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Interpreting Narrative Objectives for Biostimulatory Substances for California Central Coast Waters

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Summary

This technical paper describes an approach for interpreting the 1994 California Central Coast Water Quality Control Plan (Basin Plan) narrative language stating that "waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses." In this approach, Central Coast Water Board staff employed Basin Plan Objectives, U.S. Environmental Protection Agency (U.S. EPA) standards, guideline values from the literature, our own monitoring data, and modeled estimates of potential algal growth and resultant oxygen deficits. The resulting numeric endpoints can be used for regional water quality assessments and to support assessment decisions for the California Integrated Report for addressing Clean Water Act Sections 303(d) and 305(b). To conduct this analysis, we have relied heavily upon data collected by the Central Coast Ambient Monitoring Program (CCAMP). CCAMP conducts monitoring for the Central Coast Water Board and is the Central Coast regional component of the California Surface Water Ambient Monitoring Program. CCAMP data can be viewed at www.ccamp.org.

We identified a pool of long-term monitoring locations, or "sites", from the extensive CCAMP dataset that have always met either warm or cold water oxygen objectives based on both monthly grab samples and 24-hour continuous monitoring. From this dataset, we identified an upper range for dissolved oxygen concentration of 13 milligrams per liter (mg/L), over which site oxygen concentrations rarely or never fell. We established 13 mg/L as an upper limit for oxygen, to address the U.S. EPA 'Gold Book' (1986) water quality standard for excessive gas saturation. We identified a reference subset of the initial set of sites that showed no other signs of eutrophication, such as oxygen levels over 13 mg/L, water column chlorophyll a exceeding 15 micrograms per liter (ug/L) or observed floating algal cover exceeding 50%.

We examined nutrient characteristics of data from this reference set to identify a proposed screening criterion of 1.0 mg/L nitrate as nitrogen (mg/L NO3-N) to protect aquatic life. This number represents the 95th percentile of the reference data set. We then used the California Benthic Biomass Tool (Tetratech, 2007), or "Benthic Biomass Tool", to evaluate individual monitoring sites in terms of predicted oxygen deficits, maximum benthic algal biomass and benthic chlorophyll a concentrations. These modeled outputs can be evaluated against the "presumed impaired" thresholds identified in the "Technical Approach to develop Nutrient Numeric Endpoints for California" (Creager, 2006), to characterize the risk of eutrophication associated with specific conditions at a given site or water body.

Based on this analysis, we will designate water bodies as impaired for aquatic life use when nitrate concentrations exceed 1.0 mg/L NO3-N and there is additional evidence of eutrophication, including depressed or supersaturated dissolved oxygen concentrations, pH over 9.5, floating algal mats over 50%, water column chlorophyll *a* concentrations over 15 ug/L, predicted oxygen deficits over 1.25 mg/L, and predicted benthic algal biomass or predicted benthic chlorophyll *a* concentrations over levels recommended by the "Technical Approach to develop Nutrient Numeric Endpoints for California" (Creager et al., 2006).

Background

Nitrate is regulated as a toxicant in California, because of its impacts on the public water supply and human health. The drinking water standard is set at 10 mg/L NO3-N to protect against methemoglobinemia ("blue baby syndrome"), and more recent research implies that lower levels may be required to protect against thyroid cancer (Ward et al., 2010) and other health concerns. Also, a growing body of research on aquatic toxicity recommends even lower thresholds for protection of aquatic life; for example, Camargo et al. (2005) recommends 2.0 mg/L NO3-N for protection of sensitive aquatic species. However, no numeric standards for nitrate are currently in place in California for protection of aquatic life, either for direct toxicity or for indirect effects as a biostimulatory substance. The purpose of this document is to address nitrate and related biostimulatory indicators as they relate to aquatic life beneficial uses.

In some environmental conditions, excessive nutrient concentrations in stream systems stimulate algal growth, which can create nuisance conditions for several beneficial uses including irrigation, industrial supply and recreational use. More importantly, excessive algae can remove oxygen from water, creating conditions unsuitable for many aquatic life forms. This condition is called "eutrophication". Some algal blooms are also toxic to aquatic life, wildlife, and even humans. Waters that contain excessive algal growth are characterized by wide swings in dissolved oxygen concentrations, typically dropping below concentrations set to protect for aquatic life at night, and often rising above fully saturated levels during daytime (U.S. EPA, 2000b). Low oxygen conditions can result in fish kills and harm to other aquatic life. Some species, such as trout, are particularly sensitive to low oxygen conditions, which is why more rigorous standards are set to support cold water fish habitat.

Supersaturated oxygen conditions can be indicative of excessive algal photosynthetic activity and can be exacerbated by rapid increases in water temperature. Total gas supersaturation can cause direct harm to fish when total dissolved gas saturation increases enough to cause "gas bubble trauma". This is a sometimes fatal condition which occurs when gas bubbles, primarily nitrogen and/or oxygen, are released into the bloodstream and accumulate in the skin, eyes, and gills of fish (Weitkamp, 2008). It is usually considered a problem for fish in discharge waters from dams, but can also be associated with eutrophication (Canadian Council of Ministers of the Environment, 1999; Fidler and Miller, 1994). Edsall and Smith (2008) showed gas bubble trauma could be induced with oxygen supersaturation alone. U.S. EPA (1986) has recommended an upper limit of 110% total dissolved gas saturation to protect fish from gas bubble trauma.

Regulatory Setting - The 1994 Central Coast Water Quality Control Plan (Basin Plan) contains narrative language stating that "waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses." Similar narrative language is used throughout California. In the past, states lacked guidance on how to "translate" this narrative language into quantifiable endpoints, making it difficult to apply this objective in a regulatory setting.

In 2000, the U.S. Environmental Protection Agency (EPA) released technical guidance for developing numeric nutrient criteria for the Xeric west (U.S. EPA, 2000a). This guidance recommended states follow one of three approaches:

1) Adopt nutrient criteria that reflect local conditions, either as numeric criteria or as procedures to translate a narrative criterion into quantifiable endpoints, following EPA Technical guidance (U.S. EPA, 2000b).
2) Adopt EPA Section 304(a) criteria, described in the technical guidance (U.S. EPA, 2000a), either as numeric criteria or as procedures to translate a narrative criterion into quantifiable endpoints.
3) Develop criteria capable of protecting beneficial uses using other scientifically defensible methods and data.

