario.*

Comparative velocity modeling for the proposed diversions aggregated velocities throughout the channel and did not provide velocities in the areas most likely to have cyanobacteria blooms (Hearing Transcript, April 27, 2017, pp. 192-194 [explaining how DSM2 averages velocity across the channel].) In addition, only nine locations were selected for analysis, and were claimed to be representative of the entire Delta. (DWR-81, p. 27; see also Hearing Transcript, April 27, 2017, p. 208.)

The lack of model-predicted change in mid-channel flow velocities, which was the basis for contending that no change in HABs would occur with the CWF, is not considered pertinent to the effects of reduced flows on water turbulence and water residence times (WRT) in the vegetated shoreline areas and backwater sloughs where HABs have been observed. Cyanobacteria blooms already occur in some Delta areas where flows will decrease and water residence times will increase in side channels, sloughs and backwater areas with CWF conditions, as indicated by Ringelberg (SJC-04) and predicted for the southern Delta by Burke (SDWA-76 errata, SDWA-257). Cyanobacteria blooms have also been documented in the southern and central Delta by Berg & Sutula, 2015 (DWR-558, pp. 35–36) where DWR predicts that CWF will increase residence time (e.g., SWRCB-104, Table 6.6-17 [model showed median water residence time at Mildred Island increased 238% in July]). Extensive cyanobacteria blooms have also been documented in the shoreline areas and backwater sloughs of Discovery Bay by the Contra Costa County Health Department (SJC-217 [Discovery Bay Sample Locations (2016), available at: http://cchealth.org/eh/pdf/algae-map-discovery-bay.pdf) where the 2016 BA also discloses increased residence times (e.g., SWRCB-104, Table 6.6-20 [model showed median water residence time at Discovery Bay sub-region increased 57% in July]). Nutrient concentrations and physical conditions are currently favorable, especially during recent low inflow years, for promoting summer blooms of *Microcystis,* and other cyanobacteria such as *Aphanizomenon* in the Delta. Thus, if water residence times are increased due to the CWF, as expected, especially in side channels, backwater sloughs and the central and south Delta, then that would mean more time for cyanobacteria HABs growth and biomass accumulation.

As illustrated in the exchange below, Petitioner's expert Bryan did not attempt to explore how the proposed new diversions would change velocities in the dead end sloughs throughout the Delta:

MR. KEELING: Why did you not also examine any of what you characterize as the many dead-end sloughs in the Delta?

WITNESS BRYAN: Primarily because I don't think that the DSM-2 model necessarily can model velocities in dead-end sloughs very well. And, secondly, I don't know -- Well, I guess I can leave it at that. I'm not so sure that, when we're trying to look at how the California WaterFix would affect velocities in channels in the Delta, how it can affect microcystis blooms. If you get into a dead-end slough, no matter how you operate the system, that dead-end slough's going to have low velocities. By definition, it's a dead-end slough, so you're not going to see much of a difference in that slough between the No-Action Alternative and the California WaterFix scenarios.

MR. KEELING: Do you have any reports or studies to back up that conclusion?

WITNESS BRYAN: No. Just -- Just my years of experience in working on aquatic systems.

MR. KEELING: Did you do any testing or modeling yourself to reach that conclusion?

WITNESS BRYAN: I'm not sure I understand the question.

MR. KEELING: You just -- You just told me that you didn't think that the WaterFix, if it's approved, would make a difference with respect to velocities in dead-end sloughs, and I'm asking if you did any modeling or testing yourself on that.

WITNESS BRYAN: No.

(Hearing Transcript, April 27, 2017, pp. 210-211.)

Bryan also relied on critical flow velocity estimates based on results from the Darling River in Australia, where increased flow rate was observed to discourage blooms of *Anabaena*, a filamentous cyanobacteria (Mitrovic et al., 2011 (DWR-730)). However, the Darling River has several weirs along its length for water diversion and these weirs provide a longer WRT which facilitates biomass accumulation. The authors considered prevention of water column stratification, was one reason flow management was effective at controlling *Anabaena circinalis* blooms. However, these authors also indicated that dilution and translocation of cells was important. Thus, continual wash-out of cells at higher flow velocities, due to short WRTs, was also important for bloom disruption/prevention. In any case, the morphology of the Darling River (with its weirs, which pool water) is not an appropriate reference system for the Delta, where flow velocities are determined by tidal processes.

