Received via e-mail HAS 4/20/13

CITY OF LAKE ELSINORE
DREAM EXTREME

April 20, 2013

Hope Smythe, Chief, Inland Basin Planning
Santa Ana Regional Water Quality Control Board
3737 Main Street, Suite-500
Riverside, CA 92501

RE: Comments on Final CNRP for the Lake Elsinore/Canyon Lake Nutrient TMDL

Dear Ms. Smythe:

Thank you for this opportunity to comment on the Comprehensive Nutrient Reduction Plan (CNRP) for Lake Elsinore submitted by the MS4 Permittees. Overall, the CNRP is very good and the City concurs with most of the CNRP. However, the City is underwhelmed by the slow and piecemeal approach proposed for In-Lake remediation, which consists primarily of support for the existing aeration system. This piecemeal approach is destined to fail, without stabilizing the lake elevation and implementing the Fisheries Management Plan. The City believes the science supports the "In-Lake Sediment Nutrient Reduction Plan (2007)" by the TMDL Task Force that uses a whole-lake approach to improving the aquatic ecosystem and is the right adaptive management strategy to restore the beneficial uses of Lake Elsinore.

EXECUTIVE SUMMARY

Lake Elsinore is the largest natural freshwater lake in southern California. Recent model simulations of the pre-development conditions of the watershed predict water quality conditions in Lake Elsinore below the Regional Board's established TMDL numeric targets for phosphorus and algae (chlorophyll-a), indicating these numeric targets are achievable.

Most natural lakes are a product of their watersheds. Predicted conditions in Lake Elsinore prior to development in the watershed would be much better (mesotrophic to weakly eutrophic), as opposed to present conditions (eutrophic-hypereutrophic). Phosphorus, being a conservative element, repeatedly recycles from the sediment to the water column and back. External loading of phosphorus from the Watershed can substantially increase internal loading of phosphorus in the Lake. It is estimated that external phosphorus received from the watershed has a half-life of 15 years and persist in the Lake for 30 years before being sequestered.

The cost of conventional watershed nutrient BMPs throughout the entire Lake Elsinore/San Jacinto River Watershed to the degree required to meet federal/state water quality targets for Lake Elsinore may be cost prohibitive. For example, the CNRP

951.674.3124
130 S. MAIN STREET
LAKE ELSINORE, CA 92530
WWW.LAKE-ELSINORE.ORG

estimates a "total cost for Lake Elsinore and Canyon Lake watersheds could range from $500 million to $2 billion if watershed BMPs were solely deployed" (Pg 3-21).

Alternatively, a combination of limiting nutrients in the watershed to the maximum extent practicable, lake aeration, lake-level stabilization and fisheries management may be the most rapid and low cost approach to achieve the water quality targets. The TMDL Task Force, which consists of all major stakeholders in the Lake Elsinore/San Jacinto River Watershed, embraced this low cost alternative by submitting the "In-Lake Sediment Nutrient Reduction Plan for Lake Elsinore" to the RWQCB in October 2007. This Plan promotes an ecological and whole-lake approach to restore the beneficial uses.

In November 2007 the Santa Ana Regional Water Quality Control Board adopted Resolution No. R8-2007-0083 approving the Plans and Schedules submitted by the Canyon Lake/Lake Elsinore TMDL Task Force pursuant to the Lake Elsinore TMDLs specified in the Water Quality Control Plan. The Board's approval included the "In-Lake Sediment Nutrient Reduction Plan for Lake Elsinore". Below is an excerpt from the TMDL Task Force Plan showing the Implementation Schedule includes a three pronged adaptive management strategy of stabilize lake levels, install aerators and initiate fishery management.

6.0 Implementation Schedule

The In-Lake Sediment Nutrient Reduction Plan for Lake Elsinore is divided into two phases. Phase 1. to stabilize lake levels. install aerators and initiate a fishery management strategy. is well underway. If. as expected. Phase 1 is successful. then there is no need to develop Phase 2 implementation strategies. There will. however. be a need to ensure that the previous projects continue to operate effectively.

Given the Regional Board has previously approved the implementation of three in-lake remediation measures, why now would the Board accept less from the MS4 Permittees? This would be backsliding at a time that Lake Elsinore needs to move forward.

WARM FRESHWATER AQUATIC HABITAT

The prime directives of the Federal Clean Water Act are to provide waters that are "fishable & swimmable". One of Lake Elsinore's beneficial uses is a warm freshwater aquatic habitat (WARM). Excess nutrients can substantially change the structure of a fishery and degrade this beneficial use. Implementation of substantial improvements are needed to re-structure a degraded fishery. In 2005, the Lake Elsinore/San Jacinto Watersheds Authority (LESJWA) prepared a Fisheries Management Plan. This voluminous document details the measures required to restore the fishery. In contrast, the CNRP is woefully lacking implementation measures to restore this important beneficial use.

Traditionally, excess nutrients have been determined to be the sole causal variable(s) that result in a biostimulatory response to produce nuisance algae blooms. This simplistic view that chemicals solely determine the biological response overlooks the complex interaction of the aquatic food web in regulating algae biomass through predator-prey interactions. The structure of a fishery can have a substantial impact on water quality. Limnologist recognize there are two types of stable states for nutrient enriched shallow lakes, like Lake Elsinore, that result in very different environmental outcomes. One stable state is like the current condition of Lake Elsinore, in which the vegetative community is dominated by single-celled planktonic algae (like blue-green algae) and the fishery is dominated by planktivores (bait fish like, Threadfin Shad minnows and rough fish, like Carp). This stable state is characterized by turbid water, low dissolved oxygen, fish kills (especially sport fish) and swamp type odors.

In contrast, the more desirable second type of stable state for the same nutrient enriched lake is one dominated by true aquatic plants and piscivores (sport fish). This stable state is characterized by clear water, abundant zooplankton and a high number of sport fish. The key to this stable state's desirable outcome is the high density of large bodied zooplankton that filter feed on algae, as well as the beneficial shelter and sequestering of nutrients by aquatic plants.

