California Regional Water Quality Control Board

San Diego Region

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Supporting Document 4

TO: Barbara L. Evoy,
Deputy Director
State Water Resources Control Board
Division of Financial Assistance

In reply refer to:
SWU:255407:Lwalsh

FROM: David W. Gibson
Executive Officer
SAN DIEGO REGIONAL WATER QUALITY CONTROL BOARD

DATE: **May 27, 2010**

SUBJECT: **REQUEST FOR CLEANUP AND ABATEMENT FUNDS BY THE CITY OF SAN MARCOS FOR THE LAKE SAN MARCOS NUTRIENT DIAGNOSTIC AND CLEANUP PLANNING STUDY, SAN DIEGO REGION**

The California Regional Water Quality Control Board, San Diego Region (San Diego Water Board) is requesting an allocation of $969,576 from the State Water Pollution Cleanup and Abatement Account (CAA) to the City of San Marcos (City) to conduct the Lake San Marcos Nutrient Diagnostic and Cleanup Planning Study (the "Study").

The Lake experiences large external nutrient loading from the watershed evident by seasonal algal blooms and occasional fish kills. Residents living near the Lake report repeat occurrence of large algae blooms and prolonged nuisance odor conditions caused by the release of hydrosulfide from decomposing bacteria that surface during turn over of Lake waters (e.g. thermal mixing) in late fall each year.

The City's goal is to work in coordination with other parties to cleanup and abate the nutrient impairment in Lake San Marcos (the "Lake"). In furtherance of this goal, the City worked closely with stakeholders to develop a technically sound scope of work (including detailed activities, budget, and schedule) that will further assess, investigate, and plan for remediation of the nutrient impairment in the Lake. In April 2009, San Diego Water Board Executive Officer encouraged likely stakeholders to proceed with a voluntary investigation and cleanup as a model, in lieu of a Board directed Investigative Order and/or other enforcement action.

Within the last year, the City and some of the other parties[1] spent approximately $250,000 collecting water quality data, studying the existing condition of the Lake and San Marcos Creek, and developing preliminary investigation reports. The City and some of the other parties spent nearly $400,000 in money or in-kind administrative and third party professional services on development of a consensual framework to work under towards cleanup and abatement of the Lake nutrient impairments, to voluntarily accomplish the same work as an otherwise directed cleanup effort.

I will be recommending that the San Diego Water Board adopt R9-2010-0079, a resolution for CAA funding of the City's Study, at the June 9, 2010 Board meeting. A copy of the adopted resolution will be forwarded to you following the meeting. The CAA Funding Request Form, Scope of Work, budget and letters of support are enclosed.

Thank you for in advance for your consideration. If you have any questions, please contact Chiara Clemente of my staff at (858) 467-2359.

DWG:dtb:cmc:law

Enclosures:

1. State Water Board Cleanup and Abatement Account CAA Request Form for the Lake San Marcos Nutrient Diagnostic and Cleanup Planning Study
2. Scope of Work
3. Budget
4. Letters of Support

cc: John Lormon, Procopio, Cory, Hargreaves & Savitch LLP, 525 B Street, Suite 2200, San Diego, CA 92101
john.lormon@procopio.com

Lake San Marcos Lyris List of Interested Parties

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[1] Other parties currently include: County of San Diego, City of Escondido, California Department of Transportation, San Marcos Unified School District, Vallecitos Water District, Community Development Corporation, Lake San Marcos Remediation Group, Lake San Marcos Task Force, Lake San Marcos Community Association, Batiquitos Lagoon Foundation, San Diego Coastkeeper, and Coastal Environmental Rights Foundation.

STATE WATER RESOURCES CONTROL BOARD
CLEANUP AND ABATEMENT ACCOUNT (CAA)
FUNDING REQUEST FORM

Send the completed form and attached documentation to Cristina Mayorga-Ochoa at cochoa@waterboards.ca.gov or at 1001 I Street,17th Floor Sacramento, CA 95814

APPLICANT INFORMATION

Agency Name: (maximum of 40 characters)	City of San Marcos
Address:	City of San Marcos 1 Civic Center Drive San Marcos, CA 92069-2918
Agency Phone Number:	(760) 744-1050, Ext. 3218
Agency Representative:	Erica Ryan
Region:	San Diego Water Board
Region Representative:	Chiara Clemente
Representative Phone Number:	858-467-2359

PROJECT INFORMATION

Name of Project:	THE LAKE SAN MARCOS NUTRIENT DIAGNOSTIC AND CLEANUP PLANNING STUDY	**Project Start and End Dates:** Project would start upon execution of the funding agreement be complete within 24 months.	
Project Location:	**San Marcos, California**		
Funding Amount:	**$969,576**		

PURPOSE OF REQUEST

1) **Purpose of Request (attach additional sheet if needed):** City of San Marcos (the "City"), in coordination with other parties, is requesting Cleanup and Abatement Funds (CAA) to support a detailed diagnostic investigation and development of a cleanup planning document (feasibility study and plans for a remedial action plan) to address listed Clean Water Act section 303(d) impairments in Lake San Marcos. Other Parties include public and private entities that have partnered with the City to conduct the work performed at the Lake thus far and who have committed to participate via money and/or in-kind services in the future. The parties include: County of San Diego, City of Escondido, California Department of Transportation, San Marcos Unified School District, Vallecitos Water District, and the Community Development Corporation.

2) **Background:** Lake San Marcos ("the Lake") is listed under the 2006 Clean Water Act (CWA) section 303(d) as an impaired water body caused by ammonia as nitrogen, nutrients and phosphorous. The Lake is an impoundment of the San Marcos Creek (the "Creek") upstream of a concrete arched dam (the "Dam"). The Creek is listed under the 2006 CWA section 303(d) as an impaired water body for phosphorous, including that portion of the Creek upstream of the Dam. The CWA section 303(d) listings for the Lake and the Creek include a schedule for the development of TMDLs to address the impairments by 2019. In April 2009, San Diego Water Board Executive Officer encouraged likely stakeholders to proceed with a voluntary investigation and cleanup of the Lake's impairments as a model in lieu of a Board directed Investigative Order and/or other enforcement action.

   After a year of gathering data, investigating possible nutrients sources, and developing a preliminary draft site conceptual model to better understand sources and causes of nutrient impairment to the Lake, the City, along with other parties, realized that a detailed diagnostic effort was required. Therefore, the City, with support from other parties, is requesting CAA funds to conduct a more detailed diagnostic investigation and to develop a cleanup planning document (feasibility study and plans for a remedial action plan) to support their remedial action decision.

3) Impact to community or surrounding areas in regards to water quality: The Lake experiences large external nutrient loading from the watershed evident by seasonal algal blooms. Water quality data collected to date confirms the presence of cyanobacteria toxins. The Lake also experiences occasional fish kills. Residents living near the Lake report repeat occurrence of large algae blooms and prolonged nuisance odor conditions caused by the release of hydrosulfide from decomposing bacteria that surface during turn over of Lake waters (e.g. thermal mixing) in late fall each year.

4) What is the waste being addressed by this project?: Lake San Marcos is listed in the 2006 Clean Water Act (CWA) section 303(d) as an impaired water body caused by ammonia as nitrogen, nutrients and phosphorous.

5) List any responsible party: Because this Study is aimed at identifying sources and nutrient fate and transport, no responsible parties have been identified yet.

6) Will any of these funds be used for Regional Board oversight? ☐ YES X NO **If YES, how much?**

DOCUMENTATION

X **Scope of Work (Attached)** ☐ **Regional Board Resolution or proof of Regional Board support (Attached)**

State Board Decision for $100,000 and Below:

☐ **Approved** ☐ **Denied**

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Deputy Director **Date**

Deputy Director's Recommendation for Funding (over $100,000):

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Deputy Director **Date**

LAKE SAN MARCOS WATERSHED
SWRCB CLEANUP AND ABATEMENT FUND APPLICATION

NUTRIENT WORKPLAN
May 26, 2010

Lake San Marcos ("the Lake") is listed under CWA Section 303(d) as an impaired water body (called "San Marcos Lake" in the listing) due to impairments caused by:

- Ammonia as Nitrogen*,
- Nutrients, and
- Phosphorous*.

The Lake is an impoundment of San Marcos Creek ("the Creek") upstream of a concrete arched dam (the "Dam"). The Creek is also listed as an impaired water body for Phosphorous. This Workplan addresses only Lake San Marcos and nutrient sources from the contributing watershed upstream of the Dam.

The 303(d) listings include a schedule for development of TMDLs to address the impairments. A group of local stakeholders (the "Working Group") has been working over the past year to address these issues, and San Diego Regional Water Quality Control Board ("Water Board") staff has encouraged the stakeholders to proceed with a non-TMDL approach to address the listings. This Workplan is a product of the Working Group, and specifically meets the following Working Group goal:

> *"Develop a technically sound Workplan (including a Scope of Work and Budget) for a Cleanup and Abatement Fund application to address nutrient issues in Lake San Marcos and San Marcos Creek upstream of the Dam."*

Essential background documents that were used as references during the development of the Workplan include:

- Lake San Marcos CWA Section 303(d) Listings (2006) (Attachment A-1)
- RWQCB Executive Officer Summary Report, 4/8/2009, Revised 2/10/2010; Status Report: Lake San Marcos (Attachment A-2)
- Water Quality Management in Lake San Marcos: Analysis of Available Data, Final Report, Michael Anderson, 3 February 2010 (Attachment A-3)

Those documents are appended to this Workplan.

As indicated in both the Executive Officer's Summary Report and Dr. Anderson's report cited above, substantial gaps exist in knowledge and understanding of internal Lake processes, watershed sources of nutrients, and watershed hydrology. These gaps must be addressed before a meaningful or comprehensive plan for cleanup, abatement, and mitigation can be developed. This Workplan describes the necessary diagnostic and investigative research that is proposed, the need for comprehensive data analysis and interpretation, and the preparation of a feasibility study to facilitate and inform cleanup implementation planning.

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* Throughout this Workplan nitrogen is abbreviated as "N" and phosphorous is abbreviated as "P".

As specified in the CAA fund application, the City of San Marcos will serve as lead agency for the proposed work. The following three phases of activity are proposed under this Workplan:

A. Monitoring and Research – this is the investigative/diagnostic phase of the Workplan. This phase will include multiple projects and studies involving data collection, targeted to address identified knowledge gaps.
B. Data Analysis and Interpretation – this phase is essential in order to make effective use of the results of the Monitoring and Research phase – for both individual investigative/diagnostic studies as well as to synthesize results across multiple studies. The results of the Data Analysis and Interpretation phase will be published in a separate report and submitted to the Water Board as a Workplan deliverable.
C. Feasibility Study and Cleanup Implementation Planning – based on the results of the Monitoring and Research and Data Analysis and Interpretation phases, a feasibility study will be performed, and a prioritized list of cleanup and abatement options will be developed. This will include measures aimed at reducing the primary causes of nutrient impairment in Lake San Marcos, with the goal of meeting applicable water quality standards, and may include actions designed to mitigate, abate, remediate or cleanup nutrient levels in the Lake. The work product from this phase will include a priority-ranked list of specific measures expected to result in demonstrable improvements in lake water quality.

The specific activities proposed under each of these phases are described in the Scope of Work, below.[1] The Workplan Schedule and estimated Budget follows the proposed Scope of Work.

SCOPE OF WORK

A. Monitoring and Research

1) Determine Modeling Approach
This task will involve creation of a conceptual model for the watershed, and selection of a surface water hydrology model, groundwater hydrology model, and water quality model (or modules for the hydrology models). Note that the model selection will be done in a comprehensive way to ensure that the models can be effectively integrated. Upon model selection and review of existing data, the conceptual model will be updated and additional data needed to run each model will be specified. [The models also will be used to predict improvements in Lake nutrient levels based on evaluations of various alternatives and scenarios for cleanup/mitigation/remediation; see Task C.] This task includes the following steps:

a) Develop Conceptual Model
A conceptual model will be created to illustrate the key sources, sinks, transport pathways, and transformational processes of nutrients within the watershed. The conceptual model will be used to help identify the areas where significant data gaps exist, as well as guide the selection and development of the surface water and groundwater models.