Bryan (DWR-653) unreasonably focused most of his analysis on the effects of flow velocity. Flow velocity is a surrogate for water column turbulence, and it is the high turbulence that actually interferes with cyanobacteria bloom development – not high velocity (although in non-laminar flows high turbulence and high velocity tend to go hand in hand). Because the Delta is tidally influenced, much of the flow velocity patterns for that system are driven by tidal exchange and are therefore less sensitive to total flow than water residence time would be. Assuming the volume of the water contained within the Delta is determined by mean channel depth and surface area at mean sea level (i.e., Volume=mean depth*surface space area), there is a direct mathematical relationship between flows in the Delta and water residence time (i.e., WRT = volume/flow). Thus Bryan (DWR-653) chose to focus his analyses on the parameter that is actually least likely to be influenced by flow diversions in the Delta due to the California WaterFix (CWF).

Bryan (DWR-653) also took a quite broad perspective on the published literature on the influence of flow velocity on cyanobacteria blooms, and a very narrow perspective to the published literature on the influence of water residence time on cyanobacteria blooms. Specifically, Bryan (DWR-653) reviewed papers that examined flow velocity influences on cyanobacteria broadly speaking worldwide. Conversely, Bryan (DWR-653) restricted his analysis of water residence time influences to *Microcystis aeruginosa* within the Delta. This asymmetrical analysis of the literature creates the impression of “stacking-the-deck” in favor of emphasizing the importance of flow velocity for regulating cyanobacteria bloom development.

In addition, I believe Bryan misrepresented some of the literature on the flow velocity topic, especially whether the literature actually supports their claim that *"a number of studies report critical velocity rates that disrupt* Microcystis *blooms to be in the 0.1 to 1.3 ft/s range.*" (DWR-653, p. 5.) To support his flow velocity perspective Bryan (DWR-653) cited publications by Mitrovic et al. 2003, Mitrovic et al. 2011, Zhang et al. 2007, Zhang et al. 2015, Li et al. 2013, and Long et al. 2011. None of the studies cited by Bryan in DWR-653, however, addressed tidally influenced systems like the Delta.

It should also be noted that the papers by Mitrovic et al. 2003 and 2011 did not focus on *Microcystis*, as both of these papers primarily dealt with *Anabaena circinalis*. (SJC-207, DWR-730.) Even more importantly, Mitrovic et al. 2011 attributed the control of the cyanobacteria blooms in the river they studied to *"dilution and translocation of cells*." (DWR-730.) As Mitrivic et al. 2011 further noted *"Cyanobacteria are generally advantaged under scenarios of reduced discharge and flow velocity due to increased retention time and decreased washout of cells (Oliver and Ganf, 2000)."* (DWR-730, p. 230.)

The two papers by Li et al. 2013 and Zhang et al. 2015 did allude to *Microcystis* being less prevalent at high flow velocities. (DWR-724, DWR-757.) However, the phytoplankton species composition results showing high flow velocities were associated with lower proportions of cyanobacteria were in both studies based on experiments carried out in very small unreplicated flumes that had dimensions of 1.5 m length, 0.4 m width and 1.5 m height for a total volume of 0.9 m^3. I do not believe that the results of experiments carried out in flumes with extremely small volumes can be used to infer processes in a very large tidally advected and complex system like the Delta.

Similarly, Li et al. 2013 cautioned against their results being over-extrapolated by stating *"the present study indicates that a universal critical flow velocity might not exist, because each freshwater water body has its unique physical, chemical and ecological features like water body size, morphology, nature of water flow, sediment condition, nutrient level, water temperature, light intensity and species composition, which may all affect the critical velocity value."* Similar to the studies by Li et al. 2013 and Zhang et al. 2015, the paper by Zhang et al.

2007[1] reported field data responses for Chl a, and laboratory experiment responses for Chl a and phytoplankton species composition. The laboratory experiments that Zhang et al. 2007 carried out were done in even smaller containers (i.e., diameter = 0.6 m, height = 0.55 m, and volume 0.33 m^3) than the experiments by Li et al. 2013 and Zhang et al. 2015. Finally, the study by Long et al. 2011 did not look at the relationship between flow velocity and cyanobacteria bloom development. The model Long et al. 2011 developed only predicted Chl a concentrations in response to water velocity; this study made no attempt to predict phytoplankton species composition shifts in response to flow velocity.