INTERNAL NUTRIENT LOAD & LAKE STABILIZATION

In the SARWQCB LE/CL Nutrient TMDL Technical Report (June-2004), the internal phosphorus loading in Lake Elsinore was considered static and pegged to the water year 2000-2001. Below is an excerpt (Pg. 36) from this Technical Report.

> It is important to note that the internal nutrient loading to Lake Elsinore and Canyon Lake was determined for the specified study period. i.e.. water year 2000-2001 for Lake Elsinore and water year 2001-2002 for Canyon Lake. This period represents a dry hydrological time period when there was limited contribution of nutrients from the watershed (external sources) and no outflow from either lake. No data are available to determine the internal nutrient loading under other hydrologic conditions. It is possible that the internal loading would increase after heavy rainfall when the San Jacinto River carries nutrient rich water to the lakes. Further study and modeling is required to estimate the long-term internal loading to Lake Elsinore and Canyon Lake under various hydrologic regimes. However. for the development of this TMDL. the best available data are used with the recognition that additional studies are needed.

The state of the current knowledge on Lake Elsinore shows the total phosphorus concentration and internal phosphorus load in Lake Elsinore are dynamic and increase with external nutrient input and low water volume, as shown in Fig. 11 and Table 4. on the next page.

The Lake elevation was higher than 1,240' above Mean Sea Level during the water study year 2000-2001, which formed the basis for Lake Elsinore's assumed "static" internal load under the SARWQCB LE/CL Nutrient TMDL Technical Report (June-2004).

However, as shown below, the TP concentration increased 2.5-times and the internal loading increased by a factor of 4-times when the Lake elevation dropped from 1,240' aMSL in 2001 to 1,234'aMSL in 2004. The CNRP's proposal to operate the aeration system alone will not offset the increase to the internal loading under high or a low lake elevation. Fisheries Management and Lake Stabilization are also needed.

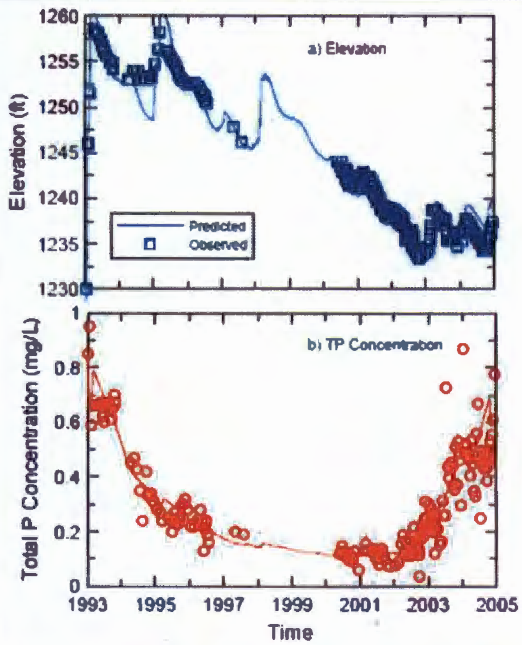

Fig. 11. Predicted and observed: a) lake surface elevation and b) TP concentration.

Table 4. Predicted annual loading (kg) of P to Lake Elsinore for the period 1993-2004.

Year	Total Loading (kg)	External Loading (kg)	Internal Loading (kg)	Wind (kg)	Bioturbation (kg)
1993	588,839	99,487 (16.9%)	484,411 (82.3%)	179 (<0.1%)	4,762 (0.8%)
1994	274,162	2,948 (1.1%)	266,644 (97.3%)	193 (0.1%)	4,377 (1.6%)
1995	244,019	22,257 (9.1%)	216,724 (88.8%)	110 (<0.1%)	4,928 (2.0%)
1996	137,965	2,455 (1.8%)	131,093 (95.0%)	226 (0.2%)	4,191 (3.0%)
1997	96,744	3,816 (3.9%)	88,885 (91.9%)	317 (0.3%)	3,726 (3.9%)
1998	108,252	9,107 (8.4%)	94,679 (87.5%)	215 (0.2%)	4,250 (3.9%)
1999	74,356	1,207 (1.6%)	69,143 (93.0%)	325 (0.4%)	3,681 (5.0%)
2000	56,535	1,191 (2.1%)	51,840 (91.7%)	521 (0.9%)	2,984 (5.3%)
2001	52,696	2,330 (4.4%)	47,070 (89.3%)	727 (1.4%)	2,569 (4.9%)
2002	53,699	4,339 (8.1%)	46,349 (86.3%)	1,142 (2.1%)	1,869 (3.5%)
2003	130,359	8,593 (6.6%)	119,105 (91.4%)	909 (0.7%)	1,751 (1.3%)
2004	212,278	9,897 (4.7%)	199,753 (94.1%)	814 (0.4%)	1,814 (0.9%)

Federal, State, Regional and Local agencies came together in the 1990s to construct improvements and add recycled water to Lake Elsinore to normalize the peaks & valleys of lake elevations. This group included the U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, State Parks Department, California Dept of Fish & Game, Riverside County Flood Control & Water Conservation District, SAWPA, EVMWD and the City of Lake Elsinore.

The importance of stabilizing the lake elevation for flood control, recreation and economic development cannot be overstated. Recent scientific evaluation also shows that water quantity & quality can go hand in hand on Lake Elsinore. Recycled water was an existing discharge before the TMDL was promulgated. From the data below and associated report, the annual addition of 5,660 acre-feet of recycled water results in a lower TP concentration than the "No flow" scenario.

