Response to the Peer Review Comments on the Draft Basin Plan Amendment for Nutrients in the Clear Lake Watershed from Dr. Vladimir Novotny, Chair Professor of Environmental and Water Resources Engineering at Northeastern University in Boston, MA

February 2006

Dr. Novotny began his discussion with an overview of his qualifications and experience with TMDLs and water quality. He described existing conditions in Clear Lake and discussed the goals of the nutrient TMDL and the applicability of the water quality models that were used to develop the technical TMDL. Dr. Novotny summarized his comments in a conclusion section. Following are Regional Board staff response to these comments. Dr. Novotny's comments are in plain text. Regional Board responses are in **bold type**.

<u>Comment 1:</u>

The TMDL arbitrarily failed to incorporate the fact that the lake is nitrogen limited and there is very little correlation of blue-green algae concentrations to phosphorus.

Arguments will be made that blue green algae can fix atmospheric nitrogen and the only reasonable alternative is to control phosphorus even when the outcome of the phosphorus controls is highly uncertain. This argument is contradicted by many efforts to control nitrogen limited water bodies by reducing nitrogen loads such as the European nitrate directive or the starting efforts to control anoxia in the Gulf of Mexico. Nitrogen load control has already been partially successful to reduce hypereutrophic (in the 1980s) Lagoon of Venice to a lower eutrophic, approaching mesotrophic status today. The surface area of the lagoon is about 500 km^2.

Nitrogen limitation was discussed and shown in Figures 3-5 and 3-7 of the Technical TMDL report. Figure 3-5 of the report illustrates the range of monthly limitation patterns and makes the point that August is always nitrogen limited. Horne and Goldman (1994) estimated that 30% to 60% of Clear Lake's nitrogen budget is due to N-fixing. The discussion and figure shown below by Horne and Goldman (1994) suggest that when nitrogen in the water column reaches limiting levels, nitrogen fixation begins.