Petitioner is correct that the limnological literature indicates high turbulent mixing is unfavorable for cyanobacteria bloom development. (DWR-653.) However, Bryan misrepresents the published literature to support a claim that river flow velocity can be used as a master variable to predict the severity of cyanobacteria blooms. The cited studies either indicated cell washout due to shorter WRTs was the mechanism for controlling cyanobacteria bloom development (Mitrovic et al.), or alternatively, these studies were conducted at such a small experimental scale (i.e., < 1 m^3) as to be entirely irrelevant to the management of water quality in the Delta (e.g., Zhang, Li et al.). Moreover, the study by Long et al. did not address cyanobacteria bloom development.

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[1] The paper by Zhang et al. 2007 was written in Chinese with an English abstract. I asked Professor Chen Zhang (Ph.D., Associate Professor, Department of Hydraulic Engineering, School of Civil Engineering, Tianjin University, CHINA) to translate the main ponts of this paper for me. Professor Chen Zhang is not related to any of the authors on the Zhang et al. 2007 paper. Professor Chen Zhang is visiting my university for one year as a guest professor and he and I are doing a collaborative study on the utility of mechanistic water quality models to accurately represent the biogeochemical responses of reservoirs to modified hydrologic and climatic regimes. I asked Professor Chen Zhang to provide a brief summary of the main points of the Zhang et al. paper, as well as comment on aspects of the experimental design. Professor Chen Zhang told me that the experimental system used in the Zhang et al. 2007 paper had dimensions of 0.6 m diameter and 0.55 m height. He also told me that this paper reported field observations from Lake Taihu on chlorophyll concentrations, and laboratory experimental observations of phytoplankton species composition and chlorophyll biomass. The laboratory experiments focused on *Microcystis aeruginosa*.

Rebuttal Opinion #6 - Water Residence Time

> *Petitioner contends that "increased residence time alone does not equate with increased Microcystis bloom frequency or magnitude."*

Sur-Rebuttal

> *Increased water residence time, which Petitioners admit would occur if the proposed diversions are built and operated, would likely lead to an increase in the frequency and magnitude of cyanobacteria HABs formation.*

DWR-653 states *"Hydraulic residence times may increase in parts of the southern and central Delta for the CWF, relative to the NAA. Increased residence time provides the opportunity for cyanobacteria to accumulate in areas. However, other factors such as daily in-channel absolute velocities, turbulence, and mixing; competition with other algal species; and grazing losses to zooplankton, fish, and clams exert their own effects on cyanobacteria accumulation, and thus a given magnitude increase in residence time will not always equate to a given magnitude increase in bloom size, or an increase in bloom size at all. Because of the many factors involved beyond residence time alone, relationships between bloom size and residence time are expected to be highly variable both spatially and temporally in the Delta. Additional* Microcystis *research would be needed before definitive determinations regarding how modeled changes in residence time caused by the CWF would affect the magnitude of* Microcystis *blooms in the Delta can be made."*

The conclusion in DWR-653 appears to be an attempt to create an unrealistic Straw Man argument. Specifically, the statement that "*a given magnitude increase in residence time will not always equate to a given magnitude increase in bloom size, or an increase in bloom size at all*" is overly simplistic. The case-in-chief Protestant testimony (SJC-4) did not claim that increased WRT will always lead to a directionally proportional increase in *Microcystis* biomass.

Consistent with the opinions expressed in SJC-4, the literature indicates a longer WRT will lead to a greater likelihood and magnitude of *Microcystis* blooms in the Delta because it is already evident that these blooms are a feature of the Delta ecosystem when their main growth requirements are met (e.g., high phosphorus and nitrogen concentrations, high temperature, adequate light, and low salinity, etc.). However, there is no evidence in the limnological literature that a change in any single bloom predictor will lead to directly larger HABs.

