# Technical Memo for Machado Lake Eutrophic, Algae, Ammonia, and Odors (Nutrient) TMDL

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This memorandum describes the application of the California Nutrient Numeric Endpoints (NNE) BATHTUB spreadsheet model to Machado Lake for TMDL development. The NNE was used for the Machado Lake Nutrient TMDL to calculate nutrient concentrations in the lake for the specified nutrient loadings and to evaluate the effectiveness of the TMDL wasteload and load allocations in addressing the 303(d) listings for eutrophic effects. This technical memo includes a general description of the NNE BATHTUB Tools and model input information and a discussion of analysis conducted such as calibration and sensitivity analysis.

## Description of California NNE BATHTUB Spreadsheet Model

The California Nutrient Numeric Endpoints (NNE) BATHTUB spreadsheet model was developed by Tetra Tech. for California State Water Resource Control Board. The BATHTUB model was developed by U.S. Army Corps of Engineers to analyze water quality response in lakes and reservoirs to different nutrient loading scenarios. BATHTUB is designed to facilitate application of empirical eutrophication models to reservoirs and was modified by Tetra Tech for analyzing lakes in a spreadsheet application, which is called California NNE BATHTUB spreadsheet model or NNE BATHTUB tools.

The model performs water and nutrient balance calculations under steady-state conditions. Eutrophication related water quality conditions are expressed in terms of total phosphorus, ortho-phosphorus, total nitrogen, inorganic nitrogen, chlorophyll a, transparency (Secchi depth), and hypolimnetic oxygen depletion rates. These conditions are predicted using semi-empirical relationships developed and tested on a wide range of reservoirs.

The NNE BATHTUB spreadsheet tool allows the user to input physical, chemical, and biological parameters. The input parameters are listed below.

- Lake volume
- Lake surface area
- Average depth
- Mixed depth
- Net evaporation – precipitation rate
- Secchi depth at typical chlorophyll a
- Typical chlorophyll a
- Total phosphorus load
- Ortho – phosphorus load
- Total nitrogen load
- Inorganic nitrogen load
- Inflow volume

The model allows the user to analyze many different nutrient loading scenarios and evaluate the lake response. Likewise, the user may specify a chlorophyll a concentration or change in Secchi depth and the model will predict the probability of exceeding the target under the specified nutrient loading.

Additionally, the model will show allowable nitrogen (N) and phosphorus (P) loading combinations to meet the chlorophyll or Secchi depth target. This model was selected to develop the Machado Lake Nutrient TMDL because it is an effective tool for predicting growing season lake response to nutrient loading scenarios.

## Input Information

The California BATHTUB model requires the following input information for calculations.

Table 1 - Input Information for California BATHTUB Spreadsheet Model

| Input Parameters | Values | Remark |
|---|---|---|
| Lake volume | 0.114 x $10^6$ $m^3$ | surface area x average depth |
| Surface area | 136,262 $m^2$ | Estimated based on GIS map |
| Average depth | 0.84 m | Estimated based on measured data |
| Mixed depth | 0.67 m | 80 % of average depth |
| Net evap-precip rate | 8.9 in/year | Estimated |
| Secchi depth at typical Chl-a | 0.38 m | Field data |
| Typical Chl-a | 74 µg/L | Field data |
| P load | 10,421 kg | See Table 6 |
| N load | 24,327 kg | See Table 6 |
| Ortho P load | 5,700 kg | See Table 6 |
| Inorg N load | 20,256 kg | See Table 6 |
| Inflow | 8.45 $hm^3$ | See Table 2 |

The physical parameters of the lake such as volume, surface area and average depth were based on estimates from recent GIS maps of the lake and measured data. The Secchi depth and Chlorophyll a values were obtained from field data.

For the Machado Lake TMDL, nutrient loading from each sub-watershed was analyzed. The Machado Lake sub-watersheds were defined by the land areas draining to each storm drain that discharges to Machado Lake. Tables 2 - 4 provide the information to calculate nutrient loading from the surrounding watershed. Nutrient loading from each sub-watershed was calculated by multiplying the volume of runoff with the average nutrient concentration in each sub-watershed (Table 5).

The annual runoff from each sub-watershed was estimated by multiplying the average annual rainfall of 10.63 inches with the area of the sub-watershed (Table 2). The area of each sub-watershed was based on information in the Machado Lake Watershed Management Plan prepared by Parsons for City of Los Angeles, Department of Recreation and Park. The average annual rainfall value is based on 5 years of precipitation data collected from a California Irrigation Management Information System (CIMIS) weather station. The weather station is located thirteen miles from the lake at Eldorado Park in the City of Long Beach.