[1] Phases A and B are referred to as the Diagnostic Phase and Feasibility and Cleanup Implementation and Planning Phase in the CAA Application.

b) Surface Water (Hydrological) Model Selection
A surface water model will be developed as a tool for understanding the hydrology of the watershed, including providing a means of evaluating seasonal and annual variations in the water budget. This initial task will involve the following steps:

- Select model
- Contract with modeling consultant
- Refine conceptual model
- Assess data gaps; Specify needed data

The modeling consultant will review the known conditions and existing data within the watershed, help refine the conceptual model, and then specify the additional data that will be needed for model input, calibration, and verification.

c) Groundwater (Hydraulic) Model Selection
A groundwater model will be used as a tool for understanding the sources and volumes of groundwater contributing to the water budget of Lake San Marcos, and the pathways groundwater takes to reach the lake: directly through subsurface flow, via infiltration into storm sewers, by pumping from groundwater dewatering wells, or by contributing to base flow in the creek. This initial task will involve the following steps:

- Select model
- Contract with modeling consultant
- Refine conceptual model
- Assess data gaps; Specify needed data

The modeling consultant will review the known conditions and existing data within the watershed, help refine the conceptual model, and then specify the additional data that will be needed for model input, calibration, and verification.

d) Water Quality Model/Module Selection
A water quality model will be used as a tool for understanding the concentrations and loadings of nutrients from the various sources contributing to nutrient levels in the Lake, including in-lake processes and seasonal and annual variations. It is anticipated that the water quality modeling can be accomplished by adding the appropriate components or modules to the surface water hydrology and groundwater models. This initial task will involve the following steps:

- Select model(s)/module(s)
- Contract with modeling consultant (may be same as selected for hydrological/hydraulic models above)
- Refine conceptual model
- Assess data gaps; Specify needed data

The modeling consultant will review the known conditions and existing data within the watershed, help refine the conceptual model, and then specify the additional data that will be needed for model input, calibration, and verification.

For subtasks 1b, 1c, and 1d, the existing/historical data will be compiled and evaluated as part of the data gap analysis. This analysis will identify data collection targets and monitoring frequencies that will be supportive of the statistical data requirements of the modeling efforts, with due consideration of budgeting constraints and established protocols, to help ensure scientifically valid and statistically verifiable outcomes for the various studies described in this Workplan.

2) Understand Water Budget

The rate at which water flows into the Lake from various sources is a key determinant of nutrient loadings, and both water flow rates and Lake water levels are key factors in understanding the fate and transport of nutrients affecting the Lake. Therefore, it is critical to understand the differential rates of water movement through the various pathways into and out of the Lake. Sources of inflow include urban and agricultural irrigation, stormwater runoff (urban, agricultural and open space), groundwater inflows (surface and subsurface), direct precipitation, and dewatering. Outflows (losses) include loss to groundwater, evaporation, dewatering/diversion, and flows over or through the Dam. A key issue involves the relative contribution of groundwater to the Lake volume under both dry and wet season conditions. This includes the following steps:

a) Quantify Surface Inflows/Outflows

Based on the data gap analysis from Task 1, field measurements will be made to quantify specific types of surface inflows to the lake, as well as outflows. This will involve field collection of flow data at representative locations within the watershed. In addition to quantifying standard rainfall/runoff and dry weather inflows, including precipitation and evaporation, the effects of the operation of the Dam (including issues relating to impoundment and bypass) and the exercise of riparian, overlying, and appropriative water rights (including issues relating to dewatering) will be quantified.

b) Calibrate and Validate Surface Water Model

The flow measurements will be used as input to the surface water hydrology model. The model will be calibrated and validated, and run to illustrate the range of seasonal and annual (e.g., wet vs. dry years) conditions.

c) Quantify Groundwater Inflows/Outflows

Evaluate groundwater elevation contours (if available) to assess hydraulic gradient, review available hydraulic parameters (hydraulic conductivity and storativity) from the local aquifers, and assess likely discharges to derive a local groundwater budget – inflow (recharge sources), outflow (e.g., pumping) and storage.

This will be validated against a macro water budget obtained by calculation from estimated surface flows and evaporation.

d) Differentiate Groundwater Sources

Once the relative proportion of groundwater contributing to the lake water budget has been estimated, it will be necessary to determine the proportional origin of that groundwater; i.e., to distinguish between "natural" groundwater derived from local aquifers or percolation of precipitation through the soil, vs. irrigation water derived from surface sources that infiltrates through the soil and migrates to the lake. This will be done by attempting to establish "signatures" or "fingerprints" for the various groundwater and surface water sources, using standard water quality parameters such as Total Dissolved Solids (TDS) or conductivity, as well as stable isotopes of oxygen and hydrogen. TDS and conductivity are easily measured in the field or lab using standard field equipment. Stable isotope analyses also can be performed in commercial laboratories using standard procedures. Groundwater samples are analyzed using EPA Test Method CF-IRMS for oxygen isotope ratios and EPA Test Method DI-IRMS for hydrogen isotope ratios. Stable isotopes of oxygen (delta oxygen-18 $d^{18}O$) and hydrogen (delta deuterium dD) are presented as ratios in parts per thousand (commonly expressed "permil" and indicated by ‰) relative to Vienna Standard Mean Ocean Water (VSMOW).

e) Calibrate and Validate Groundwater Model
Available hydraulic and other data will be used as input to the groundwater model. The model will be calibrated and validated, and run to illustrate the range of seasonal and annual (e.g., wet vs. dry years) conditions.

3) Understand Nutrient Budget
It is necessary to quantify concentrations and loadings of nutrients in inflows to the Lake, within the Lake (water column, sediments, and flora), and in discharges from the Lake. Nutrient sources likely include urban and agricultural irrigation, storm water runoff (urban, agricultural and open space), groundwater inflows (surface and subsurface), dewatering discharges, and direct inputs from wildlife. Losses may include biological uptake, sedimentation within the lake, loss to groundwater, dewatering/diversion, and flows over or through the dam. Seasonal and annual variation in relative concentrations and loadings from various sources may be substantial. This includes the following steps (internal Lake processes are covered under Task 5):

a) Quantify Nutrient Concentrations in Surface Inflows/Outflows
Based on the data gap analysis from Task 1, monitoring will be performed to quantify N and P concentrations in specific types of surface inflows to the lake, as well as outflows. In addition to quantifying nutrient concentrations in runoff and dry weather inflows, the effects of the operation of the Dam (including issues relating to impoundment and bypass) and the exercise of riparian, overlying, and appropriative water rights (including issues relating to dewatering) on Lake nutrient levels will be quantified.
This will involve collection and analysis of samples for concentration data at representative locations within the watershed. Samples will be analyzed for the standard set of field parameters (temperature, dissolved oxygen, pH, conductivity, and possibly turbidity), and analyzed by a certified laboratory for total suspended solids, total dissolved solids, total and dissolved organic carbon, biochemical oxygen demand, hardness, silica, chlorophyll a, and major anions, in addition to the various forms of N and P (including Total N, Total P, Total Dissolved N, Total Dissolved P, Nitrate+Nitrite, Ammonium, and Soluble Reactive P). This work will be coordinated to the extent feasible with the flow monitoring performed under Task 2a.

b) Quantify Atmospheric Deposition of Nutrients
Monitoring will be performed to quantify N and P concentrations in atmospheric deposition within the watershed. This will involve collection and analysis of samples of bulk dry and wet deposition at representative locations within the watershed during both dry season and wet season.

c) Calibrate and Validate Surface Water Quality Model
The available nutrient concentration data will be used as input to the surface water quality model/module. The model will be calibrated and validated, and run to illustrate the range of seasonal and annual (e.g., wet vs. dry years) conditions.

d) Quantify Nutrient Concentrations in Groundwater Inflows/Outflows
Based on the data gap analysis from Task 1, monitoring will be performed to quantify N and P concentrations in specific types of groundwater inflows to the lake, as well as outflows. This will involve collection and analysis of samples for concentration data at representative locations within the watershed. For irrigated lands that drain to the lake, the irrigation source water also will be tested. Samples will be analyzed for the standard set of field parameters (temperature, dissolved oxygen, pH, conductivity, and possibly turbidity), and analyzed by a certified laboratory for total suspended solids, total dissolved solids, total and dissolved organic carbon, biochemical oxygen demand, hardness, silica, chlorophyll a, and major anions, in addition to the various forms of N and P. The newly-acquired data will be combined with existing/historical data to create a more comprehensive picture of groundwater quality.

e) Calibrate and Validate Groundwater Quality Model/Module
The available nutrient concentration data will be used as input to the groundwater quality model/module. The model will be calibrated and validated, and run to illustrate the range of seasonal and annual (e.g., wet vs. dry years) conditions.

4) Calculate External Nutrient Loadings
The results of Tasks 2 and 3 will be evaluated to create a picture of nutrient loadings to the Lake from the various external sources, and the fate of those nutrients once discharged to the Lake, including quantification of any outflows. This will include quantification of seasonal and annual variations (depending upon type of water year).

5) Understand In-Lake Processes
The two processes most critical to the nutrient impairment of the Lake are the build-up of sediment behind the Dam and thermal stratification of the Lake.

Dams provide a physical barrier that blocks the downstream movement of sediment and associated constituents, and they also slow the water flow, enhancing the sedimentation process. In Lake San Marcos, as in other lakes formed by a dam across a creek, sediment builds up on the Lake bottom over the years – in the case of Lake San Marcos this process has been ongoing for several decades. Various forms of N and P are among the constituents contained within the sediment build-up.

In thermally-stratified lakes, the lake is separated vertically into three distinct strata:

- the epilimnion, or upper layer, where temperature and dissolved oxygen are relatively high,
- the thermocline, an area of rapidly declining temperature and dissolved oxygen, and
- the hypolimnion, or lower layer, where temperature and dissolved oxygen are relatively low.

The hypolimnion has very little exposure to air or photosynthetic activity, and therefore tends to be very low in dissolved oxygen, and may even be anoxic. As there is nominally little vertical mixing in stratified lakes, constituents tend to become trapped in the lower level of the lake (the hypolimnion), below the thermocline, and the water may be anoxic. Exchange of pollutants between water column and sediment is limited to this zone during periods of thermal stratification. As the upper layer of water cools with the onset of winter, the stratification may break down, and the lake can mix rapidly in a process known as turnover. If turnover occurs, pollutants trapped within the hypolimnion and the sediments can be mixed throughout the lake. Dr. Anderson's report confirms that the lake is thermally stratified, but he was not able to conclude whether turnover occurs.

The following monitoring programs and studies are proposed to provide needed information regarding in-lake processes:

a) Depth Profiling
It is essential to understand stratification within the lake as it changes seasonally, and particularly important to know whether turnover occurs. This will be determined with a vertical series of measurements (depth profiling) of key water quality parameters* (temperature, dissolved oxygen, pH, conductivity, and turbidity) throughout the water column at two selected locations within the lake: in deeper water near the dam, and at a midway point (corresponding to Dr. Anderson's sites 1 and 2).
*These parameters all can be field-measured using standard field equipment. Depth profiles will be field-measured as described above during the quarterly field monitoring described in Task A.5.e below. In addition, automated data sondes (*in situ* monitoring devices) will be installed in place to automatically record these parameters at three specific depths (near surface, mid-depth and near-bottom) at two locations: the deep-water and mid-lake sites identified in Dr. Anderson's report as sites 1 and 2, respectively.

b) Determine Depth and Volume of Accumulated Sediment
It is important to determine how much sediment has accumulated within the lake, as the sediments represent a substantial potential source of nutrients, particularly in the event of lake turnover. This will be assessed through comparisons of historical vs. contemporary bathymetry. A field survey employing multi-beam survey equipment will be performed to determine the current, detailed bathymetry of the lake; the results of this survey will be stored in computerized format (auto-CAD or GIS shape files) and compared to as-built drawings from the original construction of the dam, also in computerized format.

c) Contributions from Shallow Sediments
In shallow areas of the lake stratification typically does not occur, and sediments that accumulate in those areas are subject to mixing into the water column by wind turbulence, storm flows, or physical disturbance from human activities such as use of watercraft. An attempt will be made to assess the extent to which these activities release nutrients from the sediments of shallow areas.

d) Sediment Chemistry
Sediment samples will be collected from approximately 20 sites throughout the lake, including the side "fingers". Samples will be collected from the upper layer of sediment and analyzed by a certified laboratory for a suite of standard

sediment properties, including % solids, grain size distribution, total and dissolved organic carbon, biochemical oxygen demand, pH, hardness, silica, sulfides and sulfites, in addition to the various forms of N and P.
Three sediment cores also will be collected if feasible in the deepest area of the lake, near the dam, with analysis of discrete core sections by a certified laboratory for the list of parameters given above.

e) Water Chemistry
Water quality monitoring will be performed at several locations throughout the lake, with sufficient numbers of samples to characterize seasonal differences, including wet weather vs. dry weather. This will include at a minimum quarterly sampling during dry weather (all four seasons), plus three storm events (early, middle and late wet season). Samples will be collected within one foot of the lake surface. For sites located in areas where the depth exceeds 10 feet, additional samples will be collected from a depth of one-half the estimated water depth. Samples will be analyzed for the standard set of field parameters (temperature, dissolved oxygen, pH, conductivity, and possibly turbidity), and analyzed by a certified laboratory for total suspended solids, total dissolved solids, total and dissolved organic carbon, biochemical oxygen demand, hardness, silica, chlorophyll a, and major anions, in addition to the various forms of N and P (including Total N, Total P, Total Dissolved N, Total Dissolved P, Nitrate+Nitrite, Ammonium, and Soluble Reactive P).

f) Other Water Quality Measurements
Secchi depth measurements will be collected at representative locations in the Lake on an ongoing basis as an indication of Lake water transparency/clarity, along with Lake level measurements, and near-surface measurements of dissolved oxygen and temperature. This task may be performed by trained citizen volunteers, with professional QA/QC oversight, in accordance with SWAMP protocols.

g) Biological Measurements
Several studies will be conducted to assess the biological conditions of the Lake, including:

- Biomass – collection and analysis of phytoplankton and zooplankton, with taxonomic identification of algal community to understand current conditions. Three samples will be collected from a late-summer algal bloom and analyzed taxonomically.
- Lake flora – survey several key locations within the Lake to assess relative amounts of periphyton (attached algae), emergent macrophytes (aquatic plants), and riparian canopy cover.
- Fish and wildlife study – population structure and composition will be assessed using standard ecological assessment techniques.
- Food Web/Trophic Study – based on results of preceding studies.