Despite this, there is a substantial literature showing that long WRTs are associated with larger *Microcystis aeruginosa* blooms. For example, in a paper titled "Water residence time and the dynamics of toxic cyanobacteria", Romo et al. 2013 (DWR-742) showed that *Microcystis aeruginosa* abundance and the Microcyctin LR concentration in the seston was weakly correlated ($r^2 \approx 0.20$) with water flushing (i.e., the inverse of WRT). This weak correlation shows that there is a tendency for biomass and cyanotoxins to increase with longer WRTs, but not that the relationship is directly proportionate. Verspagen et al. 2006 (SJC-211) developed a mechanistic model to predict the usefulness of lake flushing to control *Microcystis* blooms. The model described in Verspagen et al. 2006 (SJC-211) predicted that on account of the slow growth of *Microcystis*, blooms could be suppressed in Lake Volkerak (The Netherlands) when water residence times were less than 37 days. Finally, Lehman et al. 2017 (DWR-720) concluded that a severe drought in 2014 lead to higher water temperatures and longer water residence times, which caused the largest *Microcystis* biomasses and highest microcystin concentrations recorded for the Delta. As previously noted, Mitrovic et al. (2003, 2011) (SJC-207, DWR-730) recommended riverine flushing as a means to control *Anabaena* blooms in the Lower Darling River, Australia.

In fact, Bryan (DWR-653) also concluded that *"Because* Microcystis *has a relatively slow growth rate long residence times are required for cells to accumulate and form significant blooms (Reynolds 1997 as cited in Lehman et al. 2008, Lehman et al. 2013, 2015). Wind and tides can also enhance the aggregation of* Microcystis *cells in slow moving waters (Baxa et al. 2010). Since flushing rates determine residence time, lower channel velocities increase residence time and decrease cyanobacteria loss rates (Romo et al. 2013). Several studies have found longer residence times are positively related to cyanobacteria abundance (Elliott 2010, Romo et al. 2013, Lehman et al. 2017). For example, in the extreme drought year of 2014, Lehman et al. (2017) found long residence times were one factor affecting the* *magnitude of* Microcystis *blooms within the Delta."*[2] This is consistent with the paper cited elsewhere by Bryan, *Factors Affecting Growth of Cyanobacteria, With a Special Emphasis on the Sacramento-San Joaquin Delta*, Berg & Sutula, 2013, which recognizes that with respect to the Delta, "the direct effect of increased residence time is to decrease the loss rate of cyanobacteria … . Studies that report on the effect of residence time suggest that cyanobacterial abundance, cell size, and toxin concentration are positively related to increased residence time." (DWR-558, p. 33.)

I believe the studies that Bryan and I both reference clearly show a functional relationship between water residence time and cyanobacteria bloom development. These studies also indicate that *Microcystis* blooms in the Delta are more likely to occur when WRTs are longer.

Paradoxically, after noting the importance of WRT for cyanobacteria bloom development, Bryan states that: *"Increased residence time alone does not equate with increased* Microcystis *bloom frequency or magnitude."* (DWR-81, p. 16.) As noted previously, this is a Straw Man argument since nobody would (or has) claimed that increased WRT <u>always</u> equates with proportionally increased bloom magnitude. For example, Lake Tahoe and Lake Superior have WRTs of 700 and 185 years, respectively, and nobody would predict cyanobacteria HABs in these lakes (which are oligotrophic) solely because they have long WRTs. Instead, the limnological literature indicates that in systems that already have cyanobacteria HABs (because of high nutrients, high temperature, and favorable light conditions), increased WRT will in many cases increase the severity of blooms. Furthermore, Water Quality Chapter of the Final EIS/R, which Bryan prepared, states *"Because there is no published analysis of the relationship between* Microcystis *occurrence and residence time, there is uncertainty on how increased residence times may affect* Microcystis *occurrences (ICF International 2016)."* (Chapter 8: Water Quality, FEIR/S, p. 8-980, SJC-216.) This claim

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[2] DWR-653 also followed this statement up with this caveat: *"Other studies demonstrate that long residence time alone does not cause cyanobacteria blooms to form, even when other environmental conditions are suitable for a bloom."*

ignores the substantial number of "published analys[e]s" pertaining to WRT and cyanobacteria and *Microcystis* bloom severity.

The likely effect of increased WRT was acknowledged to occur with CWF in parts of the Delta in the Final EIR/EIS (pp. 8-120, 8-979, 980, 981 (SJC-216)), but the effect was considered to be uncertain because there is no published relationship between *Microcystis* occurrence and WRT for the Delta. That assertion is incorrect. The Romo et al. 2003 study specifically looked at the relationship between WRT and *Microcystis* bloom formation, and showed that *Microcystis* blooms were more likely to occur when WRT was longer. Furthermore, there are many cases when all other conditions are present for not only cyanobacteria, but other plankton algae as well, to form blooms, except that WRT is insufficient. A few days increase in WRT can be very important. Consider a stormwater retention basin with high nutrient concentrations in summer, but with only 2 days WRT. That time is too short for phytoplankton biomass to accumulate, or nutrient concentrations to reach growth-limiting levels, even if the growth rate is 100%/day because the washout rate is 50%/day. However, if WRT were increased to 10 days, a massive bloom could develop.