Table 2. Predicted median water quality and phosphorus loading assuming 0 af yr^{-1} (reference) and 5660 af yr^{-1} EVMWD recycled water input with TP 0.2-0.5 mg L^{-1}, geometric mean San Jacinto River flow to Lake Elsinore (558 af yr^{-1}) at 0.22 mg L^{-1} total P, and 75% reduction in carp population (226 carp ha^{-1}).

Scenario	Water Quality Variables			Phosphorus Loading (mg m^{-2} d^{-1})				
Influent P Conc	TP (mg L^{-1})	Chl a (ug L^{-1})	Z_{sd} (m)	External	Internal	Wind	Carp	Total
No flow	0.812	1201	0.05	0.7	67.7	11.0	0.7	80.1
0.5 mg L^{-1}	0.189	145	0.33	1.2	16.0	1.0	0.7	18.9
0.4 mg L^{-1}	0.181	137	0.35	1.1	15.3	1.0	0.7	18.1
0.3 mg L^{-1}	0.165	119	0.38	0.9	14.0	1.0	0.7	16.6
0.2 mg L^{-1}	0.152	107	0.41	0.7	12.9	1.0	0.7	15.3

The City agrees with the CNRP that conventional nutrient control measures in the watershed alone are costly to implement and maintain. In-Lake remediation to reduce the internal nutrient loading, coupled with ecological improvements to reduce algae, are more cost-effective. However, the scientific uncertainty of this alternative approach requires a robust implementation plan that should include lake stabilization, aeration and fisheries management.

Sincerely,

Pat Kilroy, Director
Lake, Parks & Recreation Department

Cc. Grant Yates, City Manager
John Vega, EVMWD General Manager
Jason Uhley, RCFC&WCD

REFERENCES

Anderson, M.A. 2006. *Predicted Effects of Restoration Efforts on Water Quality in Lake Elsinore: Model Development and Results.* Final Report. LESJWA. 33 pp.

Anderson, M.A. 2012. Draft Technical Memorandum TMDL Task Force Task 4b: *Evaluate Water Quality in Lake Elsinore Under Pre-Development Conditions.*

Anderson, M.A. 2011. Draft Technical Memorandum TMDL TF Task 1: Estimate Rate at Which Phosphorus is Rendered No Longer Bioavailable in Sediments.

Anderson, M.A. 2011. Draft Technical Memorandum TMDL TF Task 5a: *Simulations Using Refined Model Parameters Set Under Steady-State Conditions.*

SARWQCB r.May 2004. *Lake Elsinore and Canyon Lake Nutrient Total Maximum Daily Loads.*

TMDL Task Force 2007. *In-Lake Sediment Nutrient Reduction Plan for Lake Elsinore*

Technical Memorandum

Task 5a: Simulations Using Refined Model Parameter Set Under Steady-State Conditions

Objective

The objective of this task was to evaluate the predicted steady-state concentrations of total P and chlorophyll a in Lake Elsinore using recently available phosphorus concentrations in EVMWD effluent and carp population estimates. This thus serves as a refinement of previous model predictions made based upon information available at that time (2004-05), and prior to alum treatment for P removal at EVMWD and regular carp removal at the lake (Anderson 2006).

Approach

Model calculations were conducted following the approach used in Anderson (2006) that evaluated the effectiveness of different lake management strategies. As in that study, a steady-state condition was calculated since this eliminates the complex response that results from widely varying hydrologic conditions and allows one to compare in a direct way water quality in the lake.

A numerical solution was developed for the steady-state equation:

$$C = \frac{\dfrac{H(\sum_i Q_i C_i + PRA_w C_w)}{V} + iOC + fP_f M_f B + w_r A_r B}{v} \qquad (1)$$

where

- C is the predicted steady-state concentration of total P (TP) in water column (mg m^{-3});
- H is the mean depth of the lake (m),
- Qi is the flow from source I (m^3 d^{-1}),
- Ci is the concentration of total P in source I (mg m^{-3}),
- P is the precipitation rate (m);
- R is the runoff coefficient (m m^{-1});
- Aw is the local watershed area (m^2),
- Cw is the concentration of P in the local runoff (mg m^{-3});
- V is the volume of the lake (m^3);
- I is the slope of the internal loading function (mg m^{-2} d^{-1} per mg m^{-3});
- O is a scalar to account for aeration effects;
- f is the normalized sediment resuspension flux rate due to carp (g m^{-2} d^{-1} per kg carp ha^{-1})
- P is the carp population (carp ha^{-1})
- M is the average mass of a carp (kg $carp^{-1}$)
- B is the bioavialable P fraction of resuspended sediment (mg g^{-1})
- Wr is the sediment resuspension rate (g m^{-2} d^{-1})
- Ar is the fraction of type II or II sediments resuspended by wind
- v is the total P settling velocity (m d^{-1})

For these calculations, the geometric mean flow at the USGS gaging station at Lake Elsinore was assumed (556 af yr^{-1}), along with the arithmetic mean rainfall for the region (0.25 m yr^{-1}) and average evaporation rate (1.43 m yr^{-1}). While annual evaporation rate is fairly consistent each year, rainfall and runoff is recognized to vary widely from year to year. The influence of the complex hydrology will be considered in subsequent tasks. Against this normalized average hydrologic condition at the lake that will serve as our reference, the average recycled water production from EVMWD for the past 3 yrs (5660 af yr^{-1}) will be added to the lake. Four different effluent P concentrations were evaluated, including the nominal concentration in the recycled water (0.5 mg L^{-1}), as well as 0.4, 0.3 and 0.2 mg L^{-1} assuming increased removal at the treatment plan. For these simulations, we also assumed a 75% reduction in carp population density from 2003 levels as a result of the City's highly successful carp removal program at the lake, and allowed for decreased release of P from bottom sediments via aeration.