6) Protocols, Documentation and QA/QC
All monitoring programs and research studies funded under this application will be performed according to SWAMP-approved protocols, or USEPA-approved or USGS-approved protocols in the absence of applicable SWAMP protocols. Sample collection

and analytical protocols and quality assurance/quality control (QA/QC) procedures will be documented in a Quality Assurance Project Plan (QAPP) following SWAMP format. All monitoring programs and studies will prepare a Monitoring Plan for approval by the Grant Manager prior to commencing work. All monitoring sites will be geo-located using standard GPS techniques.

B. Data Analysis and Interpretation

Data Analysis and Interpretation is essential in order to make effective use of the monitoring and research results – for both individual projects as well as to synthesize results across multiple projects.

Key analytical assessments for this Workplan include the following:

- Lake water quantity inputs: groundwater vs. surface water sources, including seasonal and annual variation
- Relative proportions of different sources of groundwater, including seasonal and annual variation
- Relative loadings of N and P from various external sources to Lake, including seasonal and annual variation
- The effects of lake level management and dam operations on water budget and in-lake nutrient levels
- Amount of accumulated sediment in Lake; historical decrease in Lake water storage volume
- Amounts of N and P in Lake sediment reservoir
- Seasonal patterns in Lake thermal stratification; estimated frequency of Lake turnover
- Relative importance of external vs. in-Lake sources of N and P
- Historical patterns in Lake sediment chemistry based on core samples
- Estimated quality of sediment that would be released from the Lake if water is released from the lower Dam outlet (based on core sample results)
- Biological condition of Lake, effects of current nutrient conditions on biota, and effects of fish and wildlife on current nutrient levels

The results of the data analysis and interpretation phase will be published in a separate report and submitted to the Water Board as a Workplan deliverable.

C. Feasibility Study and Cleanup Implementation Planning

Using the results of the various monitoring and research studies described in this Workplan, and based on the analytical and interpretive work described in Task B above, an assessment will be made of the cleanup measures most likely to produce measurable reductions in nutrient loadings to the Lake and/or mitigation of in-Lake nutrient concentrations.

A feasibility study will be performed to evaluate and rank the most promising measures. The surface water and groundwater models will be run to evaluate various alternatives and scenarios for cleanup/mitigation/remediation, including activities related to dam operations and lake management. This task will involve an evaluation and ranking of alternative measures, with an assessment of cost relative to amount of loading reduced or in-Lake concentration improvement expected.

The product of this task will be a prioritized list of cleanup and abatement options. This will include measures aimed at reducing the primary causes of nutrient impairment in Lake San Marcos, with the goal of meeting applicable water quality standards, and may include actions designed to mitigate, abate, remediate or cleanup nutrient levels in the Lake. The work product will include a priority-ranked list of specific measures expected to result in demonstrable improvements in Lake water quality.

SCHEDULE

Task	Scope Items	Timing
A	Monitoring and Research	(months from start)
1	*Determine Modeling Approach*	3
2	*Understand Water Budget*	15
3	*Understand Nutrient Budget*	15
4	*Calculate External Nutrient Loadings*	15
5	*Understand In-Lake Processes*	18
B	Data Analysis and Interpretation	21
C	Feasibility Study/Cleanup Implementation Planning	24
	QAPP and Monitoring Plan (SWAMP-Compat.)	4

BUDGET ESTIMATE

Task	Scope Items	Costs
A	Monitoring and Research	
1	*Determine Modeling Approach*	$59,500
2	*Understand Water Budget*	$200,000
3	*Understand Nutrient Budget*	$190,000
4	*Calculate External Nutrient Loadings*	$15,000
5	*Understand In-Lake Processes*	$333,849
B	Data Analysis and Interpretation	$70,000
C	Feasibility Study/Cleanup Implementation Planning	$50,000
	QAPP and Monitoring Plan (SWAMP-Compat.)	$24,000
	Project Management/Administration	$47,117
	TOTAL:	$989,466

WATER BODY NAME	WATER TYPE	WATERSHED CALWATER/ USGS HUC	POLLUTANT o POTENTIAL SOURCES	ESTIMATED AREA ASSESSED	FIRST YEAR LISTED	TMDL REQ. STATUS	DATE
San Marcos Creek	River & Stream	90451000 / 18070303	* DDE (Dichlorodiphenyldichloroethylene) o Source Unknown	19 Miles	2006	5A	2019
			* Phosphorus o Source Unknown o Unknown Nonpoint Source o Unknown Point Source o Urban Runoff/Storm Sewers	19 Miles	2006	5A	2019
			* Sediment Toxicity o Unknown Nonpoint Source o Unknown Point Source o Urban Runoff/Storm Sewers	19 Miles	2006	5A	2019
			* Selenium o Source Unknown	19 Miles	2008	5A	2021
San Marcos Lake	Lake & Reservoir	90452000 / 18070303	* Ammonia as Nitrogen o Unknown Nonpoint Source o Unknown Point Source o Urban Runoff/Storm Sewers	17 Acres	2006	5A	2019
			* Nutrients o Unknown Nonpoint Source o Unknown Point Source o Urban Runoff/Storm Sewers	17 Acres	2006	5A	2019
			* Phosphorus o Source Unknown o Unknown Nonpoint Source o Unknown Point Source	17 Acres	2006	5A	2019

State of California
Regional Water Quality Control Board
San Diego Region

REVISED
EXECUTIVE OFFICER SUMMARY REPORT
April 8, 2009

ITEM: 8

SUBJECT: Status Report: The Lake San Marcos owner, dischargers, and members of the community will provide updates to the San Diego Water Board on progress made in the past year to improve water quality in Lake San Marcos. *(Chiara Clemente)*

PURPOSE: To be briefed on progress made to improve water quality in Lake San Marcos.

PUBLIC NOTICE: Notice was provided by publication of the Board agenda on January 22, 2010. The agenda was forwarded by e-mail to the lyris list of Lake San Marcos interested parties on January 25, 2010.

DISCUSSION: According to the 2008 303(d) list of impaired water body segments, Lake San Marcos is listed as impaired due to ammonia as nitrogen, phosphorous, and nutrients. San Marcos Creek is listed as impaired due to phosphorous, DDE, toxicity, sediment toxicity, and selenium. The Lake has been subject to periodic algal blooms, confirmed presence of cyanobacteria toxins, and occasional fish kills, likely due to the confirmed presence of excessive nutrients in the water. Residents living near the Lake have reported nuisance algae and odor conditions to the Regional Board for several years. Due to the wide range of potential contributors, it has been difficult to determine how to abate these pollutants.

Lake San Marcos is the product of a dam that was built in 1953 through San Marcos Creek. The impoundment was originally used for agricultural irrigation, but the area was later developed, and the water rights appropriation was transferred to the Citizen's Development Corporation (CDC) for the current irrigation of its lakeside golf course. The Lake is still subject to agricultural discharges from surrounding groves, but the majority of the Lake

(Supporting Document No. 1 & 2) watershed now consists of commercial and residential land use.

In April 2009, the San Diego Water Board invited all known interested parties to meet and discuss a collaborative effort to identify and abate nutrient sources to the Lake. Participating dischargers included the CDC (La Jolla Development Corporation), the Cities of San Marcos and Escondido, the County of San Diego, and the Vallecitos Water District which is responsible for the sewage collection system in the Lake watershed. Additional participants included the Lake San Marcos Community Association, the Lake San Marcos Remediation Group, and Coast Law Group. Since that time, there have been multiple meetings, and participation has extended to include Caltrans and some of the Phase II MS4 designees.

Collectively, the group has:

1) Compiled all existing Lake San Marcos historical information and water quality monitoring data into a compendium document.
2) Collected additional monitoring data.
3) Indentified all drains discharging to the Lake.
4) Contracted with Dr. Michael Anderson (UC Riverside) to review existing data, fill in data gaps, and provide a report on the Lake's characteristics and possible remedial measures (Supporting Document No. 3).
5) Increased the surrounding community's awareness of potential pollution practices, and possible source control measures through public meetings, community publications, and heightened complaint response (by the MS4 entities). Pursuant to the Watershed Urban Runoff Management Plan (WURMP) requirements of the MS4 permit, the Cities and County have submitted a Nutrient Management Plan for the Upper San Marcos Creek Watershed (Supporting Document No. 4).
6) Codified source control BMPs in HOAs (e.g. prohibiting car washing, controlling irrigation and landscape application of pesticides, herbicides, and fertilizer, and disposal of yard waste).
7) Drafted a Participation Agreement that stipulates the process, roles, and cost-sharing mechanism for future work.

8) Reviewed the existing water rights agreement, and sought to bring certain requirements in compliance with their license conditions.
9) Become aware of groundwater discharges to the Lake and the need to enroll and comply with the groundwater dewatering permit.

The group currently faces challenges in:

1) Defining the desired outcome (i.e. defining the "lake" area and agreeing on success criteria).
2) Agreeing on remediation alternatives to consider.
3) Agreeing on who should be engaged in this process, and at what level the public should be engaged.
4) Obtaining appropriate representation from certain dischargers. The agricultural growers, homeowners, and HOAs that have direct and indirect discharges to the Lake are not represented by a single entity.
5) Soliciting participation and funding commitments.
6) Agreeing on a framework for how to proceed.

The Regional Board faces the additional challenge of identifying the best authorities under which our limited resources should be directing the reduction of pollutant loading to, and clean-up of, the Lake.

SIGNIFICANT CHANGES: N/A

COMPLIANCE: N/A

LEGAL ISSUES: None.

SUPPORTING DOCS:
1. Site Map
2. Lake San Marcos Area Map
3. Report by Dr. Michael Anderson
4. Upper San Marcos Creek Watershed Nutrient Management Plan
5. Background Materials Submitted by the Lake San Marcos Community Association

RECOMMENDATION: Informational item only.

Water Quality Management in Lake San Marcos:
Analysis of Available Data

Final Report

Submitted to:
City of San Marcos
San Marcos, CA 92069

Submitted by:
Michael A. Anderson
Riverside, CA 92504

3 February 2010

ATTACHMENT A-3

Table of Contents

List of Figures

List of Tables

Introduction

Lake San Marcos is a small privately owned reservoir located within the San Marcos Creek watershed in the Carlsbad hydrologic unit. The watershed includes urban, suburban and agricultural land uses, as well as wildlands. The lake suffers algal blooms and has been placed on the 303(d) list for nutrients, ammonia as N and phosphorus. The primary tributary to the lake, San Marcos Creek, is also listed for phosphorus, as well as DDE and sediment toxicity.

Objectives

A review was conducted to (i) analyze available water quality data and related information for Lake San Marcos, (ii) identify, to the extent possible, the factors and processes controlling lake water quality, (iii) identify any gaps in understanding of the limnology, ecology and water quality conditions in the lake, and (iv) to assess the feasibility of various techniques for improving water quality in Lake San Marcos.

Approach

Available data describing water quality conditions of San Marcos Creek and Lake San Marcos have been provided by the City of San Marcos, San Diego County, the San Diego Regional Water Quality Control Board, Vallecitos Water District, City of Escondido, San Marcos Unified School District, Lake San Marcos Community Association, and other private parties. The available documents and data have been compiled into 3 bound volumes totaling 3259 pages. This compendium has been reviewed, with key documents and datasets pertinent to the lake used to develop a summary of historical water quality as well as current conditions. The primary references used in this assessment are identified in Table 1.

Table 1. Primary references used in analysis.

Report	**Topic**	**Sampling Date**	**Compendium Pages**
Ball, 1974	Limnology, water quality	July - November, 1974	CMS 707-725; 2330-2338
Ball, 1979	Fishery	1978	CSM 707-725
Risk Science, 1991	Habitat, biology, water quality	October 1991	CSM 2561-2635 + Appendices
LSM Task Force, 2005	Bacteria, DO, DRP	June 2005	CSM 863-872
SDRWQCB, 2009	Water quality	May 2009	CSM 1023-1043
Anderson, 2009	Limnology, water quality	September 2009	Appendix to this report

Other documents and datasets were also used and have been identified and cited as needed. In many instances, these documents represent memos or short letters, often without clear authorship, and are simply cited by their page number in the compendium.