EPA technical guidance recommended two approaches to setting nitrogen reference conditions. The preferred approach was to use the 75^{th} percentile of data from a set of reference sites. The other approach was to use the 25^{th} percentile of all data. Using the second approach, EPA derived a reference value of 0.38 mg/L total nitrogen (TN) for the xeric west (which includes the Central Coast Region), and also identified a subregional value of 0.5 mg/L TN for the Central and Southern California Chaparral Ecoregion (U.S. EPA, 2000a).

California convened a Technical Advisory Group to develop its own approach to development of nutrient endpoints, following approach #1 above, by translating narrative criteria into quantifiable endpoints through the California Nutrient Numeric Endpoint Approach.

California Nutrient Numeric Endpoint Approach - The "Technical Approach to Develop Nutrient Numeric Endpoints for California" (Creager, et al., 2006), or "California NNE Approach", was developed by Tetratech, Inc. for the State Water Resources Control Board (SWRCB), in order to interpret the biostimulatory narrative objective, and to support development of numeric criteria for nutrients to protect for aquatic life beneficial uses. The California NNE Approach utilizes predicted benthic algae biomass and benthic chlorophyll *a* concentrations as "response variables" or "secondary indicators" to define Beneficial Use Risk Categories that can serve as preliminary numeric targets. These numeric targets are set at a conservative (protective) level to account for uncertainty and to be applicable throughout California. The California NNE Approach recommends numeric boundaries between three categories of risk in cold and warm water streams: "presumptive unimpaired", "potentially impaired", and "presumptive impaired". The recommended numeric boundary for benthic algal biomass between risk categories of "potentially impaired" and "presumptive impaired" are: 200 milligrams chlorophyll *a* per square meter (mg/m^2) for warm water streams and 150 mg/m^2 for cold water streams, and corresponding benthic algal biomass of 80 $grams/m^2$ ash free dry weight (AFDW) in warm water streams and 60 $grams/m^2$ AFDW in cold water streams. The boundary established by the California NNE approach between these two risk categories for pH is 9.5 pH units, which is well over the upper Basin Plan standard of 8.5.

Tetratech Inc. developed the Benthic Biomass Tool as a companion tool to the California NNE Approach, to predict instream benthic algal density and other secondary endpoints, in response to a number of inputs. Data on nutrient concentrations (minimums, maximums, and mean average), as well as latitude, canopy cover, stream depth and velocity is input into the Benthic Biomass Tool, to generate several model outputs. These include benthic biomass and benthic chlorophyll *a* concentrations for both cold and warm water streams. The tool predicts these outputs for five models and seven different methods taken from the scientific literature. The models and their application are described extensively in Appendix 3 of the California NNE Approach (Crieger, 2006). They include empirical models (Dodds, 1997 and 2002) and the QUAL2K simulation models (Chapra and Pelletier, 2003), including the standard model, a revised model that provides a better fit to Dodd's empirical data, and a revised model that adjusts for algae accrual time between scour events (this is especially important in areas with summer rain events). The revised QUAL2K simulation model also predicts the anticipated maximum algal contribution to oxygen deficit. This is the maximum amount of dissolved oxygen expected to be removed from the water as a result of predicted benthic algal growth. The outputs can then be evaluated using the numeric targets for secondary indicators, established by the California NNE Approach to determine the risk of impairment at a given site from nutrient over-enrichment.

The Water Quality Control Policy (WQCP) for developing California's Clean Water Act Section 303(d) list (SWRCB, 2004), or "Listing Policy", describes the process by which the SWRCB and Regional Water Boards will comply with the listing requirements of Section 303(d) of the federal Clean Water Act. Section 6.1.3 "Evaluation Guideline Selection Process" provides the requirements for a proposed guideline before it can be accepted for use as part of the 303(d) listing process. According to SWRCB staff analysis, the California NNE Approach does meet these requirements, namely it is:

- Applicable to the beneficial use
- Protective of the beneficial use
- Linked to the pollutant under consideration
- Scientifically-based and peer reviewed
- Well described, and
- Identifies a range above which impacts occur and below which no or few impacts are predicted.

Central Coast Water Board staff has used the California NNE Approach and Benthic Biomass Tool, paired with an empirical evaluation of Central Coast reference data, to develop a nitrate guideline value and supporting evidence to assess whether aquatic life uses show negative effects associated with eutrophication.

Establishing Characteristics of Unimpaired Sites

Oxygen Reference Range remaining above Basin Plan objectives and below 13 mg/L – Waters that have large amounts of algae or other plant material present can show widely ranging diel oxygen concentrations (U.S. EPA, 2000b). Water can "supersaturate" during daylight hours because plant photosynthetic activity releases oxygen to the water and in some circumstances that oxygen is trapped beneath the surface tension of the water's surface. Also, water can become oxygen depleted during dark hours because plant respiration (and decay) removes oxygen from the water column. The resulting widely ranging oxygen concentrations are a primary indication of eutrophication and one of the resulting outcomes that is deleterious to aquatic life.

Central Coast Water Board staff evaluated Central Coast Ambient Monitoring Program (CCAMP) diel oxygen data collected from 105 sites where dissolved oxygen recording probes were deployed for 20 or more hours during summer months. CCAMP collects this data to determine if oxygen levels drop during the highest risk time of day, which is pre-dawn. This is important because monitoring staff conducts routine monthly grab sampling between 9 a.m. and 4 p.m., when oxygen levels are typically highest.

From the combined dataset of grab samples and diel data, we established two data sets for potential reference sites. The first set was from the 32 sites where dissolved oxygen concentrations never dropped below 7.0 mg/L, the cold water aquatic life standard. The second was for the 59 sites where dissolved oxygen concentrations never dropped below 5.0 mg/L, the warm water aquatic life standard. We examined oxygen concentrations of both diel and monthly grab sample data for these sites for each hour of the day (Figures 1 and 2). For the 32 sites that met the cold water objective, 29 sites never exceeded 13 mg/L at any time. Of the 644 grab samples taken at these 32 sites, only 6 samples (or 1.0%) exceeded 13 mg/L. For the 59 sites that met the warm water objective, 43 sites never exceeded 13 mg/L at any time. Of the 1,695 grab samples taken at these 43 sites, only 32 samples (or 1.9%) exceeded 13 mg/L. We determined that 13 mg/L is an appropriate upper value to screen both warm and cold water sites for oxygen super-saturation outside of reference ranges.