Table 2 Average Annual Runoff from Each Sub-watershed

| | **Area [a] (acres)** | **Average Annual Rainfall [b] (in)** | **Imperviousness Ratio [c]** | **Average Annual Runoff ($hm^3$)** |
|---|---|---|---|---|
| Drain 553 | 6,100 | 10.63 | 0.62 | 4.13 |
| Wilmington Drain | 3,637 | 10.63 | 0.62 | 2.47 |
| Project 77/510 | 1,636 | 10.63 | 0.62 | 1.11 |
| Walteria Lake[d] | 3,149 | 10.63 | 0.62 | 0.74 |
| Total | 14,522 | | | 8.45 |

a: Machado Lake Watershed Management Plan ,May, 2002
b: CIMIS Weather Station
c: Los Angeles County Department of Public Works Hydrology Manual
d Only 35 % of the drainage area (3,149 A) from the Walterira Lake discharges to Machado Lake

The concentration of nutrients in stormwater runoff was estimated from Los Angeles County stormwater monitoring data collected at the mass emission sites. Nutrient concentrations in stormwater runoff vary with land use (Table 3). The land use distribution information for the mass emission stations was used to estimate the loading from each land use type. Therefore, to estimate the nutrient concentrations in runoff from each of the Machado Lake sub-drainage areas the percentage of land use distribution from each sub-drainage area (Table 4) was multiplied by the corresponding annual mean nutrient concentration for each land use type (Table 3).

Table 3 Annual mean concentration for each land use

| | **HDSFR** | **HI/LI** | **V** | **R/C** | **MFR** | **T** | **EI** | **MR** | **AO** |
|---|---|---|---|---|---|---|---|---|---|
| Total –N (mg/L) | 1.21 | 1.21 | 1.91 | 0.2 | 0.22 | 0.1 | 0.11 | 0.13 | 0.65 |
| Total-P (mg/L) | 0.57 | 0.57 | 0.52 | 0.127 | 0.15 | 0.028 | 0.04 | 0.095 | 0.22 |
| Ortho-P (mg/L) | 0.11 | 0.11 | 0.27 | 0.018 | 0.02 | 0.008 | 0.01 | 0.009 | 0.06 |
| Inorg-N (mg/L) | 0.57 | 0.57 | 1.14 | 0.1 | 0.1 | 0.05 | 0.05 | 0.05 | 0.33 |

Source: LA County Stormwater Monitoring Data Mass Emission Sites Annual Mean (1994-2005)

Table 4 Percent land use distribution for Machado Lake sub-drainage areas

| | **HDSFR** | **HI/LI** | **V** | **R/C** | **MFR** | **T** | **EI** | **MR** | AO |
|---|---|---|---|---|---|---|---|---|---|
| Drain 553 | 48.76 | 4.76 | 8.55 | 6.30 | 3.98 | 3.00 | 3.09 | 0.33 | 21.23 |
| Wilmington Drain | 35.64 | 9.65 | 3.76 | 5.81 | 7.14 | 2.45 | 5.40 | 4.39 | 25.77 |
| Project 77/510 | 39.58 | 3.03 | 1.64 | 5.93 | 8.93 | 1.63 | 2.69 | 2.16 | 34.42 |
| Walteria Lake | 46.26 | 5.79 | 1.73 | 13.85 | 9.55 | 3.66 | 4.30 | 0.68 | 14.18 |

Source: Machado Lake Watershed Management Plan, May, 2002

Table 5 shows the average annual nutrient load to Machado Lake from each sub-drainage area. This estimate of average annual nutrient loading to Machado Lake was calculated by multiplying the average annual runoff from Table 2 by the corresponding mean nutrient concentration for each land use in Tables 3 and 4.

Table 5 Average annual nutrient loads from each sub-drainage area

| | **Total N Load (kg)** | **Total P Load (kg)** | **Ortho-P Load (kg)** | **Inorg-N Load (kg)** |
|---|---|---|---|---|
| Drain 553 | 4,039 | 1,706 | 402 | 2,010 |
| Wilmington Drain | 2,043 | 886 | 195 | 999 |
| Project 77/510 | 898 | 390 | 84 | 436 |
| Walteria Lake | 607 | 278 | 56 | 292 |
| Total | 7,587 | 3,260 | 737 | 3,736 |

Table 6 represents the total annual nutrient loading to Machado Lake. This includes nutrient loading from the surrounding watershed (external loading) and nutrient loading from internal nutrient flux from the sediments (internal loading). The total annual load value presented in Table 6 is the same nutrient load information used as part of the model input information in Table 1.