In my experience with the limnological literature, changes in WRT of several days alone can be effective in promoting or discouraging HABs. For instance, *Oscillatoria,* a well known cyanobacteria that is a common bloom former in eutrophic waters, was greatly affected by WRT in a hypereutrophic, brackish bay (Persson, 1981, SJC-209). Biomass decreased by half when WRT was reduced from 21 days to ≈ 11 days, and by two-thirds when WRT was reduced to 5 days. Thus, WRT alone can affect cyanobacteria biomass in systems with short WRTs. In a reservoir example, 45% longer WRT during drought years resulted in a dramatic increase in the biomass of *Microcystis* (Romo et al., 2013, DWR-713).

Bryan admitted (DWR-453, Section 4.3) that WRT may increase in the central and southern Delta areas, but claimed that other factors, such as velocity, turbulence, mixing, and grazing losses by zooplankton, fish and clams, would obscure any effect of increased residence times.[3] Of course, there are other factors involved. For example, wind can strongly affect turbulence and discourage bloom formation, but wind would be a normal condition after CWF as before. However, he contended that mid-channel velocities would not change (see opinion #5), so that the same pattern of water column stability would also persist after the CWF. That may be true for the mid-channel, but as indicated in rebuttal to #5, mid-channel flow velocities have little relevance to the vegetated side channels and backwater sloughs where WRT is expected to increase and cyanobacteria blooms are already known to occur (Lehman et al. 2017, DWR-720).

The Paulsen (2017) report (STKN-26) provided a range of estimates for how much the WRT of the Delta would change with the CWF. I reviewed the outputs reported in Appendix F of STKN-26to calculate the average WRT change for several scenarios (i.e., EBC2 vs. B1, EBC2 vs. B2, EBC2, vs. Alt4A) during the summer months of July-September when cyanobacteria blooms are most likely to occur. I also considered the four Water Year Types, critical, dry, normal and wet. For these conditions, the results reported by Paulsen (STKN-26) indicated that on average WRT in the Delta would increase by 28 ± 11% (± 1 Std. Dev.) with the CWF under the Boundary 1 operational scenario. For these conditions, this would be equivalent to changing the average WRT for the Delta from 25.6 ± 5.2 days for the Existing Biological Conditions 2 (EBC2) model run versus 32.4 ± 4.7 days for the B1, B2 and Alt4A model runs. This equates to an overall increased WRT for the Delta of 6.9 ± 2.2 days, which is very substantial with regard to cyanobacteria bloom development according to the WRT literature I reviewed.

Not only would WRT increase—as much as 50% in some areas of the Delta (STKN-26)—water temperature would likely also increase with longer WRTs, which would allow faster growth rates of phytoplankton and produce more strongly stratified water columns that would further favor HABs. As surface temperatures warm in shallow waters, the density difference

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[3] Table 8-60a in the Final EIR/S (SJC-216) and Tables 6.6-5 to 6.6-25 in the 2016 BA (SWRCB-104, pp. 6-243 to 6-248 (SJC-218)) show increased residence times in most modeled locations, not just the central and southern Delta.

between bottom and surface increases, and that difference is considerably greater in warm than cool water. Thus, water column stability can increase in warmer water favoring buoyant cyanobacteria, which depend on that stability to outcompete other plankton algae which tend to sink in calm water.

In summary, according to project modeling, the proposed CWF diversions would increase the average water residence time of the Delta by about 28% or 7 days as compared to the No Action Alternative. (STKN-26.) The increase in WRT would be most pronounced in vegetated side channels and backwater sloughs where cyanobacteria blooms are most likely to occur (and less pronounced in the thalweg of the main channels). Longer WRTs as a result of operation of the proposed diversions would increase the likelihood of *Microcycstis* HABs in the Delta.

Opinion #7 - Temperature

Petitioner states that model predicted temperature increases with the CWF, compared to NAA, would not substantially increase the frequency and magnitude of cyanobacteria blooms within the Delta.