Water column chlorophyll *a* concentrations remaining under 15 ug/L - This value has been used for a number of years as a CCAMP screening value. The state of North Carolina has set a maximum acceptable chlorophyll *a* standard of 15 ug/L for cold water (lakes, reservoir, and other waters subject to growths of macroscopic or microscopic vegetation designated as trout waters), and 40 ug/L for warm water (lakes, reservoir, and other waters subject to growths of macroscopic or microscopic vegetation not designated as trout waters) (North Carolina Administrative Code 15A NCAC 02B .0211 (3) (a)). Oregon uses an average chlorophyll *a* concentration of >15 ug/L as a criterion for nuisance phytoplankton growth in lakes and rivers (OAR, 2000). A chlorophyll *a* concentration of 8 ug/L is recommended as a threshold of eutrophy for plankton in EPA's Nutrient Criteria Technical Guidance Manual for Rivers and Streams (2000b). The Central Coast Region has used 40 ug/L as stand-alone evidence to support chlorophyll *a* listing recommendations for the 303(d) Impaired Water Bodies list. However, we are using 15 ug/L as supporting evidence of nutrient over-enrichment, based on a review of existing and recommended limits used elsewhere.

<u>Floating algal cover not exceeding 50% of the water's surface</u> - Typical nuisance criteria cited in the literature for filamentous algal cover range from 40 to 55% (Stevenson, et al., 1996). The State of Nevada uses 50% cover as a screening threshold for filamentous algal cover to identify possible algae related problems (NDEP, 2007). CCAMP documents the percent surface coverage of floating algal mats at each monthly site visit and has associated photographs supporting these observations. We are using 50% floating algal cover as supporting evidence of excessive algal growth and nutrient over-enrichment. Floating algal cover is defined as filamentous algae that is sufficiently long and thick that it breaks the water's surface and creates nuisance algal mats.

Establishing a guideline value for nitrate-N

We evaluated CCAMP data for characteristics of sites meeting warm and cold water oxygen objectives that do not show evidence of eutrophication. These sites remained below the limits of characteristics described above, related to oxygen range, water column chlorophyll a concentrations, and algal cover. Twenty of the 32 original sites that met the cold water objective also met all of these conditions, and twenty-six of the original 59 sites that met the warm water oxygen objective also met all of these conditions. These sites are considered "reference".

No sites from the cold water data reference set and only one site from the warm water reference data set had nitrate-N concentrations that exceeded 1.0 mg/L NO3-N as an average (Figures 3 and 4). The single site that exceeded this value was located below a dam, and was well oxygenated as a result.

One approach U.S. EPA (2000) recommended for setting nitrogen criteria was at the 75^{th} percentile of reference data. One mg/L NO3-N represents the 95^{th} percentile of our reference data set. We set 1.0 mg/L NO3-N as the tentative guideline value to screen for aquatic life use protection. We recognize that this is a higher concentration threshold than that derived using the EPA approach, but we believe it is more applicable for the central coast of California because reference conditions here tend to be found in higher gradient waters of small coastal streams, whereas most land uses in the Region occur around lower gradient systems with wide, flat floodplains, where nutrient levels can be expected to be naturally higher (Franklin, et al., 2002).

Application of the California Benthic Biomass Tool to CCAMP Data

Staff submitted summary data for 209 CCAMP sites, collected between 1998 and 2006, for water body minimums, maximums, and means for nitrate, nitrite, ammonium, ortho-phosphate, total nitrogen, total phosphorus and water temperature into the Benthic Biomass Tool. To screen data for probable effects, we utilized the recommended NNE warm water threshold values of 200 mg/m^2 for benthic chlorophyll *a* and 80 $grams/m^2$ ash-free dry weight (AFDW) for algal density, and the cold water threshold values of 150 mg/m^2 for benthic chlorophyll *a* and 60 $grams/m^2$ AFDW for algal density. We used a latitude of 35 degrees and a canopy cover of 80% as model inputs. Our assumption of a relatively dense canopy cover produces an estimate of probable effects that conservatively (less frequently) identifies problem conditions. We used default values in the Benthic Biomass Tool for several other model inputs, including stream velocity of 0.3 meters per second and stream depth of 0.5 meters. Resulting outputs provided estimates of benthic algal biomass, benthic chlorophyll *a* concentration, and estimated oxygen deficit for each water body.

The Benthic Biomass Tool provides a sensitivity analysis that examines how varying model inputs alter model outputs. We examined the sensitivity of model outputs to default values. For example, reducing stream velocity or depth defaults by half produced minor increases in predicted algal biomass estimates. However, reducing canopy cover by half (from 80 to 40%) produced large increases in predicted biomass. By allowing the default value for canopy to remain at 80% (the highest value the Tool allows), we will typically underpredict algal cover, and thus can use outputs that exceed the "probable impairment" level as reliable evidence of a problem.

Predicted Oxygen Deficit – We used the Benthic Biomass Tool to further evaluate these sites in terms of predicted "maximum algal contribution to oxygen deficit". This is the amount of oxygen predicted to be removed from the water column as a result of benthic algal biomass, and is an output of the QUAL2K model (Chapra and Pelletier, 2003) embedded in the Tool. Staff evaluated resulting individual site outputs for all CCAMP data from 209 sites. The Benthic Biomass Tool generated an estimated oxygen deficit for each site based on predicted algal biomass. Based on the nitrate concentrations associated with CCAMP sites that do not show evidence of biostimulation, staff evaluated the oxygen deficit associated with sites that had average nitrate concentrations of 1.0 mg/L NO3-N or lower. The maximum contribution of algae to oxygen deficit at this nitrate concentration was approximately 1.25 mg/L (Figure 5). All of the cold water reference sites and most of the warm water reference sites fall within this level of predicted oxygen deficit (Figures 6 and 7). We identified 1.25 mg/L oxygen deficit as a threshold below which risk of eutrophication is minimized. It should be recognized that the actual oxygen deficit at any given location may vary significantly from this modeled estimate, because of other variables such as vertical stratification, water residence time, transparency and distance downstream from pollution sources.