Results

Lake Basin Characteristics

The physical dimensions of a lake represent important baseline information needed to manage and restore lakes and reservoirs. For example, the area, depth and volume of a lake is needed to develop water and nutrient budgets, design aeration and oxygenation systems, and implement lake management strategies. Lake San Marcos came into being as a 40-acre lake following construction of a small dam on San Marcos Creek in 1946 (CSM000326). The current concrete arch dam was completed in 1962, the shoreline was recontoured, and the lake filled with Colorado River water from the San Diego Canal in 1963 (Ball, 1974). In response to a request from the County of San Diego concerning the elevation-area-volume relationships for the lake (CSM000669), a 1969 DWR memo provided area, capacity and depths taken from a 1952 application indicating a maximum depth of 38.5 ft, a lake surface area of 54 acres and a capacity of 480 acre-feet (CSM000671). This yields an average depth of 8.9 ft (Table 2). Following raising of the dam and other activities, the area, capacity and depth were reported to have increased by 50% or more (e.g., area of 80 acres and capacity of 1200 acre-feet) (LSM Fact Sheet).

Table 2. Basin characteristics reported for Lake San Marcos.

Characteristic	1952[a]	1963[b]	1974[c]	2006[b]
Area (acres)	54.0	80	57.9	NA
Capacity (acre-ft)	480	1200	658.5	NA
Mean Depth (ft)	8.9	15.0	11.4	NA
Maximum Depth (ft)	38.5	54	34	38

[a]DWR, 1969; [b]LSM Fact Sheet; [c]Ball, 1974

Ball conducted a bathymetric survey for the lake in 1974 and found values quite a bit lower than reported however (Table 2). In that survey, he reported the upper part of the lake, representing 78% of the lake surface area, was a constructed basin of rather flat uniform depth between 8-9 ft (CSM000711). The lower portion of the lake located within the natural steep-sided canyon was about 12 acres (22% of the lake area), with an average depth of 20 ft and a maximum depth of 34 ft (CSM000712). These values can be compared with more recent values measured by Norman Peet for the County of

San Diego Department of Public Works on Nov.19-20, 2005 (CSM000896-906). In that survey, lake depth was measured at 19 transects across the short axis of the lake (approximately E-W) with about 15 depth measurements per transect. The maximum depth reported was 27.9 ft at a transect in the southern part of the lake near the dam, while depths were typically 6-8 ft near the middle and upper-middle region of the lake. While the lake surface elevation was not specified in Ball's survey in 1974, assuming similar water levels, it appears that the upper part of the lake has filled in with about 2 ft of sediment in the intervening 31 years. This corresponds to an average sedimentation rate of about 0.8 inches/yr or 2 cm/yr. This sedimentation rate is intermediate between the sedimentation rate of 2.4 cm/yr reported by the USGS for Canyon Lake in southwestern Riverside County for the period 1927-1998 (USGS, 1998), and the average 20th century value of 1.35 cm/yr for Lake Elsinore (Byrne et al., 2004). A higher rate of sediment deposition near the dam is likely to have occurred due to the focusing of fine organic sediments into deeper water (Anderson et al., 2008), although the trend in maximum depth is unclear. A maximum depth of 34 ft reported by Ball (1974) is actually lower than that reported more recently by the LSM Task Force of 38 ft, although a survey transect about 100 ft from the dam conducted as part of the 2005 survey for the County revealed a maximum depth of 27.9 ft (CSM000899).

Infilling of lakes and reservoirs with sediment is a natural process, although accelerated sediment accumulation is commonly found in disturbed watersheds, especially those with significant agricultural activities. Lake San Marcos thus serves as a sediment trap, reducing sediment load to downstream reaches of the impounded San Marcos Creek. In addition to the loss of storage capacity and average depth of the lake, particulate forms of nutrients are also retained in the reservoir. This can lead to long-term biogeochemical recycling of nutrients from the sediments to the water column. Such nutrient recycling can persist for several years, or even a decade or longer in some cases.

Nutrients

Nutrient concentrations have been measured occasionally at the lake, with Ball (1974) offering the most comprehensive look at water quality. In that study, nutrient concentrations and other water quality parameters were measured monthly from July – November 1974. Concentrations reported in that study were averaged across all samples sites and dates for comparison with site-averaged single-day measurements made in 1991, 2005 and 2009 (Table 3).

Nutrient concentrations were very high in 1974, *e.g.*, with the average NO_3-N concentration over 14 mg/L and dissolved reactive phosphorus (DRP) of 1.6 mg/L (Ball, 1974). These very high concentrations of readily bioavailable forms of nutrients indicate that the availability of light, rather than nutrients, regulated phytoplankton abundance in the lake. By 1991, significantly lower nutrient levels were present in Lake San Marcos (Table 3). Dissolved nutrient concentrations were only about 5-10% of those found 17 years prior; total P was also substantially lower (0.37 mg/L, a reduction 85% from 1974) (Table 3). Moreover, relatively little of the total P was in a dissolved form, suggesting P may have been limiting algal growth.

Table 3. Dissolved and total nutrient concentrations in Lake San Marcos – surface samples.

Nutrient	1974[a]	1991[b]	2005[c]	2009[d]	2009[e]
	Jul-Nov (n=5)	*Oct (n=2)*	*Jun (n=1)*	*May (n=3)*	*Sep (n=3)*
NH_4-N	1.07±0.34	0.13±0.03	-	0.16±0.04	0.16±0.13
NO_3-N	14.66±4.92	<0.1	-	0.07±0.03	0.16±0.04
Total N	-	-	-	2.72±0.79	3.14±0.12
DRP	1.64±0.49	0.085±0.035	0.34±na	0.044±0.023	0.064±033
Total P	2.56±0.93	0.37±0.08	-	0.23±0.03	0.16±0.01

[a]Ball, 1974; [b]Risk Sciences, 1991; [c]LSM Task Force; [d]RWQCB, 2009; [e]Anderson, 2009

Following the near-record runoff in early 2005 and resulting problems in the watershed, the measured DRP concentration in June 2005 had increased to 0.34 mg/L. Increases in DRP concentrations were also observed during this time period in other lakes in the region; e.g., DRP concentrations in Lake Elsinore increased markedly from values of 0.036 mg/L in June 2004 to 0.449 mg/L in June 2005 (Anderson and Lawson, 2005). Nutrient concentrations in May (RWQCB, 2009) and September (Anderson, 2009) of this year (2009) were comparable to concentrations reported in 1991 (Risk Sciences, 1991). It seems likely that changes in land-use and improvements in agricultural practices and waste treatment and disposal were responsible for the dramatic reductions in nutrient concentrations between 1974 and 1991. Analysis of water quality data suggests, however, that limited subsequent improvements have been achieved over the past 18 years, with periodic episodes of large external nutrient loading from the watershed.

Nutrient concentrations are known to increase dramatically in bottom waters of eutrophic lakes that are thermally stratified. Measurements of concentrations above the sediments were made only in 1974 and 2009 (Table 4). Very high concentrations were present in bottom waters of the lake in 1974; high concentrations of dissolved nutrients result from the mineralization and release of N and P from the sediments and accumulation in the hypolimnion of the lake. Concentrations of NH_4-N and DRP in 2009 were about 40% lower than found in 1974 (Table 4), but remain very high and no doubt contribute to algal blooms following cooling and mixing of the water column in the fall. Internal loading of nutrients from bottom sediments can account for >95% of the overall annual nutrient loading to the water column in shallow lakes during periods of drought (Anderson, 2001).

Table 4. Dissolved and total nutrient concentrations in Lake San Marcos – bottom samples.

Nutrient	1974[a]	1991[b]	2005[c]	2009[d]	2009[e]
	Jul-Nov (n=3)	*Oct*	*Jun*	*May*	*Sep (n=1)*
NH_4-N	18.62±3.14	-	-	-	10.27
NO_3-N	18.10±5.96	-	-	-	0.37
Total N	-	-	-	-	8.73
DRP	5.76±2.46	-	-	-	3.63
Total P	6.56±2.05	-	-	-	3.45

[a]Ball, 1974; [b]Risk Sciences, 1991; [c]LSM Task Force; [d]RWQCB, 2009; [e]Anderson, 2009

<u>Other Water Quality Measurements</u>

In addition to nutrient concentrations, a number of other measurements are often made to provide information about water quality in lakes. A simple measurement of water clarity is routinely made using a Secchi disk, a small disk with alternating quadrants of white and black. The Secchi depth (Z_{sd}) represents the depth at which the disk is no longer visible and is directly related to the turbidity in the water column due to both phytoplankton and suspended solids. The average Z_{sd} values have been very low since 1974 (Table 5). Values less than 2.0 m are generally considered to be excessively productive (eutrophic) and values <0.5 m are considered hypereutrophic (Carlson, 1977; Carlson and Simpson, 1996). Low transparencies also limit aquatic plant growth. Secchi depths were observed to increase since 1974, however, with transparencies 50% higher in 1991 (0.76 m) and 100% (2x) higher in 2009 (0.95 m) (Table 5). For comparison, Z_{sd} values for Canyon averaged about 1.0 m in 2006-07 (Anderson, 2007).

Chlorophyll concentrations were only measured on two occasions (October 1991 and May 2009) (Table 5). The reported concentration of 11.8 µg/L for 1991 is considered somewhat suspect given the low Z_{sd} value. A regression of Z_{sd} values and chlorophyll a concentrations yielded an equation by Rast and Lee (1978) of the form:

$$Z_{sd} = 6.35 * Chl\ a^{-0.473} \qquad (1)$$

A chlorophyll concentration of 11.8 µg/L would thus be expected to yield a Z_{sd} value of 1.98 m (compared to the value of 0.76 m reported) (Table 5). This Z_{sd} value is in fact predicted to yield a chlorophyll a concentration of 90 µg/L.

Table 5. Other water quality measurements in Lake San Marcos – near surface.

Property	1974[a]	1991[b]	2005[c]	2009[d]	2009[e]
	Jul-Nov	*Oct (n=2)*	*Jun (n=1)*	*May (n=3)*	*Sep (n=3)*
Z_{sd} (m)	0.48±na	0.76±0.15	-	-	0.95±0.15
Chl a (µg/L	-	11.8±3.3	-	152±67	-
pH	9.15±0.18	9.15±0.05	-	8.83±0.09	8.06±0.08
DO (mg/L)	-	3.8±1.5	8.4±na	17.4±3.2	5.0±2.6

[a]Ball, 1974; [b]Risk Sciences, 1991; [c]LSM Task Force; [d]RWQCB, 2009; [e]Anderson, 2009

The pH values found in Lake San Marcos are typical of productive lakes here in the arid western U.S., with daytime values exceeding somewhat the theoretical pH near 8.2 for waters in a calcareous watershed in equilibrium with atmospheric CO_2. Photosynthesis depletes dissolved CO_2, shifting the following equilibria to the left:

$$CO_2 + H_2O \leftrightarrows H_2CO_3 \leftrightarrows H^+ + HCO_3^- \qquad (2)$$

To compensate for the utilization of CO_2 by phytoplankton during photosynthesis, carbonic acid (H_2CO_3) undergoes dehydration; protons (H^+) react with bicarbonate (HCO_3^-) to replace lost H_2CO_3, thus lowering the H^+ concentration and raising the pH. The slightly lower pH found this past fall is thought to result from a partial mixing of deep water into the surface, bringing lower pH water with excess CO_2 to the surface as well.

The final and often critical water quality parameter for lakes is dissolved oxygen (DO). Adequate DO is necessary to support fish and other organisms in aquatic ecosystems. A value of 5 mg/L or higher is considered suitable for a productive fishery, although fish kills often result only when DO concentrations drop below 1-2 mg/L. Water in equilibrium with atmospheric O_2 has a DO concentration of about 8-10 mg/L (depending upon temperature), so values less than this indicates undersaturation resulting from net consumption of DO, while values greater than that indicates supersaturation (net production). The reported DO levels varied from values of 3.8 –

17.4 mg/L (Table 5); values below 8-10 mg/L found in October 1991 and late September 2009 indicate that anoxic bottom waters were partially mixed into the surface waters . Strong sulfide odors were present in bottom waters and very low DO levels were also present near the dam in the morning during the recent sampling on September 30, 2009 (Appendix). Rapid mixing of sulfidic bottom waters in the surface waters has resulted in numerous fish kills this past summer and fall (*e.g.*, Lake Elsinore and Canyon Lake), and extreme odors (*e.g.*, Upper Oso Reservoir).