Results

Reference (no EVMWD flow)

Assuming the geometric mean annual San Jacinto River flow to Lake Elsinore of 558 af yr^{-1} persisted for a sufficient number of years for an approximate steady-state condition to be established, we see that a very low water level would be present in the lake (Table 1). The lake is predicted to have a surface area of only 1190 acres, surface elevation of 1222.7 ft above MSL, and mean depth <1 m (Table 1). Delivery of the average annual volume of recycled water produced at the EVMWD plant (5660 af yr^{-1}) to the lake resulted in a much larger body of water with over 2x the area, 4x the mean depth and almost 10x the volume (Table 1).

Table 1. Hydrologic submodel results.

Scenario	Area (acres)	Elevation (ft)	Volume (af)	Mean Depth (m)
No EVMWD Flow	1190	1222.7	3752	0.96
5660 af Flow	2652	1238.1	33,224	3.80

These dramatically different lake levels yielded very different water qualities as well (Table 2). With only average precipitation and runoff to the lake for at least 6 years (assuming an initial lake level of 1240'), the model predicts a total P concentration of over 0.8 mg L^{-1}, chlorophyll a concentration over 1200 μg L^{-1} and negligible transparency (Table 2). Rapid internal recycling of nutrients from the bottom sediments is expected, with significant contributions due also to wind resuspension at this very low lake level. External loading is minimal due to low flows from the San Jacinto River modest local runoff, while carp removal was assumed to keep levels below their potential densities and thus also contribute only minimally to the overall P loading to the water column (Table 2). The extreme conditions predicted at this lake level lay far outside of the conditions used to develop and calibrate the model, however, so one should not over-interpret these values. For example, the model does not explicitly consider the necessarily very high salinity level and corresponding ecological changes at the lake that would be present.

The steady-state and differential forms of the model has been shown to do a quite reasonable job of reproducing water quality at higher lake levels, however (Anderson, 2006). The model was used to predict the steady-state conditions at the lake assuming (i) the full recycled water production at the EVMWD plant was used to supplement natural flows, and (ii) continued carp removal to maintain a population density of about 226 carp ha^{-1} (or 91 carp $acre^{-1}$) was assumed for all scenarios. With these supplemental flows at the average total P concentration of 0.5 mg L^{-1}, not only is the lake level up markedly relative to the no-supplementation (reference) condition (Table 1), but water quality is improved as well (Table 2). Average total P concentration was predicted to decline from >0.8 mg L^{-1} to 0.189 mg L^{-1}, chlorophyll a concentration to decrease from >1200 μg L^{-1} to 145 μg L^{-1}, and Secchi depth to increase from 0.05 to 0.33 m (Table 2). Total P loading to the water column was predicted to decline from >80 mg m^{-2} d^{-1} to 18.9 mg m^{-2} d^{-1}.

Further reductions in the total P concentration in the recycled water delivered to the lake resulted in correspondingly lower total P and chlorophyll a concentrations there, although the effect was damped due to the comparable levels of loading resulting from wind resuspension, bioturbation by carp, and other external inputs (Table 2). Higher lake levels and additional removal of carp would be needed to achieve greater benefit from reduced P concentrations in the recycled water. This can be seen in Fig. 1, where the steady-state total P concentration in the lake is shown for a range of recycled water P concentrations and carp population densities. Even with no P in the recycled water and removal of all carp, the lake is predicted to have a TP concentration of about 85 mg m^{-3} (or 0.085 mg L^{-1}) due to remaining external loading from the San Jacinto River and local watershed, and due to wind resuspension (Table 2). Increasing recycled water P and/or the carp population resulted in increased predicted lake TP concentrations (Fig. 1).

Table 2. Predicted median water quality and phosphorus loading assuming 0 af yr^{-1} (reference) and 5660 af yr^{-1} EVMWD recycled water input with TP 0.2-0.5 mg L^{-1}, geometric mean San Jacinto River flow to Lake Elsinore (558 af yr^{-1}) at 0.22 mg L^{-1} total P, and 75% reduction in carp population (226 carp ha^{-1}).

Scenario	**Water Quality Variables**			**Phosphorus Loading (mg m^{-2} d^{-1})**				
Influent P Conc	TP (mg L^{-1})	Chl a (ug L^{-1})	Z_{sd} (m)	External	Internal	Wind	Carp	Total
No flow	0.812	1201	0.05	0.7	67.7	11.0	0.7	80.1
0.5 mg L^{-1}	0.189	145	0.33	1.2	16.0	1.0	0.7	18.9
0.4 mg L^{-1}	0.181	137	0.35	1.1	15.3	1.0	0.7	18.1
0.3 mg L^{-1}	0.165	119	0.38	0.9	14.0	1.0	0.7	16.6
0.2 mg L^{-1}	0.152	107	0.41	0.7	12.9	1.0	0.7	15.3

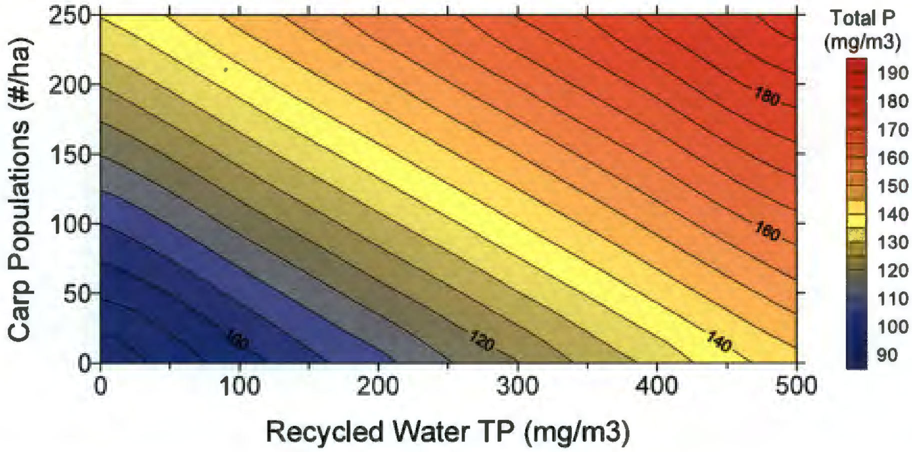

Fig. 1. Predicted lake TP concentration as function of recycled water P concentration and carp population.