Table 6 Total annual nutrient load to Machado Lake

| | **Total N Load (kg)** | **Total P Load (kg)** | **Ortho-P Load (kg)** | **Inorg-N Load (kg)** |
|---|---|---|---|---|
| External load from Table 5 | 7,587 | 3,260 | 737 | 3,736 |
| Internal load (sediment flux*) | 16,520 | 7,161 | 4,963 | 16,520 |
| Atmospheric Dep.** | 220 | 0 | 0 | 0 |
| Total annual load | 24,327 | 10,421 | 5,700 | 20,256 |

*Internal loading estimates were obtained from the Lake Machado Nutrient Flux Study conducted by the Southern California Coastal Water Research Project (SCCWRP), June, 2007

**Estimate based on the annual mean air deposition flux of total nitrogen indicated in the report "Nitrogen deposition on coastal watersheds in the Los Angeles region", SCCWRP Annual Report, 2002.

## Model Calibration

The empirical equations implemented in California BATHTUB Lake Model are generalizations about reservoir behavior. When applied to data from a particular lake or reservoir, observations may differ from predictions by a factor of two or more. Such differences reflect data limitations (measurement or estimation errors in the average inflow and outflow concentrations), as well as unique features of the particular lake and can be represented in model calibration factors. For the Machado Lake Nutrient TMDL, the model was calibrated to match the predicted results with observed data in the site-specific lake conditions by modifying calibration factor before the model was applied to predict the real management scenarios. The calibrated model then can be applied subsequently to predict changes in lake conditions under the assumption that the calibration factors remain constant. For the Machado Lake TMDL, it was assumed that all NNE calibration factors have a default value of 1.0.

To calibrate the model, the input parameter information of Machado Lake is employed (Table 1). The loadings from each sub-watershed were obtained by utilizing six annual average rainfall data (2001-2006). Based on these loading conditions, the calibration of the model can be performed by adjusting the calibration factor under same input condition such as, lake volume, surface area, average depth, and inflow. Then, the predicted results are compared with measured data to find the best calibration factor.

The calibration factor for total phosphorus was adjusted to match the model results with the measured data collected during TMDL development in 2006 and 2007. The predicted results for three calibration factors used in the model against measured data of total phosphorus and total nitrogen are shown in Figure 1. It can be seen that the results for calibration factor of 0.2 is the best fit with measured data and hence the calibration factor for total phosphorus of 0.2 is selected for Machado Lake. The calibration for chlorophyll-a can also be adjusted to match the model results with the measured data. The predicted results for four calibration factors used in the model against measured data of total phosphorus and chlorophyll-a are shown in Figure 2. It can be seen that the results for calibration factor of 1.2 is the best fit with the measured data.

To further calibrate the NNE input parameters and annual loads the predicted nutrient concentrations in the lake are compared to the measured data as shown in Table 7.

There is very good to good agreement between the NNE predicted and measured results for the average chlorophyll *a*, median Secchi depth, total phosphorus, and total nitrogen concentrations with a Relative Percent Difference (RPD) of 2.2, 0, 6.5 and 15.3 percent, respectively. Overall the NNE BATHTUB Model did a good job or recreating the water quality situation in Machado Lake. Likewise, this agreement between measured and predicted water quality provides confidence that the estimated annual nutrient loads to the lake are good estimates of existing loads entering Machado lake. Thus, greater confidence can be provided to estimates of loading capacity and load reduction schemes.

Table 7 NNE predicted and measured growing season water quality

| Growing Season - Summary Results based on annual nutrient loading | | | |
|---|---|---|---|
| | **NNE Result** | **Measured Data** | **Relative Percent Difference** |
| Avg. Chl a (µg/L) | 89.8 | 91.8 | 2.2 |
| Median Secchi Depth (cm) | 0.3 | 0.3 | 0.0 |
| TP (mg/L) | 1 | 1.07 | 6.5 |
| TN (mg/L) | 2.6 | 3.07 | 15.3 |

## Sensitivity Analysis

Uncertainty in model inputs lead to uncertainty in model outputs. To estimate the uncertainty in model predictions, the following sets of inputs for different model input parameters are performed for sensitivity analysis.

- Lake Volume
- Inflow
- Total –P Load
- Total –N Load
- Calibration Factor for P Concentration
- Calibration Factor for N Concentration
- Calibration Factor for Chlorophyll-a Concentration

The Machado Lake input information for the sensitivity analysis was previously described. The annual nutrient loading estimates shown in Table 6 were also used as part of the sensitivity analysis.