Dissolved oxygen thus varies vertically within the water column of most stratified lakes in a manner that is related to the distribution of heat. That is, lakes thermally stratify with warm less-dense water floating on top of cooler, denser water (Fig. 1). Heat is added at the lake surface due to absorption of shortwave and longwave radiation, with wind energy only able to mix the heat a finite distance into the water column (the epilimnion). Beneath this layer is an often pronounced thermal gradient (metalimnion) and layer of cool, dense water (hypolimnion) (Fig. 1a). Buoyant forces keeping heat from being mixed down through the entire water column also prevent DO from being mixed downward; bacterial decomposition and respiration reactions rapidly consume available DO, resulting in anoxic or anaerobic conditions in the hypolimnion (Fig. 1b). It is in this zone that H_2S, NH_4-N and DRP accumulate (Table 4).

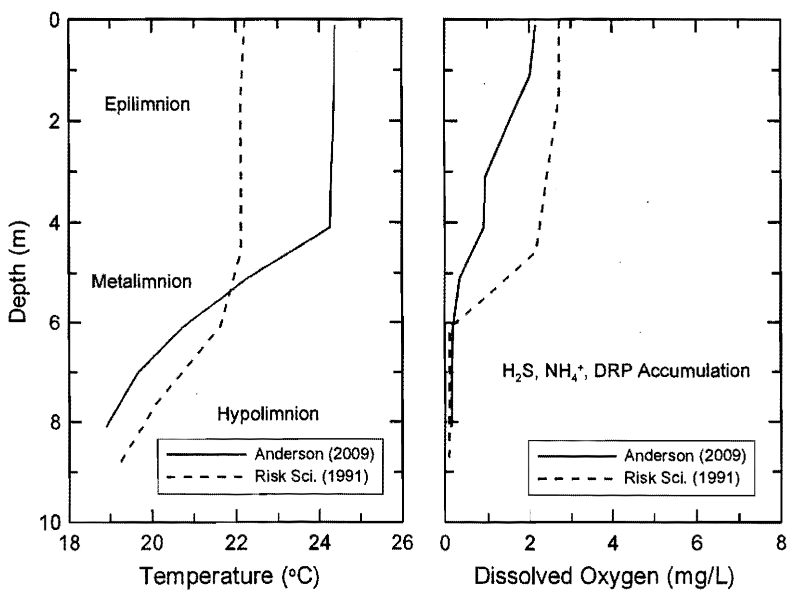

Fig. 1. Vertical profiles of a) temperature and b) dissolved oxygen in Lake San Marcos.

Broadly similar temperature and DO profiles were present on both September 30, 2009 (Appendix) and October 17, 1991 (Risk Sciences, 1991) (Fig. 1). Slightly greater cooling into the fall lowered the epilimnetic temperature of the water column measured by Risk Sciences relative to that present in late September.

These temperature and DO profiles are part of the regular seasonal trends in most lakes here in Southern California (*e.g.*, Fig. 2), where cool isothermal conditions are present in the winter, the surface water warms in the spring forming an epilimnion that reaches maximum temperatures in late summer (August) before cooling in the fall (Fig. 2). DO concentrations are initially high throughout the water column, although levels decline rapidly in the hypolimnion once the lake stratifies in the spring (Fig. 2).

An anoxic hypolimnion is thus present through much of the spring, summer and into the fall, with significant DO recurring only in the winter when the lake is well-mixed (Fig. 2). The mixing event in late fall brings this anoxic bottom water, also enriched in NH_4-N, DRP and H_2S, up into the surface resulting in potential fish kills and subsequent algal blooms.

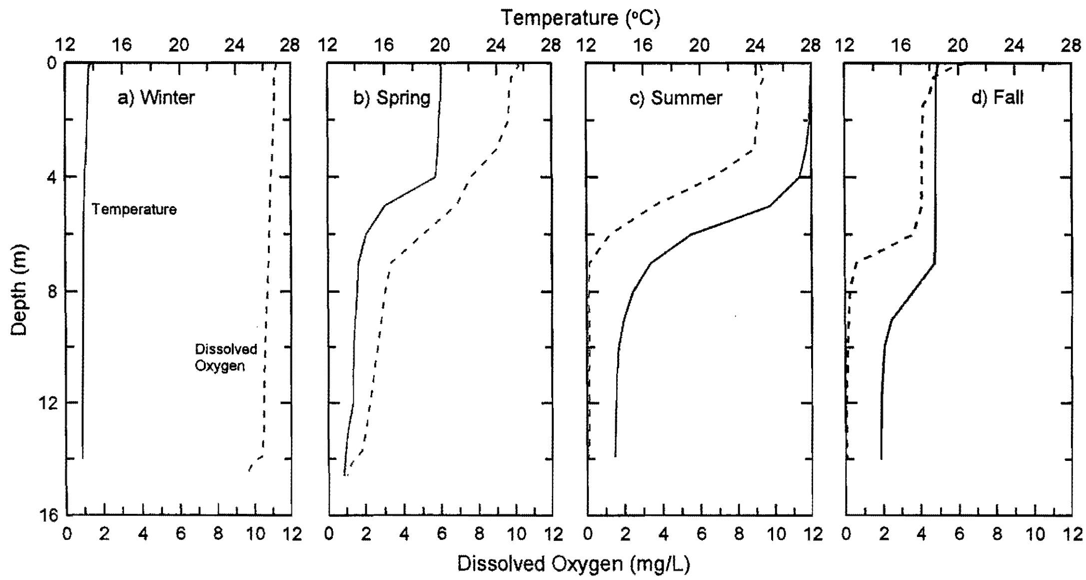

Fig. 2. Seasonal temperature and DO profiles in small lakes in Southern California (Canyon Lake, CA).

<u>Fishery</u>

Fish kills have in fact occurred occasionally at the lake; fish kills were recorded in 1968, 1974, 1976 and 2006, although other smaller episodes may have also occurred. Information concerning the fishery is restricted to two studies: Ball (1979) and Risk

Sciences (1991). A seine survey by Ball (1979) found most of the fish biomass to be in small bluegills, followed by bass and catfish (Table 6). This mass distribution is rather unusual since the fewer number of large fish tend to dominate the total fish biomass in a lake. Ball (1979) noted the presence of too many small bluegills and apparent over-fishing of bass. He made several recommendations to improve the fishery in Lake San Marcos, including the stocking of threadfin shad as forage for bass; construction of habitat in upper part of the lake through addition of rocks, aquatic vegetation such as water lilies; and installation of an aeration system.

Table 6. Summary of available fishery survey results.

Species	**Ball (1979) (% by Mass)**	**Risk Sciences (1991) (% by Abundance)**
Bluegill	46.9 %	-
Black bass	22.6 %	4.3 %
Catfish	19.3 %	-
Green Sunfish	6.1 %	-
Bullhead	0.1 %	1.4 %
Threadfin Shad	-	94.2 %

Risk Sciences (1991) conducted an overnight gill net survey about 12 yrs later and reported a different fishery in the lake. While the use of a very different sampling technique makes it difficult to compare these results with those from Ball (1979), the survey clearly shows the emergence of threadfin shad as a dominant fish in the lake. It is not clear if the shad were stocked based on Ball's recommendation or if they simply arrived in flows from the Colorado River aqueduct. The threadfin shad appear to have remained a dominant species, *e.g.,* in 2006 a fish kill removed a large number of the population. While threadfin shad are a favorite prey species for many large piscivores, they are zooplanktivores, grazing down beneficial zooplankton populations in the lake. As a result, they can adversely affect the zooplankton community and impair water quality.

<u>Zooplankton and Benthic Invertebrates</u>

The report by Risk Sciences (1991) provides the only assessment of invertebrates in Lake San Marcos. Zooplankton were sampled with a plankton trap deployed during the day in the photic zone at 2 sites on the lake. Surprisingly, no zooplankton were reported present in either of the samples. The small sample volume (30 L) near the surface during the daytime may have resulted in a severe undersampling of individuals.

Risk Sciences (1991) concludes that predation by shad and poor food quality may be responsible for their apparent absence in the lake.

Benthic invertebrates were sampled at the same 2 sites with an Ekman dredge. The dredge was used to sample the uppermost 10 cm or so of soft bottom sediments, with organisms subsequently sieved out of the mud. Risk Sciences reported high abundance of chironomids at one of the sites, although few other types of benthic invertebrates were found (Risk Sciences, 1991). Chironomids (midge larvae) are common in nutrient-rich bottom sediments with low DO concentrations, and are thus often an indicator of poor water quality (EPA). These benthic invertebrates are presumably a part of the diet of bluegills and other fish species in the lake.

Phytoplankton

Abundant blue-green algae have been reported in Lake San Marcos in 1974 (Ball, 1974) and more recently in the summer of 2005 (CSM000866 & 877). Risk Sciences also evaluated the phytoplankton community in the lake in October 1991. A comparatively diverse community was present at that time, with diatoms and dinoflagellates comprising 22 and 32% of the total population, with a substantial number of cryptophytes and green algae also present (20 and 18%, respectively). As a group, blue-green algae comprised only 8% of the phytoplankton of the lake (Risk Sciences, 1991). Inspection of water samples from July 2009 found a diatom-dominated phytoplankton community (chiefly *Synedra spp.*), while a more diverse community was present in September 2009, one that included diatoms, green algae, dinoflagellates and small colonial blue-green algae (Appendix). Unlike other types of phytoplankton, diatoms and dinoflagellates both have a nutrient requirement for silicon (Si); the presence of large numbers of diatoms in mid-July is somewhat unusual, since diatoms are most abundant in the winter and early spring, when cooler temperatures are present and runoff delivers a fresh supply of Si to the lake. Si limitations (<0.5 mg/L) are often witnessed by late spring (*e.g.*, in Lake Elsinore, Big Bear Lake), at which time green algae and then blue-green algae tend to take over. The large numbers of diatoms in mid-July provides some indication of a steady-input of Si to the lake, presumably through groundwater flow.

Water Budget

Sources of water to Lake San Marcos include flows from San Marcos Creek, direct precipitation onto the lake surface during rain events, local runoff into the lake from storm drains and the local watershed, and spring and other ground water sources. Water is lost from the lake due to outflow and to evaporation. Mathematically this can be represented as:

$$\frac{dV}{dt} = Q_{SMC} + Q_{Runoff} - Q_{out} + PA_s - EA_s \pm G \qquad (3)$$

where V is the volume of the lake, t is time, Q_{SMC} is the surface inflow from San Marcos Creek, Q_{Runoff} represents other surface inflows, *e.g.*, storm drain flows, Q_{out} is the flow at the spillway, P is the precipitation rate, A_s is the lake surface area, E is the evaporation rate, and G is net groundwater flow. Groundwater flow is often calculated from the difference between observed lake volume and the other inputs and outputs.

During the summer, there is no direct precipitation on the lake and greatly reduced inflows from San Marcos Creek and local runoff. As a result of such conditions, most lakes in the region undergo pronounced reductions in lake surface level in the summer due to evaporation. In fact, evaporation removes about 0.8 m (2.6 ft) of water over the May-September time period based upon meteorological data at the Escondido CIMIS station (CIMIS, 2009). At a surface area of 58 acres, this corresponds to 150 acre-feet of water lost from the lake due to evaporation, occurring at an average rate of 3 acre-feet per day (or 1.5 cfs). Observations of the surface elevation within an estimated 6-8" of the dam crest in July and September 2009 suggests large inputs of water into the lake through the summer. The magnitude of these inputs can be estimated from equation 3 assuming approximate steady-state volume (i.e., dV/dt=0). Thus, to maintain approximate steady-state volume in the lake, inflows of about 1.5 cfs are required (eq 3). Recent measurements made by San Diego County indicate that inflows due to San Marcos Creek is about 0.3 cfs, while the sum of the major storm drains adds another 0.12 cfs inflow to the lake (CSM000152). Against an average evaporative flux of 1.5 cfs, and correcting for the change in storage (about 0.1 cfs), this leaves an unspecified additional input of up to 1 cfs to the lake that we can reasonably hypothesize is principally due to groundwater flow (Table 7).

This groundwater would be high in dissolved Si, and thus may account for the previously noted persistence of diatoms in the lake through much of the year. Interestingly, Ball (1974) also noted high lake levels and estimated that >200 af of water enters the lake annually from springs and irrigation drainage. Groundwater flows are thus helping to maintain lake level, unlike most other lakes in the region.