Allowance for reduction in internal loading as a result of aeration lowers predicted lake TP and chlorophyll a concentrations in a nonlinear way (Table 3). For example, assuming a 20% reduction in the recycling of TP from the bottom sediments through the feedback loop achieves a 50% reduction in steady-state lake TP concentration and an associated reduction in chlorophyll a concentration and increase in Secchi depth (Table 3).

Table 3. Predicted median water quality and phosphorus loading assuming supplementation with 5560 af/yr EVMWD flow with TP concentration of 0.5 mg L^{-1}, geometric mean San Jacinto River flow to Lake Elsinore (558 af yr^{-1}) at 0.22 mg L^{-1} total P, 75% reduction in carp population (226 carp ha^{-1}), and aeration (as % reduction in internal loading)

Scenario	Water Quality Variables			Phosphorus Loading (mg m^{-2} d^{-1})				
Aeration Reduction	TP (mg L^{-1})	Chl a (µg L^{-1})	Z_{sd} (m)	External	Internal	Wind	Carp	Total
0%	0.189	145	0.33	1.2	16.0	1.0	0.7	18.9
+10%	0.121	77	0.51	1.2	9.2	1.0	0.7	12.1
+20%	0.090	50	0.64	1.2	6.1	1.0	0.7	9.0
+35%	0.064	30	0.78	1.2	3.5	1.0	0.7	6.4

Further supplementation with groundwater via pumping of the island wells would also enhance water quality in the lake through dilution with low P water (0.12 mg L^{-1}) (Anderson, 2006) and through an increase in lake level and reduction in wind resuspension (Table 4). For example, delivery of 500 af of groundwater increases the lake level by 1.9 ft to 1240 ft while lowering TP concentration by 0.019 mg L^{-1} to 0.170 mg L^{-1} (Table 4). Adding 1000 and 2000 af yr^{-1} increases the lake level to 1242 and 1246.3 ft, while lowering TP concentrations to 0.154 and 0.134 mg L^{-1}, respectively (Table 4).

Table 4. Predicted median water quality and phosphorus loading assuming 5660 af/yr EVMWD recycled water input of 0.5 mg L^{-1} total P, geometric mean San Jacinto River flow to Lake Elsinore (558 af yr^{-1}) at 0.22 mg L^{-1} total P, 75% reduction in carp population (226 carp ha^{-1}), and 0-2000 af yr^{-1} groundwater inputs at 0.12 mg L^{-1} total P.

Scenario	Water Quality Variables			Phosphorus Loading ($mg/m^2/d$)				
Influent P Conc	TP (mg/L)	Chl a (ug/L)	Z_{sd} (m)	External	Internal	Wind	Carp	Total
0 af yr^{-1}	0.189	145	0.33	1.2	16.0	1.0	0.7	18.9
+500 af yr^{-1}	0.170	124	0.37	1.2	14.4	0.7	0.7	17.0
+1000 af yr^{-1}	0.154	109	0.41	1.2	13.1	0.5	0.7	15.5
+2000 af yr^{-1}	0.134	88	0.47	1.1	11.4	0.3	0.7	13.5

Limitations to Steady-State Assumption

The steady-state approach summarized in this technical memorandum provides a useful basis for comparing hydrologic and water quality conditions in Lake Elsinore subject to prescribed management actions, although the highly dynamic hydrology of the region indicates that such static conditions will not realistically be met (Anderson, 2006). Dynamic model simulations that previously evaluated the period 1993-2004 demonstrated the theoretical improvements in water quality that could be achieved through supplementation with low P recycled water and island well water, and with aeration and carp removal (e.g., Fig. 18 and Table 10 in Anderson, 2006). Upcoming work on tasks 2-4 and 5b will address dynamical conditions in the lake and the hydraulic linkages between the watershed, Canyon Lake and Lake Elsinore to provide a more comprehensive assessment that includes phosphorus, nitrogen, dissolved oxygen, and related physical, chemical and ecological conditions in both Canyon Lake and Lake Elsinore.

References

Anderson, M.A. 2006. *Predicted Effects of Restoration Efforts on Water Quality in Lake Elsinore: Model Development and Results.* Final Report to LESJWA. 33 pp..

Technical Memorandum

Task 4b: Evaluate Water Quality in Lake Elsinore Under Pre-Development Conditions

Objective

The objective of this task was to evaluate water quality conditions in Lake Elsinore assuming no development in the watershed.

Approach

A DYRESM-CAEDYM model for Lake Elsinore was developed to predict water quality in Lake Elsinore assuming no development in the watershed. As in previous simulations, the 2002-2011 time period was evaluated, with the same meteorological conditions as used in the Canyon Lake simulations, with overflow from Canyon Lake and runoff from the local watershed serving as the primary water and external nutrient inputs to the lake. Direct precipitation on the lake surface was included in the water budget calculations, while atmospheric deposition also provided a limited amount of direct nutrient additions (somewhat arbitrarily set at 10% of current levels). Local runoff volumes were estimated based upon precipitation rates and the area of the local watershed (54 km^2) assuming a runoff coefficient of 0.3 (Anderson, 2006). Area-volume-depth relationships were taken from the analytical model previously developed as well (Anderson, 2006). Nutrient concentrations in the local runoff were estimated from pre-development watershed values from TetraTech, while outflow nutrient concentrations were taken from predicted values of the pre-development simulation for Canyon Lake (Anderson, 2012c).