The results of sensitivity analysis for each input parameter are presented in Figure 3- Figure 6 for lake volume, Figure 7- Figure 10 for inflow, Figure 11 - Figure 14 for total – P load, Figure 15 - Figure 18 for total – N load, and Figure 19 - Figure 22 for calibration factors for P - concentration, N - concentration, and Chlorophyll-a, respectively.

The figures demonstrate that lake volume will affect total-P, total-N, and have no significant effect on chlorophyll-a and Secchi depth. As lake volume increases, the concentrations of total-P and total-N will decrease. Also as lake inflow increases, the concentrations of total-P and total-N decreases. Likewise, the chlorophyll-a concentration in the lake is shown to decease with increased inflow.

Regarding the sensitivity analysis of total–P load into the lake, as the total-P load increases, the in lake total phosphorus concentration increases and the total nitrogen concentration remains unchanged. Chlorophyll-a values however, will increase to a certain point and then remain unchanged even in the presence of continued increases in total-P loading. Regarding the total-N load into the lake, as total-N increases, the in lake concentration of total-N increases. The concentration of chlorophyll-a increases as well. From these two scenarios, it can be seen that the lake is a nitrogen-limited lake as input loads to the lake continue to increase.

Figure 19 - Figures 22 present the sensitivity analysis of each calibration factor. The concentration of total phosphorus and total nitrogen decrease as the calibration factor for phosphorus concentration and nitrogen concentration increases. Although, the concentration of chlorophyll-a increases when calibration factor for chlorophyll-a concentration increases. Recognizing the differences of nutrient concentrations between different calibration factors, calibration factor should be used very conservatively. Likewise, these figures demonstrate the sensitivity of the phosphorus and chlorophyll a calibration factors and the importance of calibrating the NNE BATHTUB Model with respect to these two parameters.

## Loading Capacity and Load Reduction

The loading capacity of nutrients for Machado Lake depends on numeric targets and mass loadings from both external and internal sources. The NNE model is used to calculate loading capacity for the lake. The NNE is a mass balance model and the principals of mass balance are used to calculate the lake loading capacity. If the numeric targets are set to be 1.0 mg/L and 0.1 mg/L for total nitrogen and total phosphorus, respectively, based on EPA guidance, the loading capacity for nutrients are 8,800 kg and 825 kg for total nitrogen and total phosphorus based on the calibrated NNE model. Under this loading capacity the predicted chlorophyll a concentration is 36.1 µg/L.

The following assumptions underlie the load reduction analysis. Input from the storm drains and overland flow occurs during wet weather and is negligible during dry weather. Also, during many wet weather storm events the input volume from the storm exceeds the lake volume thus, in lake concentrations of nitrogen and phosphorus are assumed to be equivalent to concentrations discharged from the storm drain during and after storm events. Moreover, the NNE model accounts for outflow indirectly by using inflow and lake volume to calculate residence time. This calculation assumes a constant volume, so that inflow is equal to outflow. The NNE is not a dynamic model so it is not able to evaluate a change in storage (i.e. difference in inflow and outflow).

Therefore, when evaluating the nutrient load reductions needed to meet the loading capacity the mass of nutrients discharged from the lake, as part of the outflow, is subtracted from the current mass loading before the percent load reduction is calculated (Table 8). For example, the annual nitrogen load discharged to the lake from the storm drains is 7,587 Kg, since inflow is equal to outflow this same mass is discharged from the lake. It is important to note that the total nitrogen concentration entering the lake under wet weather events is currently meeting the total nitrogen TMDL wasteload allocation of 1.0 mg/L. The source of the remaining nitrogen load into the lake is from internal sediment flux, estimated to be 16,520 Kg and atmospheric deposition estimated to be 220 Kg. It is the internal nitrogen load and the atmospheric load that require reduction to meet the TMDL loading capacity; the external load is discharged from the lake. The required nitrogen load reduction is 47 percent (Table 8).

The current annual total phosphorus load discharged to the lake from the storm drains is 3,260 Kg. The average concentration of total phosphorus in the stormwater discharge is 0.37 mg/L; the wasteload allocation for total phosphorus is 0.1 mg/L. When the wasteload allocation is met, approximately 845 Kg of total phosphorus will be discharged annually as part of the outflow from the lake. Thus, 2,415 Kg of total phosphorus from the storm drains in addition to the internal total phosphorus load requires reduction to meet the loading capacity. The required phosphorus load reduction from both external and internal sources is 91 percent (Table 8).