Sur-Rebuttal

Petitioner's conclusions regarding the effect of modeled temperature increases are unsupported.

Temperature modeling relied upon by Petitioner addressed only one operational scenario (H3+). (Hearing Transcript, April 27, 2017, p. 203 [temperature modeling for 4A, H3 and H4 and the two boundary conditions not available].)

Petitioner contends that the few tenths of a ˚C increase in modeled, mean period 1932-2003 temperatures due to CWF are not enough to increase cyanobacteria growth. (DWR-81, pp. 17-18; DWR-653, pp. 33-36.) That may be correct if the 0.1-0.3 ˚C increases were representative of extremes that could occur during warm dry summers, with increased water residence times. However, by using period means—presumably means for the whole period 1922-2003—extreme conditions that could result from the CWF were likely masked and therefore underestimated. Increases in Delta water temperatures of only a couple tenths ˚C with 30-40% of the Sacramento inflow diverted during warm summers with drought conditions (resulting in longer WRTs), seem intuitively unlikely. Bryan explained that the reason for the small temperature effect is that river temperature is at equilibrium with air temperature before the water reaches the Delta. But it appears likely that the longer WRTs in side channels, sloughs, flooded islands, etc. would actually result in additional heating, especially in lower-flow summers. In addition, reservoirs created above dams on rivers are heat sinks, because their longer WRTs allow for more solar heating of surface waters than would occur in a free-flowing river (which is continually supplied with cooler ground water inflows and shorter WRT).

Opinion #8 - Turbidity

> *Bryan claimed that any minor change in turbidity with the CWF would have no substantial effect on the frequency and magnitude of HABs in the Delta.*

Sur-Rebuttal

> *Bryan's opinion about the effect of CWF-driven turbidity changes on the frequency and magnitude of HABs in the Delta is flawed for at least two reasons: his reliance on mid-channel velocities is misplaced because they are not representative of areas of the Delta that will likely experience increased water residence times due to CWF, and because it is based in part on a misapprehension about the degree to which cyanobacteria are light limited in the Delta.*

Bryan asserted that turbidity would not change because mid-channel velocities would not change with the CWF. (DWR-81, pp. 18-19, DWR-653, pp. 36-37.) First, mid-channel velocities are probably not representative of the channel edges, sloughs, sunken islands and other off-channel coves that will likely experience increased water residence times due to 30-40% less Sacramento River inflow into the Delta during spring-summer periods. Increased WRTs would result in a larger fraction of suspended solids settling out of the water column, which would allow more light for planktonic algae as well as the opportunity for cyanobacteria blooms to occur more frequently. Also, contrary to Bryan's assertions, independent peer reviews of the CWF project have expressed concern about the project's potential to affect sediment concentration, and thus decrease turbidity: The "panel had greater concerns about future sediment movement and water quality, and in particular, about whether the North Delta Diversions (NDD) might exacerbate the downstream sediment starvation that is already occurring." (LAND-112, p. 4.)

Bryan further asserts that cyanobacteria are not now light limited so minor changes in turbidity (non-algal) would not notably affect blooms. For example, in DWR-81, Bryan states *"cyanobacteria in the Delta are not light limited during the period of the year (June–November) when temperatures are warm enough to support cyanobacteria growth. Because cyanobacteria in the Delta are not light limited, minor changes in turbidity would not have notable affects on cyanobacteria blooms."* (DWR-81, p. 19.) Bryan also stated that temperature, not light, is the factor that limits cyanobacteria growth in the Delta. (DWR-653, p. 37.) On the contrary, cyanobacteria are probably often light limited in the Delta. Chlorophyll concentrations at gauge sites on Old and Middle Rivers were often well over 200 µg/L during 2013-2016. (SJC-204.) At that concentration, the phytoplankton themselves would attenuate enough surface light intensity to restrict their growth to the upper 2 m in a mixed water column. Additional light extinction by non-algal turbidity, which is probably substantial in the Delta, would further restrict the depth to which algae could be mixed and still grow. The claim of no light limitation is also contradicted by the papers by Jassby 2008 (SJC-205) and Lehman et al. 2017 (DWR-720), which both conclude light limitation is important for phytoplankton growth dynamics in the Delta. Light probably exerts the greatest effect on HAB timing, as well as on magnitude, along with the most limiting nutrient, given that cyanobacterial growth is related to the rate of warming in a water body. Thus, changes in turbidity due to non-algal suspended solids could affect cyanobacteria biomass in water depths as shallow as 2 meters, assuming water columns are mixed, as indicated by mid-channel velocities, as Bryan asserted.