Note that aspects of this pre-development scenario are quite different than the true pre-development condition at the lake, since (i) we are using the deeper, smaller reconfigured lake basin developed as part of the Lake Elsinore Management Plan, and (ii) Canyon Lake is retained as an upstream impoundment on the San Jacinto River despite its relatively new role in the watershed. For these and several other reasons, the results presented herein should be viewed as a semi-quantitative estimate of a hypothetical pre-development condition here, and could thus be expected to differ from conditions that might be inferred from paleolimnological investigations.

Results

Lake Elsinore, prior to development in the watershed, was predicted to be relatively well-mixed vertically throughout most years (Fig. 1a). This is a result of the low nutrient levels and low corresponding chlorophyll a concentrations (described below) that yield high predicted water clarity. Based upon the predicted chlorophyll a concentrations, the Secchi depth of the lake is estimated to be 2-4 m or more much of the time, which allows for penetration of shortwave radiation to considerable depths in the lake. Combined with the long fetch and strong afternoon winds, the lake is predicted to be mixed to the bottom at lower lake elevations and during intervals of particularly clear water (Fig. 1a). This differs markedly from existing conditions in the lake, where low transparency limits heat penetration, restricts vertical mixing and maintains a relatively thin epilimnion when present.

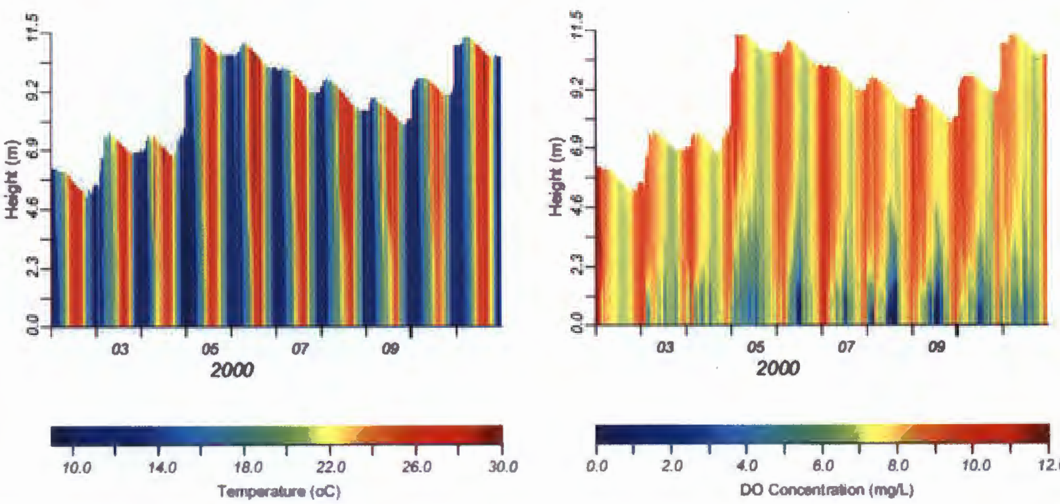

Fig. 1. Simulation results for Lake Elsinore under the pre-development scenario (using meteorological conditions for the 2002-2011 period): a) temperature and b) dissolved oxygen concentration.

The improved mixing in the lake was also predicted to maintain higher concentrations of dissolved oxygen (DO) in the water column, including concentrations near the bottom sediments much of the time (Fig. 1b). While markedly improved relative to existing conditions, where up to 75% of the bottom sediments are often anoxic (<1 mg/L) for most of the summer (Lawson and Anderson, 2007), some intervals of reduced DO concentrations were predicted near the sediments at higher lake levels *e.g.*, in the summers of 2006-2009. Nonetheless, anoxia at 1 m above the deepest point on the lake was found only 1.7% of the days in this 10 yr simulation period.

As alluded to above, predicted concentrations of nutrients were generally quite low relative to existing conditions, with concentrations generally 0.02 - 0.06 mg/L, although higher concentrations were found above the bottom sediments in the summer of 2008 and 2009 (Fig. 2a) when DO levels were low (Fig. 1b). Predicted total N concentrations within the water column were below existing concentrations as well, ranging from 0.40 to 1.2 mg/L (Fig. 2b). As with total P, some increase in total N was observed near the sediments in the summer of 2008 and 2009. The predicted TN:TP ratios typically near 20 suggest that the lake will likely be weakly P-limited under pre-development conditions.