Table 8 Percent load reduction required to meet the loading capacity

| | **Total Annual Load into the Lake (Kg)** | **Load Discharged in Outflow (Kg)** | **Remaining Load into the Lake (Kg)** | **Loading Capacity (Kg)** | **Percent Reduction Required** |
|---|---|---|---|---|---|
| Total Nitrogen | 24,327 | 7,587 | 16,740 | 8,800 | 47 |
| Total Phosphorus | 10,421 | 845 | 9,576 | 825 | 91 |

## Summary

The California NNE BATHTUB spreadsheet model was selected as part of the development of the Machado Lake Nutrient TMDL because it is an effective tool for predicting growing season water quality in response to nutrient loading and physical parameters. The model has been calibrated with a calibration factor of 0.2 for total phosphorus and calibration factor of 1.2 for chlorophyll-a. The calibration of the model was performed by adjusting calibration factor such that the predicted results are the best fit with the measured data collected in 2006 and 2007. The sensitivity analyses for different model input parameters were also investigated in this study to better understand the uncertainty in the model predictions derived from uncertainty in model inputs.

The NNE BATHTUB spreadsheet model was used to calculate the nutrient loading capacity for Machado Lake based on the numeric targets of 1.0 mg/L and 0.1 mg/L for total nitrogen and total phosphorus, respectively. The NNE predicted loading capacity for total nitrogen is 8,800 Kg and 825 Kg for total phosphorus. It is estimated that in order to attain the loading capacity for Machado Lake a 91 percent reduction in total phosphorus and 47 percent reduction in total nitrogen loading will be required. It is necessary reduce both phosphorus and nitrogen loads to the lake to attain the wasteload and load allocations of the TMDL and maintain balanced nutrient concentrations without strong nitrogen or phosphorus limitation.

## References

1. Technical Approach to Develop Nutrient Numeric Endpoints for California, Tetra Tech, Inc., July 2006
2. Machado Lake Watershed Management Plan, Ken Malloy Harbor Regional Park Improvement Program, Volume II, Parsons, May 2002.
3. Lake Machado Nutrient Flux Study, The Southern California Coastal Water Research Project, June, 2007.

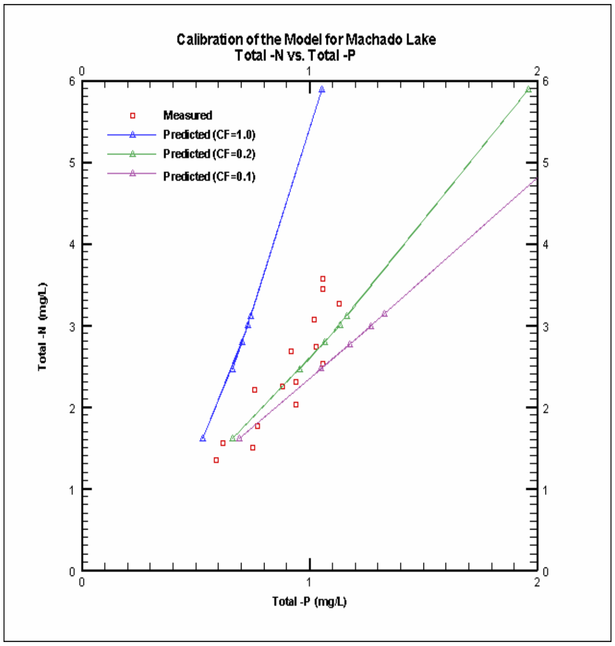

Figure 1 Calibration of the Model: Relationship Between Total Phosphorus and Total Nitrogen Concentration in the Lake

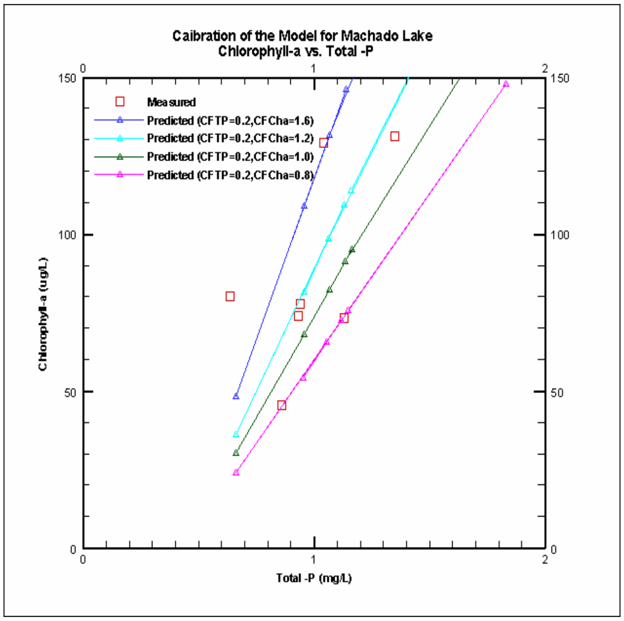

Figure 2 Calibration of the Model: Relationship Between Total Phosphorus and Chlorophyll-a Concentration in the Lake