Table 7. Dry-weather water balance (July 2009).	
Water	**Flow rate (cfs)**
Inflows (+)	
San Marcos Creek	0.3
Storm drains	0.12
Precipitation	0
Losses (-)	
Evaporation	1.5
Outflow	0
Change in Storage	0.1 cfs
Difference (Groundwater)	0.98 cfs

Current Understanding of Lake San Marcos

This review allows one to draw some general conclusions concerning the lake:

- The northern and middle part of lake is shallow with direct connection between nutrient-rich sediments and the surface layer of the water column
- Internal recycling of nutrients maintains high algal productivity and low water clarity throughout the year
- Algal turbidity limits the growth of aquatic macrophytes
- The southern part of lake is deeper and thermally-stratified through the summer-fall
- Rapid depletion of DO occurs in hypolimnion following stratification, making it unsuitable for fish, zooplankton and other aerobic organisms
- NH_4-N, DRP and H_2S accumulate to high concentrations in the hypolimnion
- Cooling temperatures in fall results in mixing of H_2S, NH_4-N and DRP into upper water column
- This depletes DO there, potentially triggering fish kills, while also fueling subsequent algal blooms
- The ecology in the lake is probably not presently suited for sustaining good water quality
- Groundwater flows help to maintain lake level through much of the year

Gaps in Understanding

While the available data is very important in defining the water quality conditions and processes affecting water quality in Lake San Marcos, some significant questions remain. Additional insights about the lake can help guide the restoration and efficient management of the lake. Five specific areas were identified (although additional data needs will likely be identified in the future):

i. *Better understanding of the current bathymetry and depth-area-volume relationships.* The recent survey conducted for the County of San Diego clearly indicates the accumulation of sediment and loss of depth through much of the lake. Notwithstanding, the estimated 300 soundings collected along the 19 horizontal transects are not sufficient to develop a detailed bathymetric map and depth-area-volume relationships for Lake San Marcos. These data are needed to conduct more accurate water budget, modeling and water management calculations for the lake.

ii. *Direct information about sediment distribution, thickness and properties.* Related to the need for higher resolution bathymetry is the need for information about the thickness, properties and distribution of sediment within the basin. In addition to depth to sediments, the thickness and distribution of bottom sediments provides essential information about the volume of sediment retained in the lake, and depositional processes operating here. This information is critical if sediment dredging is being considered anywhere in the lake now or in the future. Understanding the characteristics of the sediments (*e.g.*, hardness, texture, nutrient and contaminant concentrations) is also necessary when considering dredging or recontouring of the lake bottom. The distribution of different sediment types can also influence selection and design of in-lake treatment.

iii. *Rates of internal nutrient recycling.* In addition to understanding the distribution, thickness and types of sediments in the lake, it is also important to quantify the rate of internal nutrient recycling from each of the major sediment types, and the contribution of internal recycling to the lake's overall nutrient budget. Moreover, being able to focus on regions of high-nutrient sediments allows one to more carefully target treatment to those regions that are responsible for disproportionately large fraction of nutrients entering the water column.

iv. *Rates of external loading of nutrients.* The rate of external loading of nutrients from San Marcos Creek, and from groundwater, nuisance runoff and other inputs represents a critical gap in knowledge about the lake. Quantifying the flows, concentrations and external loading of nutrients are required for development of an overall nutrient budget for the lake, for its management, and for the efficient use of resources in managing water quality. Following the development of a nutrient budget, water quality modeling can be conducted to predict the extent of reductions in external and internal loading that would be necessary to achieve specific water quality objectives.

v. *Ecology and food web of the lake, including fishery and zooplankton communities.* Finally, significant questions remain about the ecology in Lake San Marcos. It will be essential to characterize the ecology, especially the zooplankton community, if one is to favorably modify it to improve water quality and develop a balanced sustainable food web and fishery.

Possible Remediation Strategies

Despite uncertainties about the lake, it is helpful to review some of the approaches used to improve water quality in impaired lakes. The focus here will be on in-lake techniques for the control of nutrients and algae, although it is implicit that BMPs and other actions within the watershed also need to be undertaken to limit external loading of nutrients to the lake. A number of different options exist for reducing algae (and nutrients) in lakes. Techniques include a range of mechanical, chemical and biological controls that differ in their mode of action, advantages and disadvantages (Table 8) (NALMS, 2001).

Out of these 17 different control strategies, 13 of them could conceivably play some role in the restoration of Lake San Marcos. Dilution and flushing were not considered practical given the limited water supply in the region, since flushing rates of 10-15% each day would probably be needed to substantively improve water clarity. Settling agents and pathogens were also discounted since settling agents treat only the symptom of the problem and would represent a significant recurring cost, while use of pathogens remains an experimental technique to this point. Selective nutrient addition was also discounted since it has not been demonstrated to be effective in lake studies and is more appropriate for nutrient-poor lakes where increased fish production is desired, rather than for algal control in eutrophic lakes (Table 8).

Table 8. Management options for control of algae in lakes (NALMS, 2001).			
Option	**Mode of Action**	**Advantages**	**Disadvantages**
Physical Controls			
1. Hypolimnetic aeration or oxygenation	Addition of air or O_2 maintains oxic water & sediments	Reduces internal loading of P; provides habitat for fish, zoo	May promote supersaturation of gases for fish
2. Circulation and destratification	Use of air or water to mix water column	Reduces surface algal scums, internal P loading; adds DO	May spread problems
3. Dilution and flushing	Addition of water can dilute or flush nutrients, algae	Reduces nutrient concentrations and their detention in lake	Diverts water from other uses; possible downstream effects
4. Drawdown	Lowering lake level allows oxidation of sediments	Reduce nutrients, increase capacity for flood control	Possible impacts to aquatic plants, downstream impacts
5. Dredging	Sediment is removed	Can reduce internal loading, increases water depth	Removes vegetation, benthic invertebrates; disposal issues
6. Light limitation	Creates light limitation	May achieve control of rooted plants as well	May induce thermal stratification, anoxia
7. Mechanical removal	Filters lake water	Algae and nutrients removed as needed	High backwash and sludge handling, labor, capital
8. Selective withdrawal/ release	Discharge of anoxic high nutrient bottom water	Removes bad water efficiently	Downstream problems if not treated
Chemical Controls			
9. Algaecides	Algaecides applied to target areas	Rapidly eliminates algae,	Toxic to non-target organisms, nutrient recycling
10. Phosphorus Inactivation	Application of alum or other salts that floc, bind P	Removal of algae and P; forms barrier limiting P release	Possible pH and toxic effects
11. Sediment Oxidation	Addition of chemicals to oxidize sediments	Slows internal recycling of nutrients, reduce SOD	May affect benthos
12. Settling agents	Addition of floc agent to settle algae	Removes algae and increase clarity	May affect benthos
13. Selective nutrient addition	Change nutrient ratio, alter algal community	Can promote non-nuisance forms of algae	Increase algal abundance, downstream effects
Biological Controls			
14. Enhanced grazing	Manipulation to achieve grazing control over algae	May increase water clarity, increase fish biomass naturally	May involve new species, difficult to control
15. Bottom-feeding fish removal	Remove fish that resuspend bottom sediments, nutrients	Reduces turbidity and nutrient inputs to water column	Targeted fish species difficult to control
16. Pathogens	Addition of inoculum to attack algal cells	Can be highly specific	Experimental, uncertain results
17. Competition and allelopathy	Plants can compete with algae for nutrients, light	Natural biological interactions, improve habitat	Plants can become nuisance

The remaining control strategies all offer some potential benefit to water quality, although costs vary widely (Table 9). For example, the simple strategy of selective withdrawal/release can be a relatively inexpensive way to remove nutrients from the lake if some makeup water is available, although downstream effects would need to be considered. Aeration is the most commonly used lake management technique, helping to mix DO throughout the water column, slow release of nutrients from the sediments, and keep nuisance algae fro accumulating to excessive levels near the lake surface. Dredging often represents the most expensive technique, but is the only one that deals with excess sediment accumulation and loss of depth and storage volume in lakes.

Table 9. Relative costs of possible management options for Lake San Marcos.

Option	Suitability	Relative Cost
Physical Controls		
1. Hypolimnetic aeration or oxygenation	Y	$$$
2. Circulation and destratification	Y	$$$
3. Dilution and flushing	N	-
4. Drawdown	Y	$-$$
5. Dredging	Y	$$$$
6. Light limitation	Y	$$
7. Mechanical removal	Y	$$$
8. Selective withdrawal/release	Y	$
Chemical Controls		
9. Algaecides	Y	$$
10. Phosphorus Inactivation	Y	$$$
11. Sediment Oxidation	Y	$$$
12. Settling agents	N	-
13. Selective nutrient addition	N	-
Biological Controls		
14. Enhanced grazing	Y	$-$$
15. Bottom-feeding fish removal	Y	$$
16. Pathogens	N	-
17. Competition and allelopathy	Y	$-$$

[a] *these relative costs represent very rough order-of-magnitude estimates: $ = $1K-$10K; $$ = $10K-100K; $$$ = $100K-$500K; $$$$ = >$500K.*

Chemical controls, such as algaecide application, can be comparatively inexpensive, although recurring treatments are typically needed since this treats only the symptom of the problem. Algaecides are generally effective at low µg/L concentrations and keep nuisance algae from accumulating to excessive levels; other chemical treatments that may require multiple mg/L doses to be effective become very expensive owing to the large volume of water in the lake. Algaecides can also render the sediments toxic with excessive applications, creating other longer-term problems. Phosphorus inactivation with alum has been used with some success in lakes, although it is necessary to reduce external loading as much as possible to extend the effectiveness of such a treatment. The El Nino cycle in Southern California makes it difficult to use alum to achieve long-term nutrient and algal control. Sediment oxidation via the introduction of nitrate or other oxidants into the sediments is a way to oxidize the sediments and slow internal nutrient recycling, although this approach can potentially create problems for benthic organisms. (It may be that groundwater flow into the lake is helping to achieve this if NO_3^- is present.)

Biological controls potentially offer the least invasive and most natural ways to improve water quality in lakes and reservoirs (Table 8). Since zooplankton graze upon phytoplankton a part of the natural food web in lakes, actions to maximize zooplankton populations can result in improved water clarity especially at low-moderate nutrient levels. *Daphnia* and other large-bodied zooplankton are especially important in this regard. Removal of benthivorous (bottom-feeding) fish such as carp can also improve water quality by reducing the amount of sediment and nutrients resuspended during their foraging. Competition with phytoplankton for nutrients by aquatic plants and attached algae can also favorably shift biomass production away from phytoplankton and thus increase water clarity and overall water quality.

A Strategy for Lake San Marcos

As one can see, a number of different in-lake strategies can be employed to improve water quality in Lake San Marcos. Emphasis should be placed on those actions that can reduce nutrient concentrations in the water column (per the 303(d) listing), avoid fish kills and other problems such as odors, and improve water clarity. Excessive nutrients are the cause of the impairment, and thus properly deserve intense focus. While it will be critical to control external loading of nutrients to the lake, actions within the lake will also be necessary to meet water quality goals. In some cases, in-lake treatment can offer a more cost-effective strategy for reducing nutrient concentrations than actions in the watershed. Insufficient information exists about the nutrient budget for the lake, its ecology, sediment characteristics, and rates of internal nutrient recycling and oxygen demand to predict the extent of improvements that could be expected by implementing particular restoration actions. Nevertheless, it is useful to discuss, in general terms, possible strategies for the lake.

1. Selective withdrawal/release - It is estimated that about 100 acre-feet or 15% of the lake volume lies below the thermocline in summer. This volume of (hypolimnetic) water receives NH_4-N, DRP and H_2S liberated from the sediments in the deep water in the southern part of the lake that accumulate to high concentrations (Table 4). These chemicals remain out of the surface layer, however, and thus typically present problems only when mixed into the surface waters in the fall. This can create severe algal blooms and fish kills however. One way to reduce the amount of nutrients and H_2S accumulated in the hypolimnion would be to release water through the 6" pipe near the bottom of the dam when sufficient inflows exist. That is, excess water would be better released from the bottom of the lake than over the spillway. This would reduce the accumulation of nutrients and H_2S and deepen the generally well-aerated epilimnion. This action would potentially have no direct costs to implement, although very careful consideration would need to be given to the downstream impacts.

2. Aeration, hypolimnetic oxygenation, or destratification - All of these strategies aim to eliminate anoxia (low DO) in the bottom waters of the lake and reduce internal nutrient recycling, especially of phosphorus. Aeration involves mixing the water column using air injected in the bottom of the lake (Fig. 3a); the air bubbles rise to the surface, driving anoxic bottom water up to the surface while mixing aerated water downward. This destratifies the lake (*i.e.*, eliminates the thermal gradient in the water column (Fig. 2).

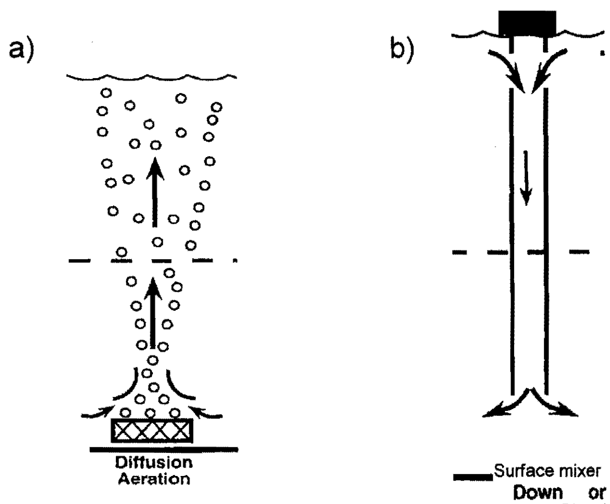

Fig. 3. Schematic of a) diffused aeration and b) surface mixer with draft tube (taken from NALMS, 2001).