Reference Site Performance - We examined the performance of our reference sites relative to NNE biomass predictions. The twenty reference sites that met cold water standards and showed no other evidence of eutrophication had predicted benthic chlorophyll *a* values that remained well under the NNE threshold of "presumptive impaired", of 150 mg/m^2 (Figure 8). In fact, for all but one of these sites, the predicted values were at around 50 mg/m^2 or lower. Similarly, all warm water reference sites remained under the NNE warm water "presumptive impaired" threshold of 200 mg/m^2; all but two of these sites remained under 100 mg/m^2. Not only do these sites show no empirical evidence of eutrophication, the model outputs show they fall into the NNE Categories of "presumptive unimpaired" (below 100 and 150 mg/m2 for cold and warm water habitats, respectively), as should be expected for reference conditions.

Using Nitrate Screening Criterion to Develop Lines of Evidence

Nitrate and other nutrients are treated as "toxins" by the Listing Policy (SWRCB, 2004). Consequently, in developing Lines of Evidence for the 2008 Integrated Report, Central Coast Water Board staff evaluated nitrate data using the binomial distribution established for toxic pollutants in Table 3.1 of the Listing Policy, based on exceedance of 1.0 mg/L NO3-N. We provided further evidence of eutrophication using supporting data and Benthic Biomass Tool model outputs. These included predictions of benthic algal biomass and/or benthic chlorophyll *a* concentrations exceeding model thresholds of "probable impairment", evaluation of model prediction of algal contribution to oxygen deficit relative to our established 1.25 mg/L threshold, as well as parameters measured in the field, including floating algal mats exceeding 50% of the water surface, water column chlorophyll *a* concentrations over 15 ug/L, pH over 9.5, and evidence of oxygen depression (concentrations less than the appropriate Basin Plan standard) and/or super-saturation (concentrations greater than 13 mg/L),.

Conclusions

In this technical paper, we have developed an integrated approach for interpreting the Central Coast Water Quality Control Plan's "narrative objective for biostimulatory substances", that will protect aquatic life beneficial uses from the consequences of nutrient over-enrichment and resulting eutrophication. We have used this approach to develop decisions related to water body impairment for the 2010 Integrated Report for addressing Clean Water Act Sections 303(d) and 305(b). In this approach we have relied on empirical data evaluation along with simulation models, guideline values from the scientific literature, regional water quality objectives, and EPA standards, to develop multiple lines of reasoning that can support regulatory decision-making.

We screen sites for evidence of eutrophication by evaluating data for exceedance of 1.0 mg/L nitrate (as N), using a binomial distribution according to Table 3.1 of the Listing Policy (2004). We further support our decisions with other evidence of eutrophication, using supporting data and Benthic Biomass Tool model outputs. These include predictions of benthic algal biomass and/or benthic chlorophyll *a* concentrations exceeding model thresholds of "probable impairment", evaluation of model prediction of algal contribution to oxygen deficit relative to our established 1.25 mg/L threshold, as well as parameters measured in the field, including floating algal mats exceeding 50% of the water surface, water column chlorophyll *a* concentrations over 15 ug/L, pH over 9.5and evidence of oxygen depression (concentrations less than the appropriate Basin Plan standard) and/or super-saturation (concentrations greater than 13 mg/L).

An EPA draft document entitled “Empirical Approaches for Nutrient Criteria Derivation” was released for review in August, 2009. This document recommended a “stressor–response” statistical approach that quantifies the relationship between nutrients and biological response measures, in this case for macroinvertebrates. In an April, 2010 peer review of this document, the U.S. EPA Scientific Advisory Board (August 12. 2009) recommended against stand-alone statistical methods such as the one used by U.S. EPA, because of the challenges associated with proving cause and effect. Instead, the SAB recommended a weight of evidence approach to criteria development. The SAB also stressed the importance of recognizing downstream impacts associated with excessive nutrients. The SAB suggested that the omission of dissolved oxygen as a response variable in the EPA approach was a significant omission, since it is clearly related to nutrient over-enrichment, whereas macroinvertebrate species diversity is not as well supported scientifically as a response variable. We feel the approach we used addresses a number of the SAB’s concerns by using multiple lines of reasoning and by including dissolved oxygen response as an important line of evidence. Our approach also addresses potential downstream impacts through its combination of both empirical and risk-based evidence.

We acknowledge that field conditions, including benthic algal biomass, benthic chlorophyll a concentration and algal contribution to oxygen deficit, may vary considerably from modeled values, depending on a number of variables including stream substrate type, streambed profile, vertical stratification, residence time, absolute temperatures and irradiance (transparency). For this reason, field evidence of widely ranging oxygen, pH or excessive algal cover or chlorophyll a concentrations is preferable for confirming impairments to the aquatic life beneficial use. However, modeled outputs also help characterize risk to downstream environments where site level characteristics may be more conducive to algal growth, and thus should be included as part of the overall weight of evidence of impairment. Our use of a relatively high default value for canopy closure ensures that we are likely to be underprotective with our modeled results, making their use as additional lines of reasoning more supportable.

In order to use this approach to develop guideline values for the Integrated Report, we are required to meet several criteria:

- Applicable to the beneficial use
- Protective of the beneficial use
- Linked to the pollutant under consideration
- Scientifically-based and peer reviewed
- Well described, and
- Identifies a range above which impacts occur and below which no or few impacts are predicted.