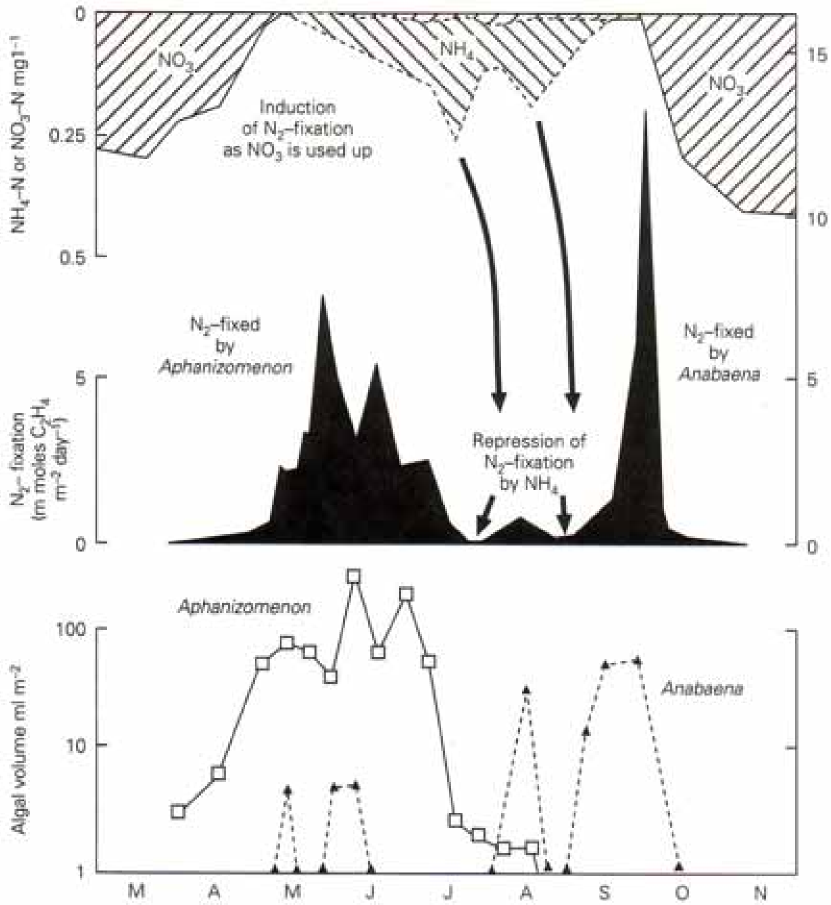


FIGURE 8-6 Seasonal variation in N_2 fixation and associated factors in the Upper Basin of Clear Lake, California. In this polymictic eutrophic lake, the spring bloom of *Aphanizomenon flos-aquae* (bottom panel) initially grew using nitrate (upper left panel) but when this was depleted *Aphanizomenon* was responsible for a long-lasting period of N_2 fixation (middle panel). In summer ammonia released from the anoxic sediments (arrows) repressed N_2 fixation. In autumn sediment ammonia releases declined and a brief but intense spell of N_2 fixation was initiated by a bloom of *Anabaena solitaria* and *Anabaena* sp. The rise in nitrate in autumn terminated the N_2 fixation. Modified from Horne and Goldman (1972).

The focus of this TMDL is on phosphorus reductions because previous studies (Horne, 1975 and Richerson, et.al, 1994) and the Technical TMDL concluded that controlling phosphorus would ultimately reduce nuisance blooms of blue-green algae in Clear Lake. However, staff agrees that the role of nitrogen, and other nutrients, are not fully understood and need further study. For this reason the TMDL requires that continued studies be completed, including studies on nitrogen and iron cycling in the lake. Regional Board staff will review the results of the studies and modify the implementation program as appropriate. Staff also notes that some of the implementation actions undertaken as part of this TMDL will address nitrogen and iron loading as well as phosphorus.

<u>Comment 2:</u>

The resiliency of the hypereutrophic status will require more drastic reduction of nutrient loads and other measures to bring about an improvement of the hypereutrophic status.

Trophic state change was not specifically set as the target for this TMDL. Beneficial uses are currently impaired because of the occurrence of nuisance algae blooms. Therefore, the goal of this TMDL is to eliminate or greatly reduce the occurrence of nuisance algae blooms in the lake. The 73 µg/L chlorophyll-a target and associated load reductions were developed to achieve this condition. In model sensitivity runs, larger reductions in phosphorus loading resulted in lower chlorophyll-a concentrations. However, the TMDL target of 73 µg/L was achieved with the reductions identified in the TMDL report. This number will be verified as the TMDL is implemented. If monitoring and continuing studies do not show significant recuctions in the frequency of nuisance blooms, additional management actions will be considered.

<u>Comment 3:</u>

Lake restoration is a comprehensive effort and focusing on one non limiting nutrient will not be successful. Not addressing nitrogen limitations and presenting alternatives that would consider nitrogen as a controlling parameter is puzzling. The fundamental rule of any lake management is focusing on the limiting nutrient first. Ideally, both nutrients should have been considered.

Ideally, reduction of both nitrogen and phosphorus loads may be required. Nitrogen loads can be reduced by controlling nitrogen in effluents, e.g., by converting the treatment plants to denitrifying and phosphorus reducing Bardenpho treatment plans and, more efficiently, by restoring and recreating riparian wetlands that provide an efficient buffer along the headwater streams. The lake itself by simultaneous nitrification/denitrification can remove more than 1/3 of the internal load provided that anoxia in the lower zones of the lake is avoided, which may require engineering measures. Keeping the bottom layer oxic will also reduce the internal phosphorus load.

Although N is not specifically addressed in meeting the TMDL target, some of the methods of reducing N that the reviewer mentions are addressed in either current policy or the TMDL implementation section of the Staff Report. The treatment plants around Clear Lake have re-diverted discharge to geothermal treatment, and wetland restoration is one of the implementation options for nutrient reduction in the TMDL. These controls, although effective in reducing phosphorus loading, are also effective in reducing nitrogen loading to the lake. Therefore, current and proposed implementation strategies should address some of the N sources.

<u>Comment 4:</u>

Biological methods of fish management have also been found successful in the overall restoration efforts.

The potential effectiveness of fish management, or biomanipulation, was investigated and the findings published in chapter 9 of Richerson et. al. (1994). It was estimated that biomanipulation would not be effective based on a number of factors. Tilapia, a tropical filter-feeder that consumes blue-green algae, was the primary candidate for biomanipulation and is thought to interfere with game fish populations. Tilapia may also not survive Clear Lake's winters, requiring the implementation of a costly fish-restocking program. The report concludes that no known biomanipulation strategy exists to resolve the blue-green algae problem in Clear Lake.

In the 1970s, silversides were introduced into Clear Lake in an unsuccessful attempt to control blue-green algae.