Rebuttal Opinion #9 - Nutrients

> *Bryan asserted that nutrient increases in the Delta would be small and not expected to increase the frequency, magnitude or duration of HABs.*

Sur-Rebuttal

> *The pertinent literature does not support Bryan's opinion that the frequency and magnitude of HABs in the Delta will not be increased as a result of CWF-driven nutrient increases: among other deficiencies in his testimony, Bryan did not examine the possibility that reduced dilution by Sacramento River water would increase Delta nutrient concentrations enough to raise seasonal average algal biomass and the magnitude of HABs.*

Discussion is presented by Bryan (and in the Final EIR/S) that argues the nitrogen (N) and phosphorus (P) concentrations that currently occur in the Delta are non-limiting, meaning that N and P are adequate to maintain maximum growth of *Microcystis* and that biomass would not increase due to any nutrient increase because growth is currently saturated with respect to nutrients. (DWR-81, pp. 19-20; DWR-653, pp. 38-39.) Presumably this conclusion refers to growth rate and not to ultimate biomass or to any seasonal average biomass of *Microcystis* (or other taxa) or chlorophyll (Chl a) to seasonal average biomass. Apparently no relationship with seasonally averaged data between nutrients and *Microcystis* has been established for the Delta.

Relationships between soluble nutrients, N and/or P, and biomass assessed during a season are often inversely related; soluble nutrient concentrations usually decrease as growth proceeds because cells extract nutrients from the water. Also, attempting to relate TP or TN to algal biomass during one season is unlikely to be productive, because there are too many complicating factors affecting growth and biomass to allow biomass to be solely related to the most limiting nutrient on a short-term basis. The only meaningful procedure to assess the effects of nutrient increase in a standing or slow moving water body with relatively long WRT is to develop a relationship between seasonal average total P and/or total N and average algal biomass, over many years. That has apparently not been done for any of the Delta areas. Such relationships typically show that seasonal average phytoplankton biomass increases proportionately with TP, to over 100 µg Chl a/L in some hypereutrophic waters; e.g., 200 µg/L average summer Chl a in Upper Klamath Lake (Kann and Welch 2005, SJC-212). As in Upper Klamath Lake, biomass can increase proportionately with TP, even if N limits growth rates, because N can be supplied by N-fixing cyanobacteria, e.g., *Aphanizomenon* (Schindler, 2016 (SJC-210); Welch, 2009 (SJC-214)). Without such data, assessment of the effect of diverting a portion of the Sacramento River on nutrients is difficult. However, if an increase in TP is expected, either through decreased dilution with lower-P water entering the Delta, or an increased accumulation of TP in the water column due to recycling from the sediment, as a result of increased WRT, then an increase in HABs may occur, given the general response of lakes and slow moving rivers to eutrophication.

Diverting a portion of the Sacramento River in the northern Delta could substantially reduce its diluting effect on both N and P in Delta waters, especially during the summer. The median TP concentration in the Sacramento River at Knight's Landing during spring-summer was about 40 µg/L, and farther downstream at Hood/Green's Landing, about 80 µg/L (EPA, 2006, SJC-204). Spring-summer median concentrations were much higher in the San Joaquin River—about 200 µg/L at Hwy 165 and farther downstream at Patterson, about 300 µg/L. Reduced dilution by the Sacramento River would be greater for N than for P, because median summer TN was only about 5 times greater than TP in the Sacramento River (Knight's Landing), while TN was 10 times greater than TP in the Joaquin River at Hwy 165. *Microcystis* is not a nitrogen fixer and its growth would likely be limited more by N than P in the Delta. The extent to which reduced dilution by the Sacramento River would increase Delta nutrient concentrations enough to raise seasonal average algal biomass and the magnitude of HABs is uncertain. However, these possibilities were not raised and discussed by Bryan and no seasonal average based relationships between seasonally averaged total phytoplankton or *Microcystis* biomass, as described above, have been presented.

Executed on the 9th Day of June at Seattle, Washington.

Michael T. Brett

Michael T. Brett

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