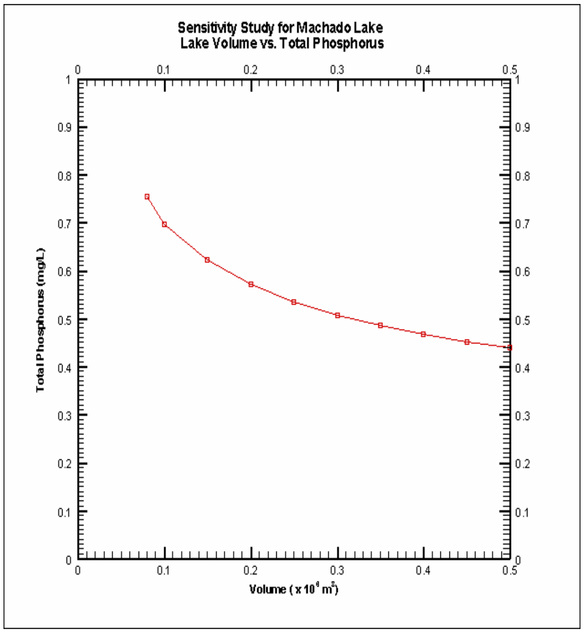

Figure 3 Concentration of Total Phosphorus vs. Lake Volume for Lake Volume Sensitivity Analysis

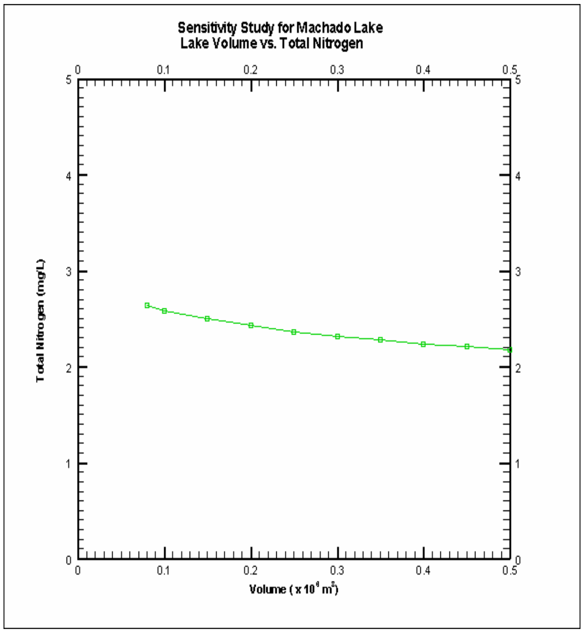

Figure 4 Concentration of Total Nitrogen vs. Lake Volume for Lake Volume Sensitivity Analysis

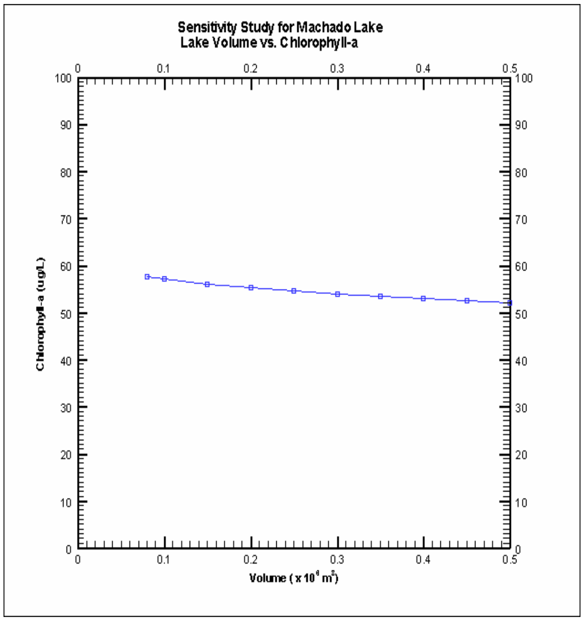

Figure 5 Concentration of Chlorophyll-a vs. Lake Volume for Lake Volume Sensitivity Analysis