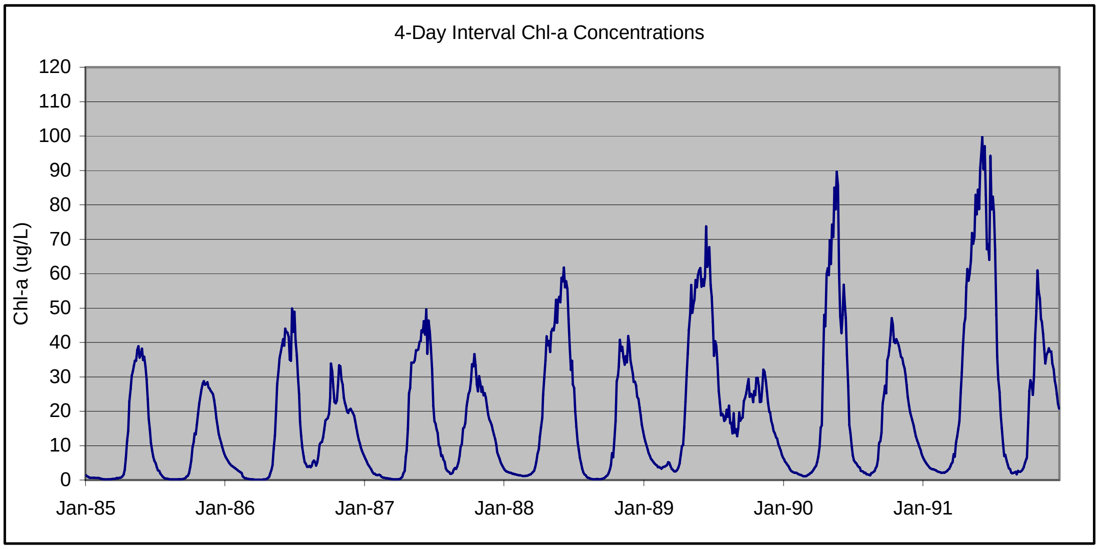
<u>Comment 5:</u>

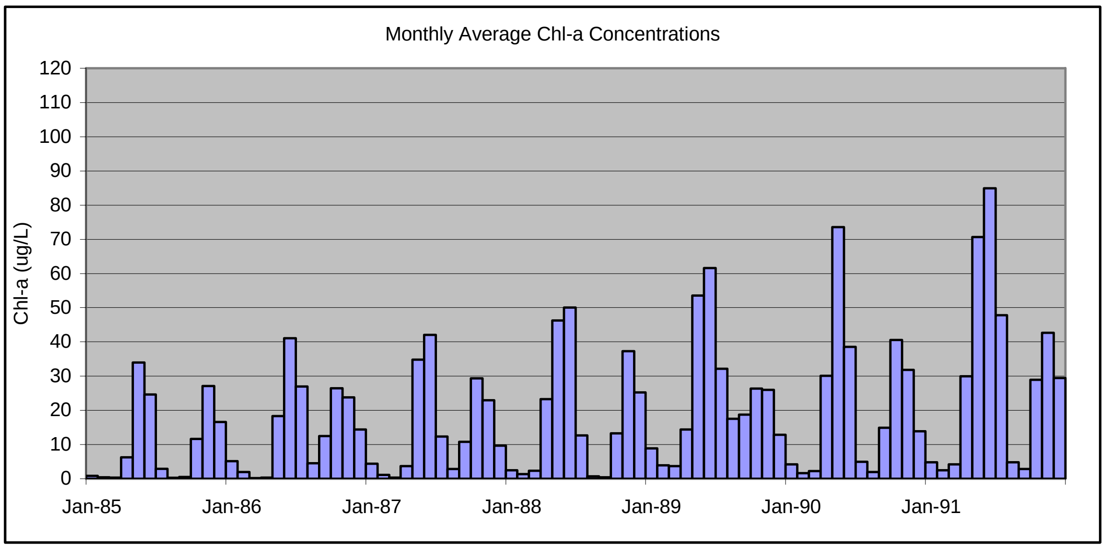
The stated goal of eutrophic to hypereutrophic goal of 73 μg/l of chlorophyll is a dubious goal. Even if the lake responds proportionally (I have serious doubts about the proportionality scenario) to the reduction of the phosphorus inputs and the borderline hypereutrophic status is achieved, the lake will hardly support the designated uses. There is too much variability involved. The selected "compliance" period had average Secchi Disc depths about 1 to 1.5 meters that are not conducive for swimming and hardly could support good quality fish. The water quality may not be suitable for water supply and the toxins produced by the blue green algae may be dangerous to human health when ingested during swimming.