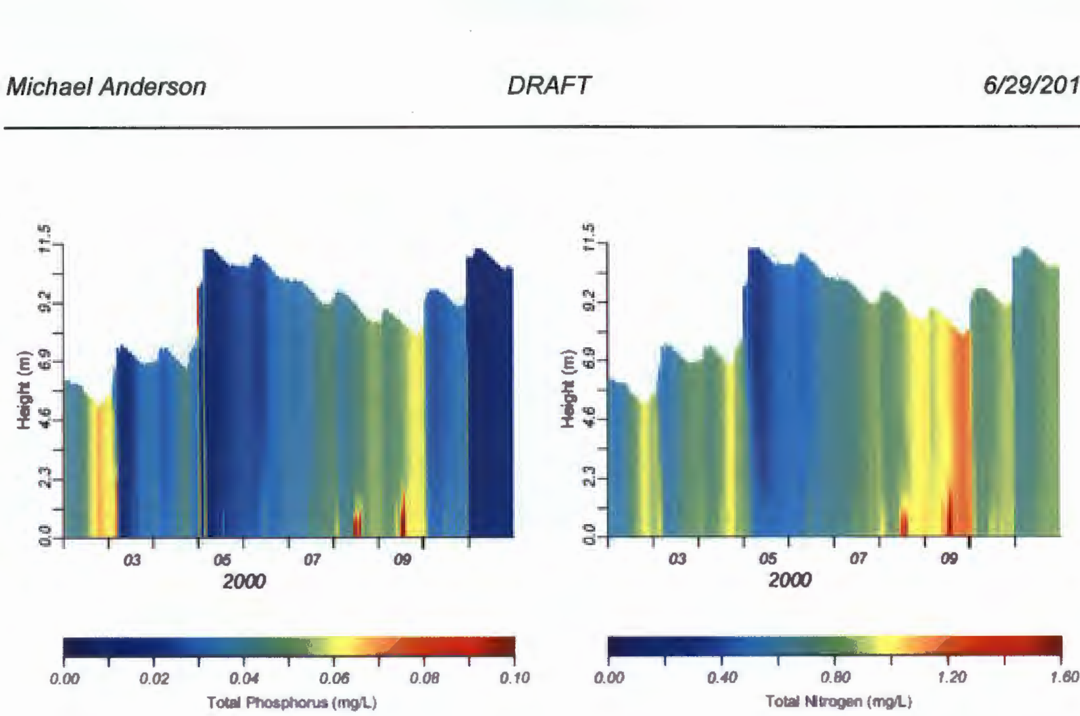

Fig. 2. Simulation results for Lake Elsinore under the pre-development scenario (using meteorological conditions for the 2002-2011 period): a) total P and b) total N concentration.

The low nutrient concentrations were predicted to support chlorophyll a levels generally 12-25 μg/L (Fig. 3a), values that stand in sharp contrast to some of the concentrations seen, e.g., in the summer of 2002 and 2004 that exceeded 300 μg/L (Veiga-Nascimento and Anderson, 2004). Simulations suggest that blue-green algae (cyanobacteria) will comprise the dominant algal species in the lake even with reduced nutrient levels, although diatoms and green algae were predicted to be present as well (Fig. 3b).

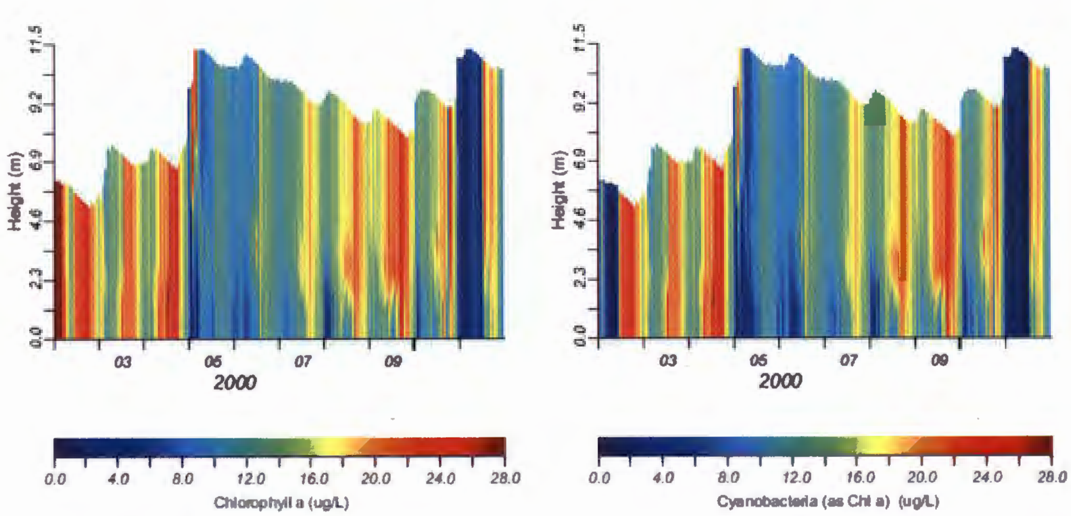

Fig. 3. Simulation results for Lake Elsinore under the pre-development scenario (using meteorological conditions for the 2002-2011 period): a) chlorophyll a and b) cyanobacteria.

Dissolved nutrient concentrations in the water column were generally predicted to be low, although some dissolved PO_4-P was predicted in the fall of 2003 and in 2008-2009 (Fig. 4a). Dissolved PO_4-P comprised essentially all of the phosphorus just above the deepest bottom sediments in the summer of 2008 and 2009, reflecting internal loading during periods of stratification (Fig. 1a) and low DO conditions (Fig 1b). Ammonium-N concentrations were uniformly low in the upper water column, with limited accumulation near sediments during intervals of stratification and anoxia (Fig. 4b). Little NO_3-N was also predicted, consistent with phytoplankton and bacteria utilizing the available inorganic forms (not shown).

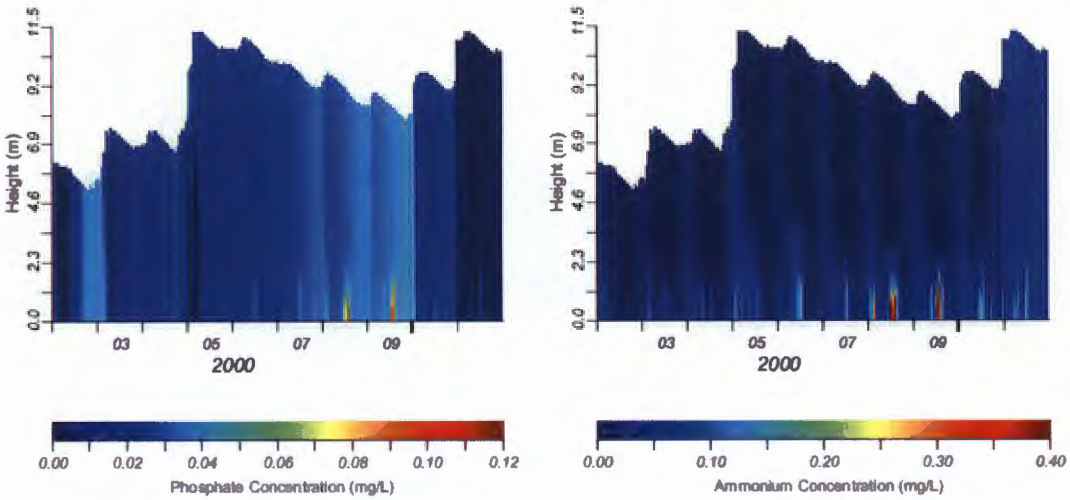

Fig. 4. Simulation results for Lake Elsinore under the pre-development scenario (using meteorological conditions for the 2002-2011 period): a) PO_4-P and b) NH_4-N concentrations.