We believe that our approach meets these criteria. This document has been peer reviewed through the SWAMP document review process, and because our approach represents an innovative use of the California NNE, we also sent a draft of this document to one of the primary authors. He responded as follows:

> *I think the approach you are using is an interesting one. Indeed, it is an approach that is well suited to the nature of the simple screening tool we created. Rather than making quantitative predictions about the status of an individual site, you are using cumulative results across multiple sites to determine an appropriate level of nitrate to protect DO criteria from algal impacts. In essence, you are using the tool predictions to rank the sites relative to their observed DO data - which is likely to be more reliable than predicting specific conditions at individual sites. This becomes one line of evidence supporting a basin plan objective of 1 mg/L NO3-N. I presume you have also done a direct comparison of nitrate concentrations versus DO excursions and found it noisier. In essence, the tool is being used to smooth the relationship and filter out other co-factors that may be controlling response at individual sites. I suspect, however, that stakeholders may ask you to provide some more direct evidence of actual harm associated with nitrate greater than 1 mg/L, so fleshing out other lines of evidence may be important. I think eutrophication effects will likely govern here.*
>
> *- Dr. Jon Butcher, Tetratech Associate Director*

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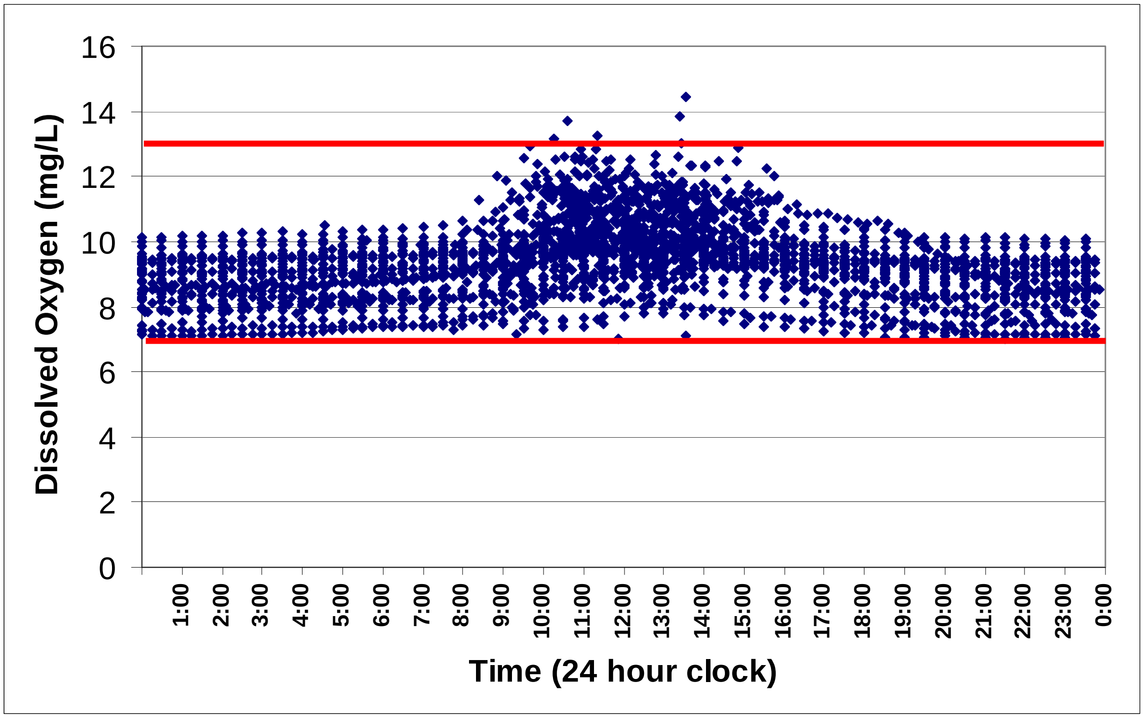

Figure 1. Hourly dissolved oxygen at 32 CCAMP sites that always meet the cold water aquatic life criterion (CCAMP data, 1998 – 2008). Includes 24-hour probe and monthly grab sample data. The cold water dissolved oxygen criterion (7.0 mg/L) and proposed upper screening limit (13.0 mg/L) are shown.

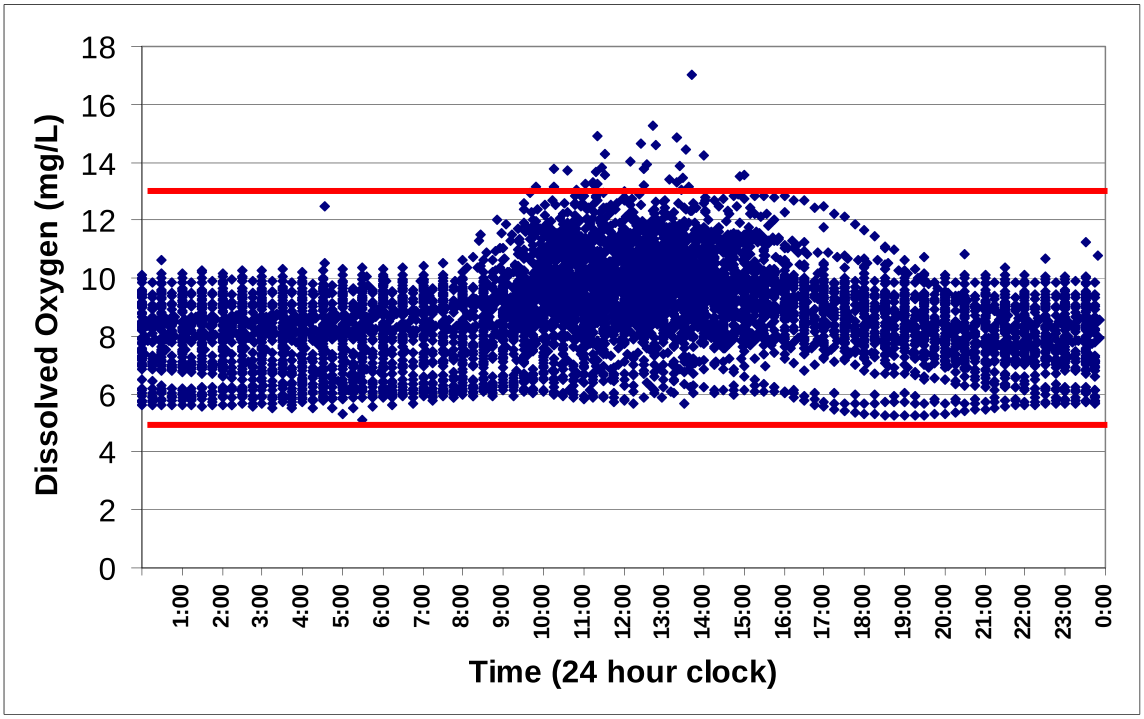

Figure 2. Hourly dissolved oxygen at 59 CCAMP sites that always meet the warm water aquatic life criterion (CCAMP data, 1998 – 2008). Includes 24-hour probe and monthly grab sample data. The warm water dissolved oxygen criterion (5.0 mg/L) and proposed upper screening limit (13.0 mg/L) are shown.