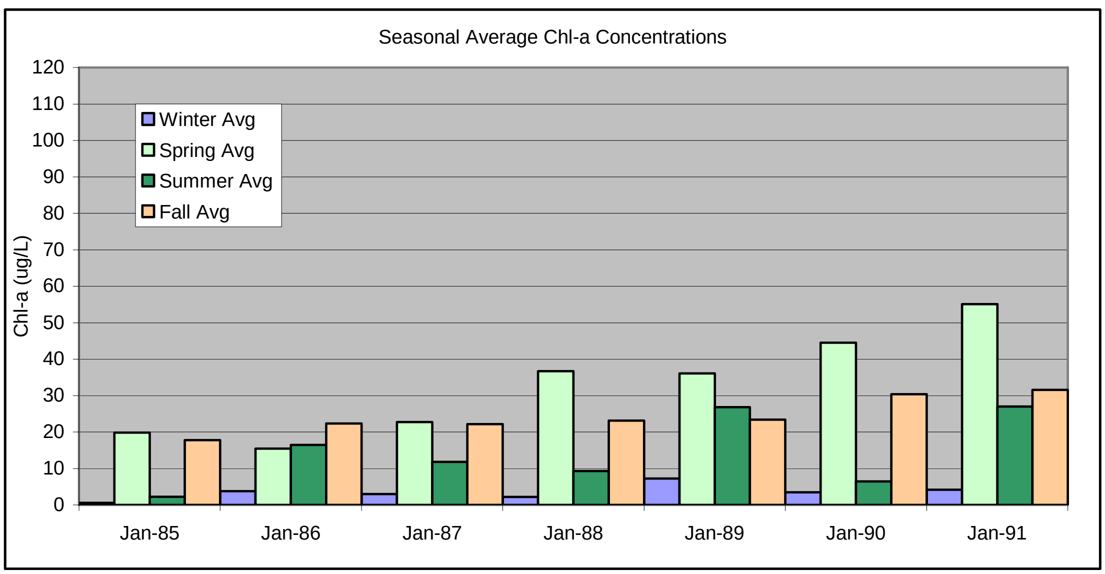
The existing water quality standard for nutrients is narrative, and the numeric chlorophyll-a target was selected based on a site-specific, acceptable condition for Clear Lake, which occurred during the "compliance period". The listing for Clear Lake was based on the narrative description that a significant bloom had occurred in 1991. The target of 73 μg/L represents a maximum instantaneous concentration that interprets the narrative criteria, based on conditions in the lake that are deemed acceptable. The trophic status referred to in this item and in the "Target

(Goals)" section of the review is based on general chlorophyll thresholds used to develop a trophic state index (TSI) for water bodies, and refers to an average condition for a given water body. Water quality in Clear Lake is extremely variable, as evidenced by the blooms of the mid 1970's, early 1990's, and the early 2000's, and by the relatively acceptable interim periods and short-lived improvements in clarity in the late 1990's. Therefore, an averaging of modeled chlorophyll may be more suitable for comparison with general trophic threshold values.

The modeling approach allowed us to investigate multi-year (i.e. droughts of the mid 1970's and 1980's) and seasonal trends and ultimately at a variety of temporal scales. The following figures interpret modeled chlorophyll-a data based on 4-day interval, monthly average, and seasonal average time scales, respectively. The 4-day interval time scale was the resolution used to identify the instantaneous target of 73 µg/L chlorophyll-a, occurring on June 16th, 1989. The second figure plots the monthly average chlorophyll-a concentrations for the same time period (1985-1991).


4-Day Interval Chl-a Concentrations
Chl-a (ug/L)
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91


Monthly Average Chl-a Concentrations
Chl-a (ug/L)
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91


Seasonal Average Chl-a Concentrations
Chl-a (ug/L)
Winter Avg
Spring Avg
Summer Avg
Fall Avg
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91

The average chlorophyll-a concentration for June of 1989, or the month used to obtain the instantaneous target, was approximately 62 µg/L. This lower value is due to the averaging effect that serves to smooth peak values. Similarly, the third figure shows seasonal averages (Winter, Spring, Summer, and Fall) for the 1985-1991 time period. The average Spring (3/21-6/20) 1989 value for chlorophyll-a is approximately 36 µg/L. The average chlorophyll-a concentration for the 1985-1991 periods, including non-acceptable years, is 19 µg/L. If we were to use the average chlorophyll-a value the lake would be classified as borderline eutrophic based on Table 1 above. The modeling approach used allowed us to investigate the variable nature of Clear Lake's water quality which ultimately led to a target that reflects the unique conditions of Clear Lake itself.