Clean Lakes Inc. has recently submitted a proposal for two alternate configurations for a diffused aeration system for the lake (CMS000978-984), a deep-water aeration system that addresses the anoxia and stratification in the southern deep part of the lake ($24,031), and a whole-lake system that would also include the shallower upper part of the lake ($74,350). The upper system would help prevent stagnation of the water column.

An alternative approach is to mix warm naturally well-aerated surface water downward using a surface impeller, delivering DO to the bottom waters, setting up circulation and serving to destratify the water column as well (Fig. 3b). The diffused aeration approach is more commonly used than surface mixers, although the surface mixers are theoretically more efficient, using less energy than diffused aeration systems that require operating a compressor(s). Surface mixers do require anchoring a relatively large floating platform on the lake, however.

The third approach involves injection of pure O_2 or O_2-saturated water into the hypolimnion of the lake. This can be done in several ways, including full-lift or partial lift aerators, a Speece cone, or other large devices that include a surface structure. The size and cost of these devices would not be practical for Lake San Marcos, although direct O_2 injection into the bottom waters in a way similar to the diffused aeration system (Fig. 3a) could potentially be implemented. Such a system involves pumping pure O_2 into gas permeable tubing, where it dissolves fully into the water. No bubbles form, so vertical mixing of the water column does not occur and therefore differs from the diffused aeration system. The O_2 can be either delivered or produced on site.

While each of these systems may achieve the goals of increasing DO, reducing nutrients, and improving clarity, capital costs, operating costs, reliability, and aesthetic and navigational impacts should also be considered. Given the small surface area of the lake, a fully submersed system would be preferable since it would not negatively impact the view across the lake or present navigational concerns. On those grounds, the diffused aeration system or hypolimnetic oxygenation systems would be preferable to surface mixers or full- or partial-lift aerators. Simplicity, reliability and low capital costs make a diffused aeration system, such as that proposed by Clean Lakes, Inc. (CSM000978-988) a reasonable engineering approach to improving water quality in the lake. It may be advisable to initially install the deep-water system to gain some experience with lake aeration and its impact on water quality. Operating costs should be low (per specs on CSM000982 it should be only about $9/day assuming two 10.6 Amp/115 V compressors at an average electricity cost of $0.15/kWh).

3. Biomanipulation.

a) Enhanced Grazing - Diffused aeration and (if practical) bottom withdrawal/ release represent engineering activities that are expected to reduce nutrient levels and improve DO concentrations and clarity, especially in the southern part of the lake. Efforts to optimize natural processes should also be considered. Although current information about the zooplankton and fish communities is not available, it is expected that enhanced grazing of phytoplankton by large bodied *Daphnia* and other zooplankton will improve clarity of the lake. To achieve this, a top-down approach is recommended whereby periodic stocking of the lake with piscivorous fish such as largemouth bass will control threadfin shad populations in the lake. This top-down approach can be seen assuming a simple linear food web for Lake San Marcos that consists of 4 types of organisms: phytoplankton, zooplankton, zooplanktivores (such as threadfin shad), and piscivores (*e.g.*, largemouth bass) (Fig. 4). Phytoplankton abundance is directly related to the availability of nutrients (*e.g.*, P) in the lake, so control of nutrients through watershed actions and through aeration via the so-called "bottom-up" approach is expected to reduce phytoplankton levels. At the same time, grazing by zooplankton (*i.e.*, "top-down" control) also lowers the phytoplankton levels in the lake. Minimizing nutrient inputs *and* maximizing zooplankton grazing thus yields the lowest standing crop of phytoplankton, and best clarity and overall water quality (Fig. 4).

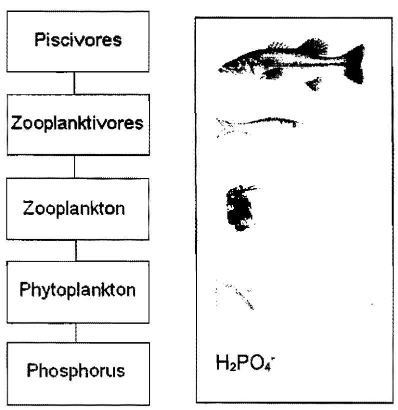

Fig. 4. Simplified linear food web showing relationship between availability of nutrients and different trophic levels in a lake.

However, zooplankton themselves are subject to predation by zooplanktivores, especially shad and other small fish. Thus, in lakes with high rates of predation, there are correspondingly low populations of zooplankton, resulting in little loss of phytoplankton due to grazing (a healthy *Daphnia* population can potentially filter the entire lake volume in 10 days). A correlation thus exists between zooplanktivore population and phytoplankton abundance, while an inverse relationship exists between zooplankton and their predators. It is advantageous then to minimize excessive zooplanktivore predation on zooplankton. This can be achieved through introduction of large sport fish capable of preying on, *e.g.*, shad. This strategy has been implemented at Lake Elsinore for several years. Along with removal of benthivorous carp and other actions, we have seen a favorable change in the fishery there (Anderson, 2008). (Carp, if shown to be present in high numbers in Lake San Marcos, should also be removed from the lake.) At the same time, aeration will help make the deep water in the lake more habitable for zooplankton.

b) Competition - Efforts should also be made to foster growth of non-nuisance aquatic plants such as water lilies, as found in the southern part of the lake. Aquatic plants remove nutrients from the sediments, thus reducing internal nutrient recycling. Aquatic plants also provide surfaces for attached algae that directly compete with phytoplankton for available nutrients in the water column. Aquatic plants further provide DO to the water column and protection for zooplankton and larval and juvenile fish. Moreover, water lilies and other emergent and floating-leaved aquatic plants provide habitat for birds and offer an attractive natural looking shoreline.

<u>Development and Implementation of Regular Monitoring Program</u>

It will be important to begin a regular monitoring program for the lake. Such a program is necessary to quantify the improvements in water quality achieved through in-lake and watershed management efforts. It will also provide needed information to guide adaptive management for the lake, quantify seasonal and longer-term trends in water quality, record inter-annual variability in water quality and response to drought and El Nino events, and develop a more complete understanding of the limnology of Lake San Marcos. At the absolute minimum, 2 simple but critical measurements should be made, specifically Secchi depth and lake level. If a staff gage is not presently installed at the lake, then one should be installed immediately. Secchi depth and lake level should be recorded weekly, and more frequently following rain events in the watershed. These measurements can be done from a dock, so it is not necessary to launch a boat. Secchi depth measurements should be made in an area that is open so as to avoid stagnant water where surface algal scums may accumulate. Several sites on the lake could be used to capture the spatial variability in transparency, but a single consistent sampling site, *e.g.*, off the far end of dock near the boat launch, would be adequate to capture short-term and longer-term trends in clarity of the water.

To quantify progress with respect to numeric nutrient targets or other water quality objectives for the lake, samples should also be collected and analyzed for total N and total P and dissolved nutrient concentrations (NH_4-N, NO_3-N and DRP). Chlorophyll concentrations and Secchi depth measurements at these sites could also be determined. These samples would be best collected from a boat on a quarterly basis. Three sites representing the northern, central and southern parts of the lake should be sampled. Samples collected directly into bottles below the surface of the lake would be adequate.

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Appendix

Lake San Marcos: September 30, 2009

Field and Laboratory Results

Water column measurements and water samples were taken at 3 locations on Lake San Marcos on September 30, 2009 (Fig. 1; Table A1). Sampling was conducted between about 9:00 – 11:30 a.m. I was assisted by Keith Plank and Fran Geneau. Special thanks to Keith Plank who graciously provided his boat and his time for this sampling.

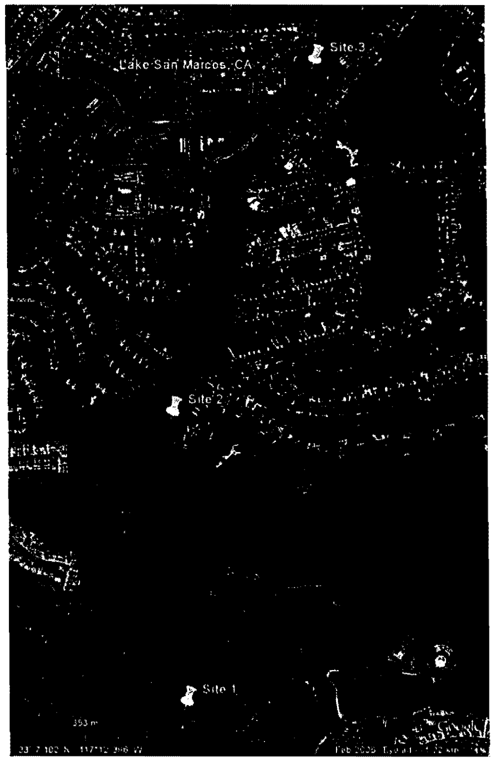

Fig. A1. Sampling sites.

Location of the sites were recorded using a Garmin eTrex GPS using the WGS84 datum. Water column temperature, dissolved oxygen (DO) and electrical conductance (EC) were recorded at 1 m depth intervals from the surface of the lake to the bottom sediments using a Hydrolab Quanta sonde. Maximum depth and conditions just above the sediments were also recorded. Transparency of the water was measured using a Secchi disk. Water samples were taken using a van Dorn sampler.

Table A1. Sampling sites on Lake San Marcos (9/30/09): latitude, longitude, depth and Secchi depth.

Site	Latitude	Longitude	Depth (m)	Z_{sd} (m)
1	33° 06.582'	117° 12.527	8.1	1.1
2	33° 07.035'	117° 12.549'	3.6	0.8
3	33° 07.584'	117° 12.262'	1.2	ND

Water samples were returned to the lab, promptly filtered through a 0.4 μm polycarbonate filter, and frozen until analysis of dissolved nutrients (NH_4-N, NO_3+NO_2-N and dissolved reactive P, DRP). Unfiltered water samples were digested using persulfate following Standard Methods (APHA, 1998). NO_3+NO_2-N, NH_4-N and DRP concentrations in the filtered and digested samples using colorimetric methods on a Spectronic 100 (Hach, 2009).

Depth at the 3 stations varied markedly, from a depth of 8.1 m at site 1 near the dam to 1.2 m near the inflow from San Marcos Creek (Table A1). Secchi depths were uniformly low in the lake, although the measured Z_{sd} value was slightly higher at site 1 (1.1 m) than at site 2 (0.8 m) (Table A1). A measurement was not made at site 3.

Results from the Hydrolab casts reveal a stratified water column was in place at this time, with about a 5.5°C difference in temperature between the surface and above the sediments at site 1 (Table A2). More significantly, low DO concentrations were present even in the epilimnion there (DO about 2 mg/L near the surface, and <0.5 mg/L below 4 m depth) (Table A2). Strongly reducing conditions were evident based upon the H_2S odor from the bottom water sample. An anoxic hypolimnion is common in eutrophic lakes in the region, although such low DO concentrations in the surface are unusual. It seems that a partial mixing event may have occurred, and mixed some of the cooler anoxic hypolimnion in the upper part of the water column. Observations reported by fisherman of patches of water with colloidal white particles in suspension are consistent with such a mixing event that also brings up bicarbonate and promotes precipitation of $CaCO_3$.

Table A2. Results from water column profile measurements.

Site	Depth	Temperature (°C)	DO (mg/L)	EC (mS/cm)
1	0	24.38	2.15	2.28
	1	24.36	2.00	2.28
	2	24.34	1.45	2.28
	3	24.27	0.92	2.28
	4	24.24	0.88	2.27
	5	22.24	0.32	2.14
	6	20.72	0.17	2.04
	7	19.66	0.15	2.01
	8	18.95	0.15	2.12
	8.1	18.9	0.13	2.12
2	0	25.03	5.51	2.28
	1	24.62	1.60	2.27
	2	24.51	0.80	2.27
	3	24.43	0.35	2.27
	3.6	24.13	0.25	2.21
3	0	25.54	7.32	2.16
	1	24.78	5.45	2.16
	1.2	24.78	4.41	1.83

Electrical conductance, a measure of the salinity or ionic concentration of the water, remained relatively stable near 2.2 mS/cm, although limited variability was present.

Water column conditions at the other 2 sites indicated no substantial vertical stratification of temperature present, owing to their shallow depth, although DO concentrations did vary (Table A2). The low DO concentrations above the sediments at site 2 may reflect high sediment oxygen demand. At the very shallow site 3, the surface layer was over 1°C warmer than at site 1, reflecting heating (Site 1 was sampled first, at about 9:00 a.m., followed by site 2 at about 10:30 a.m., and finally site 3 shortly after 11:00 a.m.). Higher surface DO concentrations at sites 2 and 3 results from increased rates of photosynthesis and production of DO.

Inspection of the water sample from site 2 following centrifugation under a Nikon E600 compound microscope revealed a fairly diverse phytoplankton community. No effort was made to quantify cell abundance, although diatoms, green and blue-green algae, and some dinoflaggelates were observed, without a single group dominating the community.