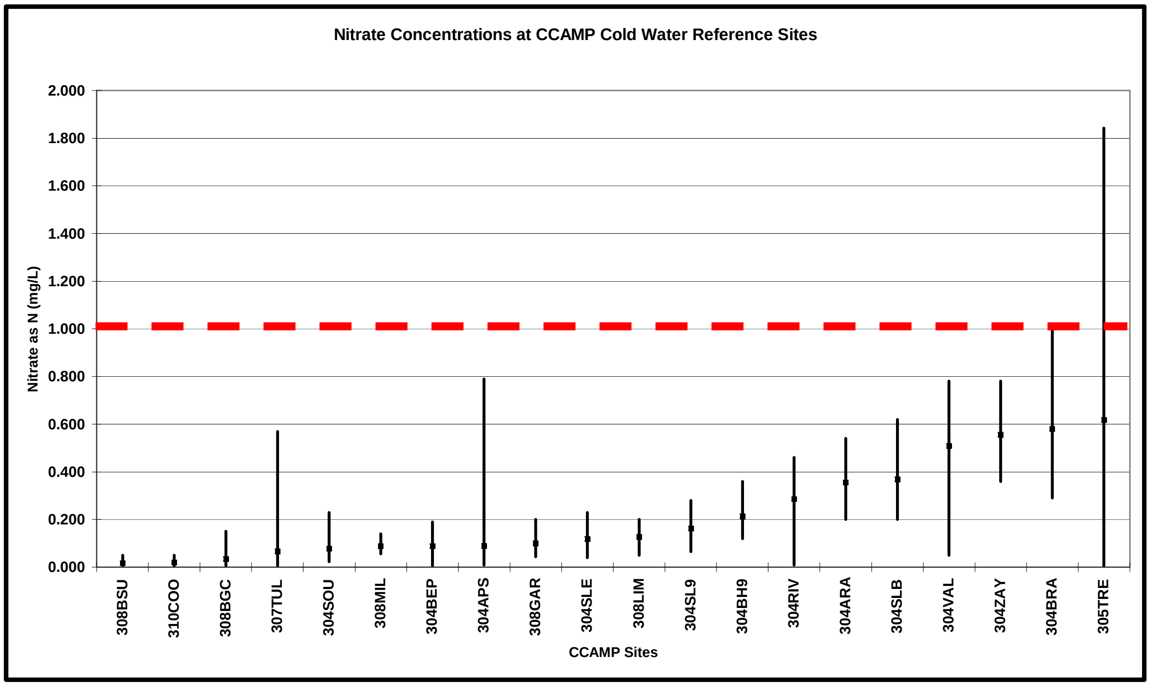

Figure 3. Mean Nitrate concentrations (mg/L-N) at twenty CCAMP sites that do not violate the Cold Water Oxygen Objective (7 mg/L) and do not exceed several screening criteria for indicators of eutrophication. Proposed guideline value of 1.0 mg/L is indicated.

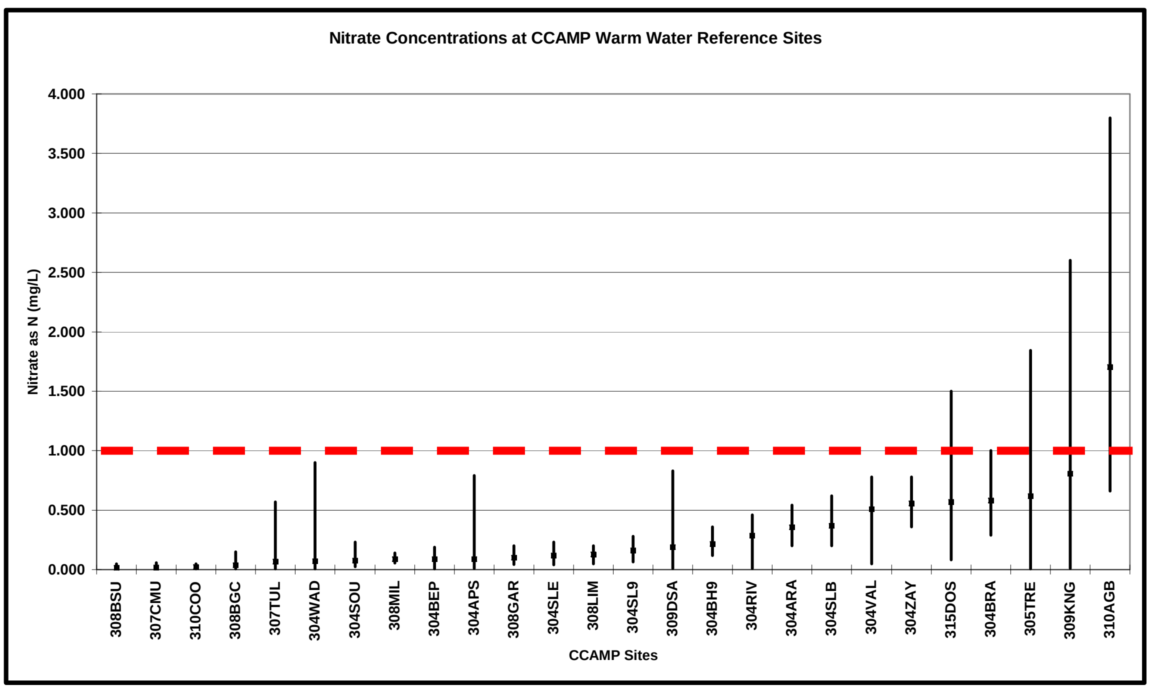

Figure 4. Mean Nitrate concentrations (mg/L-N) at CCAMP sites that do not violate the Warm Water Oxygen Objective (5 mg/L) and do not exceed several screening criteria for indicators of eutrophication. Proposed guideline value of 1.0 mg/L is indicated.