For comparison with the nutrient TMDL numeric targets for Lake Elsinore, data from the simulations used to calculate annual average total P, total N and summer average chlorophyll a concentrations, as well as the number of days each year when DO concentrations above bottom sediments were <5 mg/L (Table 1). As expected from Fig. 2a, annual average total P levels were low (mean value of 0.036 mg/L), although they did exhibit some interannual variation (0.024 - 0.056 mg/L) related to hydraulic and external nutrient loading, lake surface elevation and related factors (Table 1). Notwithstanding, these simulations suggest that the water quality in the lake prior to development in the watershed would come in well-below the TMDL numeric target for total P of 0.1 mg/L.

In contrast, the model predicted annual average concentrations of total N in Lake Elsinore that would be near or frequently exceed the numeric target of 0.75 mg/L (Table 1). For this 10-year period of time, the predicted annual total N ranged from a low of 0.44 mg/L in 2005 to a high of 1.06 mg/Lin 2009, and averaged 0.76 mg/L, just exceeding by the narrowest of margins the numeric target.

Predicted chlorophyll a concentrations were less variable than found under existing conditions, and annual summer-averaged values ranged only from 9.6 - 21.7 μg/L. Over the 10-year simulation period, the summer chlorophyll a concentration was predicted to averaged 15.7 μg/L, a value significantly below the TMDL numeric target of 25 μg/L (Table 1).

Table 1. Predicted mean annual concentrations of total P, total N, and summer chlorophyll a, and number of days each year DO <5 mg/L 1m above bottom sediments.

Year	**Total P (mg/L)**	**Total N (mg/L)**	**Chlorophyll a (μg/L)**	**# days DO < 5 mg/L**
Target	*0.10*	*0.75*	*25*	*≥5*
2002	0.052	0.74	20.6	0
2003	0.033	0.70	17.5	13
2004	0.035	0.84	21.7	2
2005	0.024	0.44	9.6	111
2006	0.029	0.56	12.2	78
2007	0.040	0.75	14.9	43
2008	0.048	0.89	16.2	121
2009	0.056	1.06	18.8	99
2010	0.032	0.83	15.5	68
2011	0.013	0.76	10.4	58
Average	*0.036*	*0.76*	*15.7*	*59*

The concentration of DO 1 m above the bottom sediments at the deepest part of the lake was strongly dependent upon lake level and duration and strength of thermal stratification (Fig. 1a). The shallow depth and well-mixed conditions in 2002 resulted in concentrations above 5 mg/L throughout the year, while higher lake levels in 2005 and beyond, combined with evapoconcentration of nutrients and other factors, increased the frequency and duration of bottom water DO concentrations below the 5 mg/L target (Table 1). As noted previously, however, anoxic conditions when the DO concentrations declined below 1 mg/L, a threshold where significant biogeochemical transformations such as Fe reduction and hydrogen sulfide production often commence, were predicted to be rare, occurring only 1.7 % of the days from 2002-2011.

Conclusions

Results from these simulations suggest that:

(i) Conditions in Lake Elsinore prior to development in the watershed would be mesotrophic to weakly eutrophic, as opposed to the eutrophic-hypereutrophic conditions presently.

(ii) Greater water clarity would allow heat to penetrate to greater depths, resulting in better mixing and improved DO conditions throughout much of the water column, especially at low to moderate lake levels.

(iii) Development of some thermal stratification and reductions in DO were predicted especially at higher lake levels, although intense and prolonged anoxia, fish kills and so on, are not generally expected.

(iv) Annual average concentrations of total P and summer average concentrations of chlorophyll a were predicted to below their respective TMDL numeric targets.

(v) The average total N concentration for the 10-year simulation period was at the numeric target of 0.75 mg/L, while DO concentrations were predicted to drop below the target of 5 mg/L above the bottom sediments an average of 59 days in a given year.

References

Anderson, M.A. 2006. *Predicted Effects of Restoration Efforts on Water Quality in Lake Elsinore: Model Development and Results.* Final Report. LESJWA. 33 pp.

Anderson, M.A. 2012a. *Evaluation of Long-Term Reduction of Phosphorus Loads from Internal Recycling as a Result of Hypolimnetic Oxygenation in Canyon Lake.* Draft Technical Memorandum, Task 2, to LESJWA. 21 pp.

Anderson, M.A. 2012b. *Evaluation of Alum, Phoslock and Modified Zeolite to Sequester Nutrients in Inflow and Improve Water Quality in Canyon Lake.* Draft Technical Memorandum, Task 3, to LESJWA. 12 pp.

Anderson, M.A. 2012c. *Evaluate Water Quality in Canyon Lake Under Pre-Development Conditions and TMDL-Prescribed External Load Reductions.* Draft Technical Memorandum, Task 4a, to LESJWA. 8pp.

Lawson, R. and M.A. Anderson. 2007. Stratification and mixing in Lake Elsinore, California: an assessment of axial flow pumps for improving water quality in a shallow eutrophic lake. *Water Res.* 41:4457-4467.

Santa Ana Regional Water Quality Control Board. 2004. *Resolution Amending the Water Quality Control Plan for the Santa Ana River Basin to Incorporate Nutrient Total Maximum Daily Loads (TMDLs) for Lake Elsinore and Canyon Lake.* Resolution R8-2004-0037. 4 pp + Attachment.

Veiga-Nascimento, R.A. and M.A. Anderson. 2004. *Lake Elsinore Recycled Water Monitoring Project*. Final Report. LESJWA. 59 pp. + Appendices.