As described in Section 3.2 of the Staff Report, Clear Lake is naturally eutrophic. Historical evidence suggests that blue-green algae blooms occurred in Clear Lake even before the beginning of severe anthropogenic impacts in the early 20th century. Historical accounts also indicate that the current state of Clear Lake (characterized by nuisance blue-green algae blooms) has worsened due to human activities. The acceptable condition that we are trying to achieve for this TMDL is to eliminate or greatly reduce the occurrence of nuisance blue-green algae blooms in the lake. The 73 µg/L target is based on the best information that we have to date to describe the desired condition in the lake. Staff recognizes that there is still some uncertainty surrounding the target and the load allocations, so this TMDL is being implemented in a phased approach. As nutrient control actions are implemented Regional Board staff will evaluate conditions in the lake and update management actions as necessary until compliance is achieved.

<u>Comment 6:</u>

A Use Attainability Analysis should have preceded the TMDL.

Staff does not believe that a Use Attainability Analysis (UAA) is necessary in this case. Clear Lake may be naturally nutrient rich (eutrophic) but we believe that beneficial uses can be fully achieved following the load reductions required in this TMDL. The beneficial uses of Clear Lake are currently impaired due to nuisance blooms of blue-green algae. We expect that once the phosphorus load reductions required under this TMDL are achieved the nuisance algae blooms will be eliminated or greatly reduced. The lake may still be eutrophic, but lack of nuisance algae blooms will result in attainment of the beneficial uses. As part of the TMDL implementation plan, responsible parties are required to periodically assess the impacts of their load reduction efforts on Clear Lake's water quality. If the loading reductions do not result in full achievement of beneficial uses staff will review the TMDL requirements and modify them as appropriate.

<u>Comment 7:</u>

The TMDL planner and the state and local agencies implementing the plan must realize the fact that more reductions and actions will be required than that estimated by linear models. The uncertainties with trying to solve the problem with reducing phosphorus loads only are so large that the end results are in doubt, especially when considering the adopted relatively small margin of safety (8%).

EFDC's representation of relationship between nutrients and biomass, which was specifically coded for the Clear Lake model, is not linear. Neither LSPC nor EFDC represented a linear relationship between nutrients and diatom, green, or blue-green algal productivity. The relationships were specifically designed to address this nonlinear relationship. In EFDC, and other eutrophication models such as WASP/EUTRO, and ICM, the relationship between algae and nutrients are characterized as a non-linear Monod-type equation, which does not represent proportionality between nutrient and algae growth for the whole range of nutrient and algae concentrations[1]. Proportionality only becomes prominent when nutrient concentration is low, which is corresponding to the linear portion of the nutrient-algae curve. When nutrient concentrations become higher, the algae response to nutrients flattens out and then proportionality become negligible.

The explicit margin of safety (MOS) referred to is not 8%, but 8 µg/L. This would equate to 10% of the 73 µg/L target. A 10% explicit margin of safety is in the high range for TMDLs that have been developed to date. In addition to an elevated margin of safety, implicit components were also applied to the TMDL MOS, such as the implied reduction of nitrogen loading as a result of reduced phosphorus loading.

1. **The Monod equation relates limiting nutrient concentration to a population's growth rate.**

References:

Horne, A. J. and Goldman, C. R. 1972. Nitrogen fixation in Clear Lake, California. 1. Seasonal variation and the role of heterocysts. Limnol. Oceanogr. 17: 678-692.

Horne, A.J. 1975 The Ecology of Clear Lake Phytoplankton. Lakeport: Clear Lake Algal Research Unit. 116pp.

Horne, Alexander and Charles Goldman, 1994. Limnology: 2nd Edition. McGraw-Hill, Inc., New York.

Richerson, Peter J. et. al. 1994. The Causes and Control of Algal Blooms in Clear Lake, Clean Lakes Diagnostic/Feasibility Study for Clear Lake, California. Report prepared for Lake County Flood Control and Water Conservation District, California State Water Resources Control Board, and the US Environmental Protection Agency.