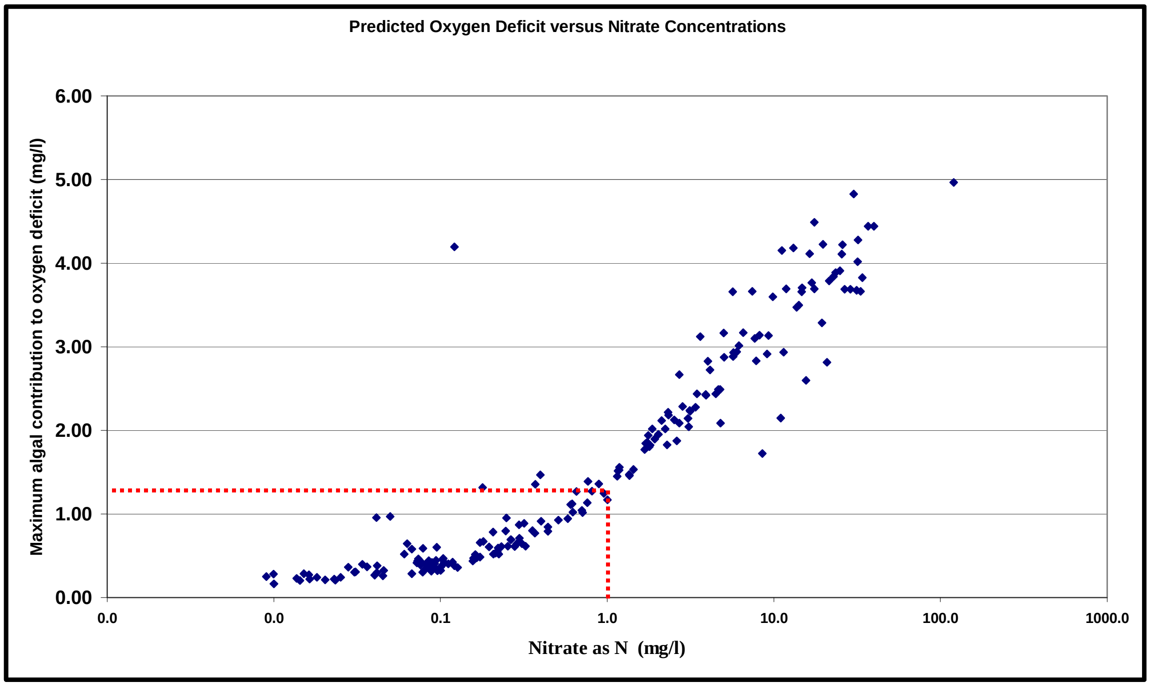

Figure 5. Relationship between average site nitrate concentrations (mg/L-N) and predicted oxygen deficit (mg/L). An average nitrate concentration of 1.0 mg/L-N predicts an estimated maximum algal contribution to oxygen deficit of approximately 1.25 mg/L, based on the California Benthic Biomass Tool (2007).

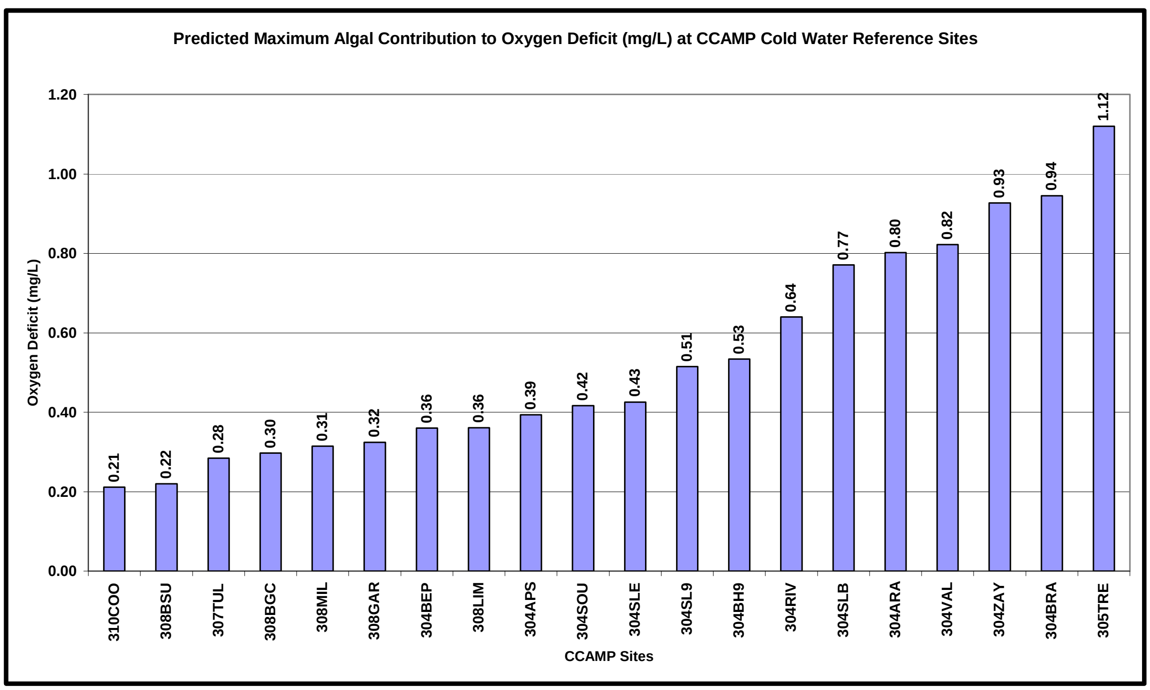

Figure 6. Predicted Maximum Algal Contribution to Oxygen Deficit (mg/L) at CCAMP sites that do not violate the Cold Water Oxygen Objective (7 mg/L) and do not exceed other eutrophication screening criteria. Proposed screening value for oxygen deficit is 1.25 mg/L.