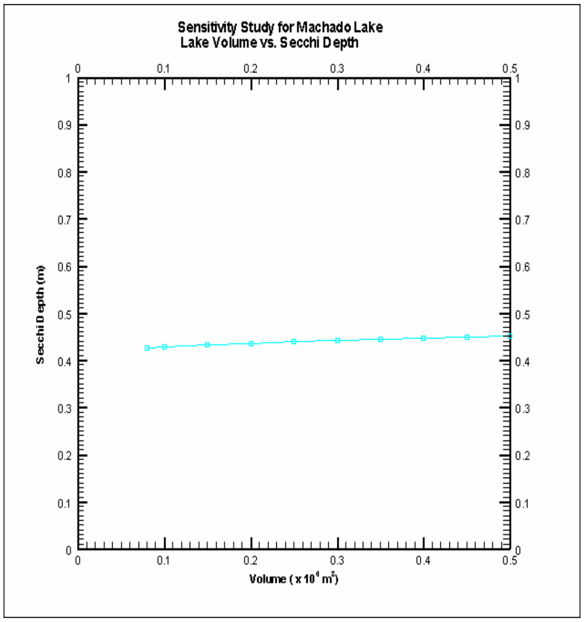

Figure 6 Secchi Depth vs. Lake Volume for Lake Volume Sensitivity Analysis

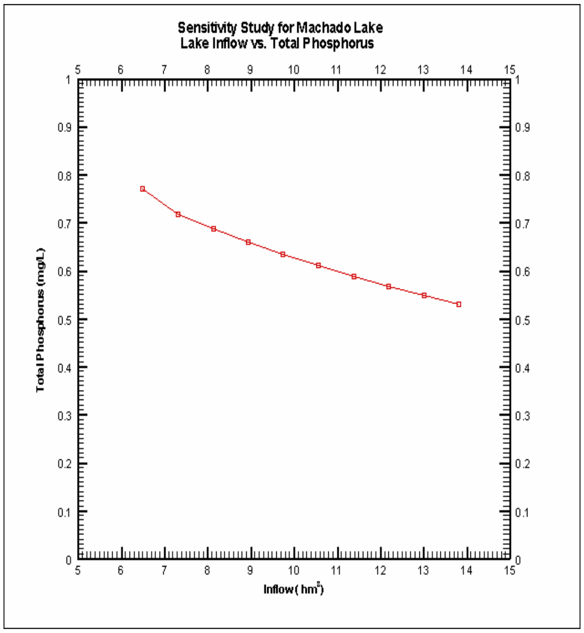

Figure 7 Concentration of Total Phosphorus vs. Inflow for Inflow Sensitivity Analysis

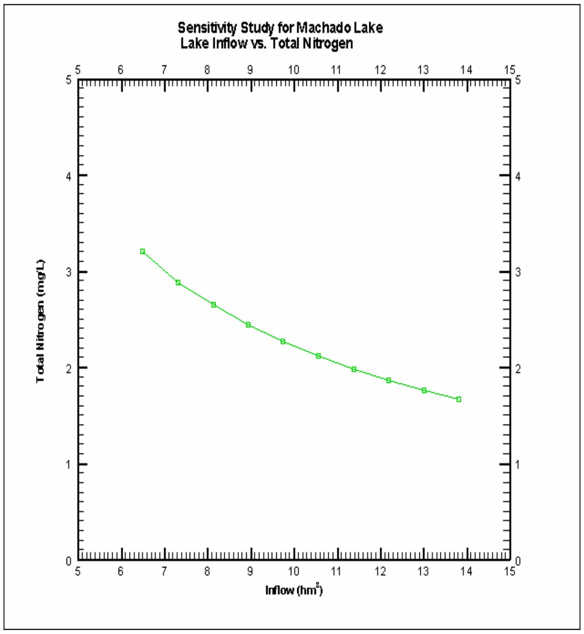

Figure 8 Concentration of Total Nitrogen vs. Inflow for Inflow Sensitivity Analysis

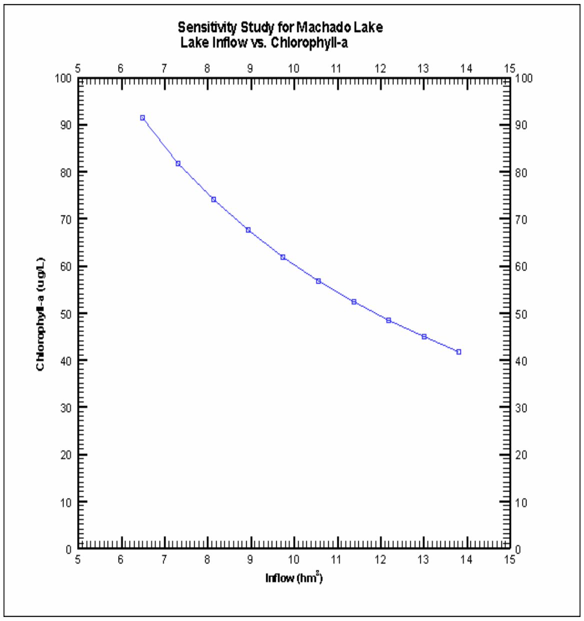

Figure 9 Concentration of Chlorophyll-a vs. Inflow for Inflow Sensitivity Analysis