Chemical analyses indicate nutrient concentrations well in excess of Basin Plan objectives for total N and total P, with comparatively little N and P in surface water samples in dissolved readily-available forms such as NO_3-N, NH_4-N or DRP (Table A3). Much higher concentrations of dissolved nutrients, especially NH_4-N and DRP, were present in the water sample collected from 7 m depth near the dam that resulted from mineralization and release from the bottom sediments (Table A3). Here, total N and total P concentrations were actually somewhat lower than the dissolved forms. This was attributed to the high sulfide concentrations present in this sample that reduced the efficiency of the persulfate digestion process.

Table A3. Results from nutrient analyses.

Site	Depth (m)	NO_3-N	NH_4-N	DRP	Total N	Total P
				(mg/L)		
1	3	0.19	0.30	0.04	3.26	0.16
	7	0.37	10.27	3.63	8.73	3.45
2	1.8	0.17	0.14	0.10	3.12	0.16
3	0.5	0.12	<0.10	0.05	3.03	0.16

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SAN DIEGO REGIONAL
WATER QUALITY
CONTROL BOARD

2010 MAY 26 P 3: 26

May 26, 2010

David Gibson, Executive Director
San Diego Regional Water Quality Control Board
9174 Sky Park Court, Ste. 100
San Diego, CA 92123-4340

Re: *Letter of Commitment Upper San Marcos Creek /*
Lake San Marcos Watershed Nutrient Abatement Project

Dear Mr. Gibson:

This office is retained as General Counsel to assist the Lake San Marcos Community Association ("the Association") as it participates in the process of addressing and resolving the water quality impairment issues in Lake San Marcos and San Marcos Creek.

The Board of Directors of the Association has, by a unanimous vote, authorized its joinder of the Participation Agreement signed by the City of San Marcos, subject to appropriate stipulations. Consistent with that stipulated authorization, the Association is committed to participate in all diagnostic, feasibility and cleanup and abatement work required to remove the Clean Water Act section 303(d) listing of nutrient impairment at Lake San Marcos ("Lake").

Since April 2009, the Association has been working on a voluntary basis with the San Diego Regional Water Quality Control Board, the City of San Marcos and other stakeholders to address the nutrient impairments in the Lake and Creek upstream of the Lake dam. Over the past year, significant progress has been made in the collection and assessment of all available data related to the Lake and Creek, and in the development of a participation agreement that provides the architecture which allows this voluntary process to function. The project is an important and unique opportunity to cleanup and abate the effects of the nutrient impairment in the Lake and Creek and to remedy a significant water pollution problem for the San Diego Region.

The Association is in full support of the City of San Marcos' request for State Water Cleanup and Abatement Account ("CAA") funding to clean up and abate the nutrient impairment in the Lake and the Creek to the degree it affects the Lake. The Association commits to work with the Applicant to accomplish all aspects of the scope of work included in the City's CAA grant request. In addition, subject to the terms of its commitment to become a party to the

Participation Agreement, the Association shall participate as directed by the Regional Board or as agreed to by the work parties, until the recommended cleanup and abatement phase of the project for the nutrient impairment of the Lake and the Creek is completed.

Sincerely,
LOUNSBERY FERGUSON ALTONA & PEAK, LLP

Kenneth H. Lounsbery
General Counsel for
Lake San Marcos Community Association

:kld

cc: John Lorman
Ken Davis

County of San Diego

DEPARTMENT OF PUBLIC WORKS

JOHN L. SNYDER
DIRECTOR

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SAN DIEGO, CALIFORNIA 92123-4310
(858) 694-2055 FAX: (858) 694-8928
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RICHARD E. CROMPTON
ASSISTANT DIRECTOR

SAN DIEGO REGIONAL WATER QUALITY CONTROL BOARD
2010 MAY 26 A 8:5

May 24, 2010

David Gibson, Executive Officer
San Diego Regional Water Quality Control Board
9174 Sky Park Court, Suite 100
San Diego CA 92123-4340

Dear Mr. Gibson:

WATER QUALITY IMPAIRMENT IN LAKE SAN MARCOS AND SAN MARCOS CREEK

This letter is regarding the water quality impairment in Lake San Marcos and San Marcos Creek, and the County of San Diego's (County) commitment to addressing that impairment. As you know, both the Lake and the Creek are listed under Section 303(d) of the Federal Clean Water Act as impaired for nutrients. The Lake is listed for ammonia (as nitrogen), nutrients, and phosphorus; the Creek is listed for phosphorus.

The County is committed to the process of investigating and addressing the impairment of the Lake and the Creek. The County has already dedicated substantial staff time and resources to that process and will continue to participate in the process until the impairment is addressed. In addition, the County agrees the City of San Marcos (the City) may act as the lead agency for an application to the State Water Resources Control Board for Cleanup and Abatement Account funds to assist the County, the City, and other public agencies in investigating and addressing the nutrient impairment in the Lake and the Creek.

Please contact Tom Deak, Office of County Counsel, at (619) 531-4810 or thomas.deak@sdcounty.ca.gov, with questions about these comments.

Sincerely,

JOHN L. SNYDER, Director
Department of Public Works

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J. Mojica Time: 9:03 AM

ESCONDIDO
City of Choice

Lori Vereker
Utilities Director
201 North Broadway, Escondido, CA 92025
Phone: 760-839-4528 Fax: 760-839-4597

2010 MAY 26 A 7:5

SAN DIEGO REGIONAL WATER QUALITY CONTROL BOARD

May 25, 2010

Mr. David W. Gibson, Executive Officer
San Diego Regional Water Quality Control Board
9174 Sky Park Court, Suite 100
San Diego, CA 92123-4340

RE: *Letter of Commitment Upper San Marcos Creek / Lake San Marcos Watershed Nutrient Abatement Project*

Dear Mr. Gibson:

This letter is regarding the water quality impairment in Lake San Marcos (the "Lake") and San Marcos Creek (the "Creek"), and the City of Escondido's (the "City") commitment to addressing that impairment. As you know, both the Lake and the Creek, to the degree it affects the Lake, are listed under Section 303(d) of the federal Clean Water Act as impaired for nutrients. The Lake is listed for ammonia (as nitrogen), nutrients, and phosphorus; the Creek is listed for phosphorus.

The City strongly supports the cooperative efforts undertaken to address the excess nutrient loads in the Lake and the Creek and is committed to the process of investigating and addressing the impairment of the Lake and the Creek to the degree it affects the Lake. To this end, the City has expended significant staff time and resources toward the process and will continue to participate in the process until the impairment in the Lake and the Creek, to the degree it affects the Lake, is addressed.

The City is in full support of the City of San Marcos's request for State Water Cleanup and Abatement Account ("CAA") funding to clean up and abate the nutrient impairment in the Lake and the Creek to the degree it affects the Lake. The City will work with San Marcos to accomplish all aspects of the scope of work included in San Marcos' CAA grant request.

If you have any questions concerning this matter, please feel free to contact me.

Sincerely,

John Burcham
Deputy Director of Utilities/Wastewater
City of Escondido

cc: Chiara Clemente, Senior Environmental Scientist, Central Watershed Unit, San Diego Regional Water Quality Control Board
Clay Phillips, City Manager
Jeffrey Epp, City Attorney
Charlie Grimm, Assistant City Manager
Lori Vereker, Director of Utilities
Corrine Neuffer, Deputy City Attorney
Cheryl Filar, Environmental Programs Manager

FOLEY

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CLIENT/MATTER NUMBER
096383-0101

SAN DIEGO REGIONAL WATER QUALITY CONTROL BOARD

2010 MAY 26 A 8:5

May 25, 2010

David Gibson
Executive Officer
San Diego Regional Water Quality Control San
Diego Regional Water Quality Control Board
9174 Sky Park Court, Suite 100
San Diego, CA. 92123-4340

Re: Lake San Marcos and San Marcos Creek Water Quality Impairment

Dear Mr. Gibson:

This firm represents Citizen's Development Corporation ("CDC") in the above referenced matter. This letter is regarding the water quality impairment in Lake San Marcos and San Marcos Creek, and Citizen's Development Corporation ("CDC") commitment to addressing that impairment. As you know, both the Lake and the Creek are listed under Section 303(d) of the federal Clean Water Act as impaired for nutrients. The Lake is listed for ammonia (as nitrogen), nutrients, and phosphorus; the Creek is listed for phosphorus.

The CDC is committed to the process of investigating and addressing the impairment of the Lake and the Creek. The CDC has already dedicated substantial staff time and resources to that process and will continue to participate in the process until the impairment is addressed. In addition, CDC agrees the City of San Marcos (the "City") may act as the lead agency for an application to the State Water Resources Control Board for Cleanup and Abatement Account funds to assist the County, the City, and other public agencies in investigating and addressing the nutrient impairment in the Lake and the Creek.

Please contact me should you have any questions in this matter

Sincerely,

S. Wayne Rosenbaum

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J. Mojica Time: 8:15 Am

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DEPARTMENT OF TRANSPORTATION
DISTRICT 11
4050 TAYLOR STREET, M.S. 242
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PHONE (619) 688-0100
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TTY 711

SAN DIEGO REGIONAL
WATER QUALITY
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Flex your power!
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May 25, 2010

Mr. David Gibson, Executive Officer
California Regional Water Quality Control Board
San Diego Region
9174 Sky Park Court, Suite 100
San Diego, CA 92123

Attn: Chiara Clemente

Dear Mr. Gibson:

SUBJECT: Lake San Marcos and San Marcos Creek Commitment Letter

This letter serves as the California Department of Transportation (Caltrans) commitment for continued involvement in the Stakeholders workgroup to address the water quality impairment in Lake San Marcos (Lake) and San Marcos Creek (Creek). Under the federal Clean Water Act Section 303(d), the Lake is listed for ammonia (as nitrogen), nutrients, and phosphorus; the Creek is listed for phosphorus.

Caltrans is committed to the process of investigation and addressing the impairment of the Lake and the Creek and has been an active volunteer member of the workgroup since April 2009. Over the past year, significant progress has been made in the collection and assessment of available data related to the Lake and Creek. Caltrans is in full support of the City of San Marcos (the City) acting as the lead agency for applying to the State Water Resources Control Board for Cleanup and Abatement Account funds to assist the City and all work parties in investigating and addressing the nutrient impairment of the Lake and Creek. In addition, Caltrans agrees to meaningfully participate until the recommended cleanup and abatement phase of the project for the nutrient impairment of the Lake and Creek is complete.

If you have any questions, please feel free to contact me at (619) 688-0100.

Sincerely,

Susanne Glasgow

SUSANNE GLASGOW
Deputy District Director, Environmental

SAN MARCOS
UNIFIED SCHOOL DISTRICT
engaging students...inspiring futures

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SAN DIEGO REGIONAL
WATER QUALITY
CONTROL BOARD

2010 MAY 26 A 9:2

May 21, 2010

Mr. Dave Gibson
Executive Director
California Regional Water Quality Control Board
San Diego Region
9174 Sky Park Court, Suite 100
San Diego, CA 92123-4340

Re: Commitment to support cleanup and abatement of excess nutrient levels in San Marcos Creek and Lake San Marcos

Dear Mr. Gibson:

The San Marcos Unified School District ("SMUSD") owns and operates several school facilities in the San Marcos Creek Watershed. As a member of the community, SMUSD has an obligation to be a good environmental steward, and ensure that its facilities do not cause or contribute to poor water quality conditions in the San Marcos Creek Watershed.

To that end, the purpose of this letter is to express SMUSD's support for current efforts by the City of San Marcos, Vallecitos Water District, the City of Escondido, the County of San Diego, the lake's owner, the surrounding community, and others, to cleanup and abate excess nutrient levels in San Marcos Creek and Lake San Marcos. SMUSD further supports the City of San Marcos' decision to act as the Lead Agency for the application of cleanup and abatement funds for the development of a diagnostic study of San Marcos Creek and Lake San Marcos, and for the potential subsequent remediation work.

SMUSD has been involved in cleanup and abatement efforts to date, donating funds and hours of staff time to the development of an initial report by Dr. Michael Anderson, and to the development of a subsequent scope of work based on Dr. Anderson's report. To the extent feasible, considering both budgetary constraints and SMUSD's contribution of constituents of concern, SMUSD is committed to continued participation in the process of addressing nutrient levels of concern in San Marcos Creek and Lake San Marcos.

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Thank you for your attention to this matter. If you have any questions or comments regarding SMUSD's support for cleanup and abatement efforts in the San Marcos Creek Watershed or any other related matters, please do not hesitate to contact me.

Sincerely,

Katherine Tanner

Katherine Tanner
Executive Director
Facilities Planning and Development

KT/dps

C: Kevin D. Holt, SMUSD
Gary M. Hamels, SMUSD
Erica Ryan, City of San Marcos
Andre Monette, BBK
Tyree Dorward, BBK
Chiara Clemente, San Diego Regional Water Quality Control Board