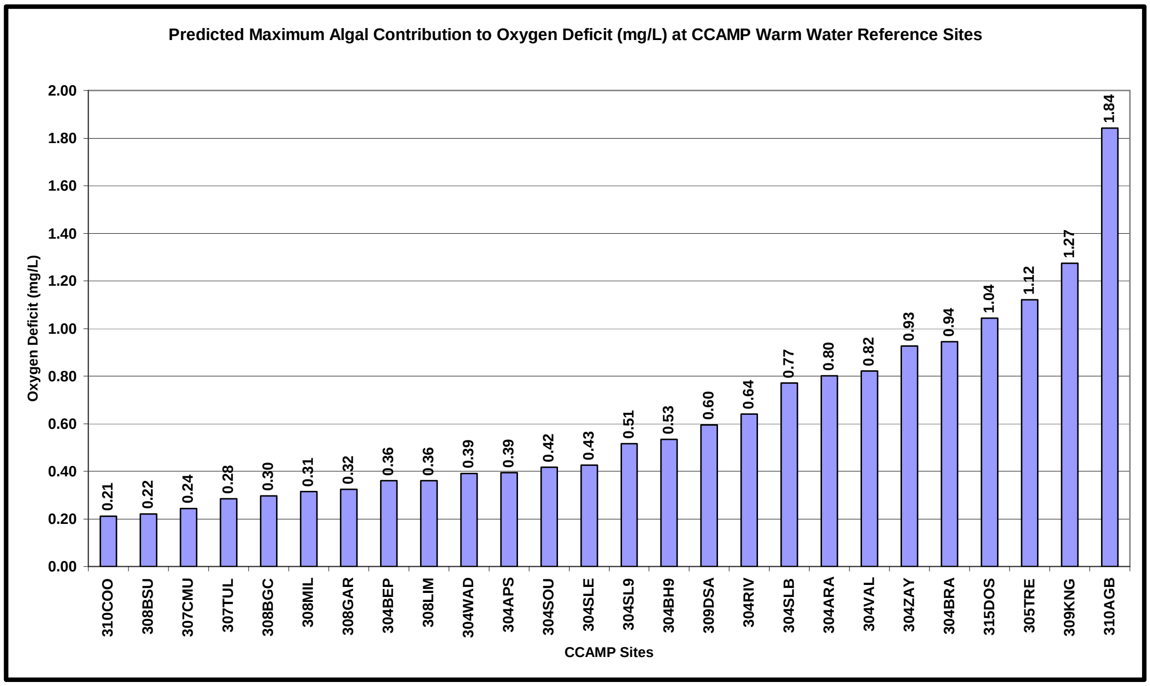

Figure 7. Predicted Maximum Algal Contribution to Oxygen Deficit (mg/L) at CCAMP sites that do not violate the Warm Water Oxygen Objective (5 mg/L) and do not exceed other eutrophication screening criteria. Proposed screening value for oxygen deficit is 1.25 mg/L.

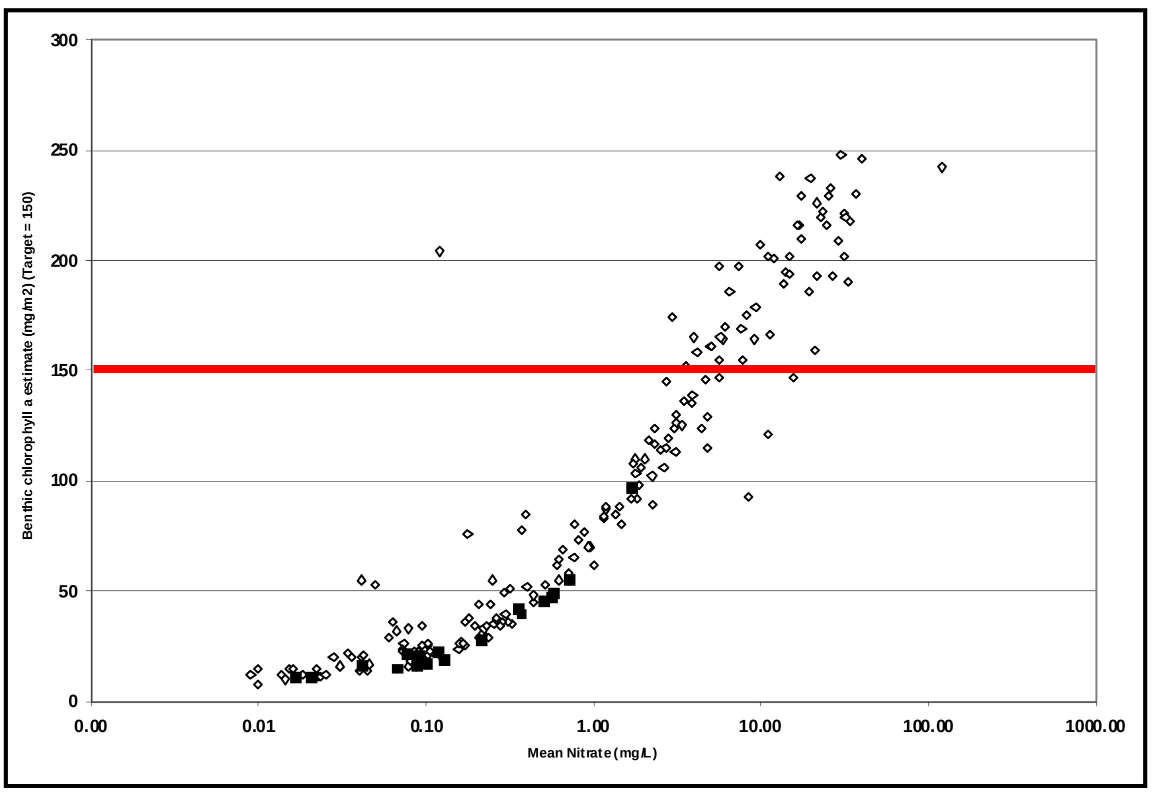

Figure 8. Benthic chlorophyll a predictions (mg/m^2) using the California Benthic Biomass Tool (2007), relative to average nitrate concentrations for 209 CCAMP sites (including cold water reference sites shown as black squares). California NNE recommended threshold for cold water is 150 mg/m^2.