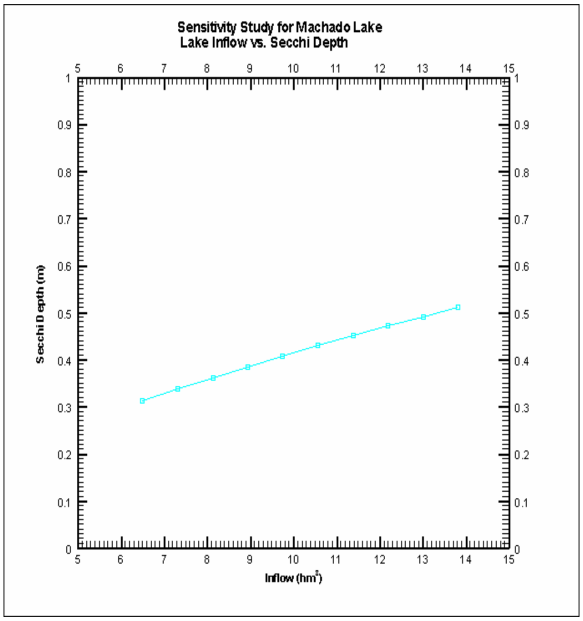

Figure 10 Secchi Depth vs. Inflow for Inflow Sensitivity Analysis

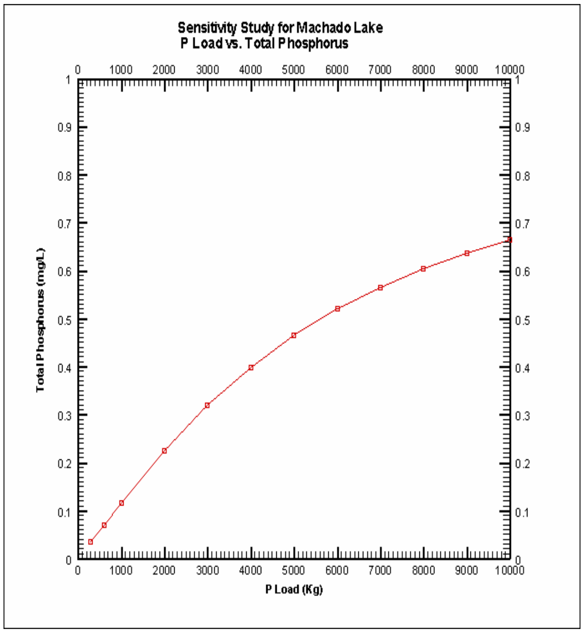

Figure 11 Concentration of Total Phosphorus vs. P-Load for P-Load Sensitivity Analysis

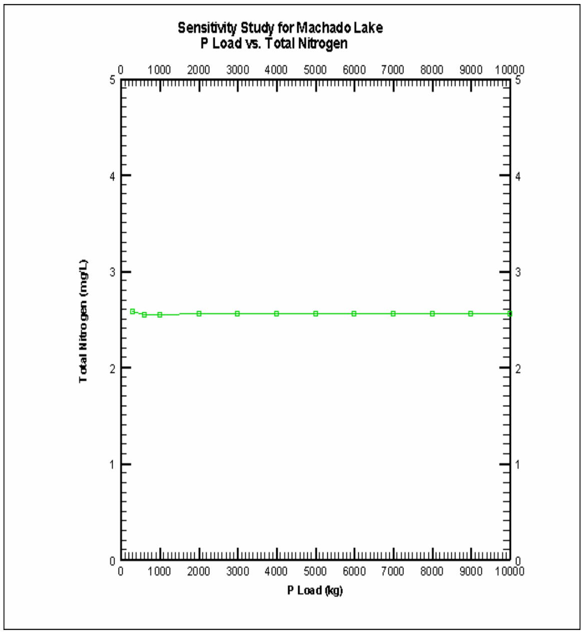

Figure 12 Concentration of Total Nitrogen vs. P-Load for P-Load Sensitivity Analysis

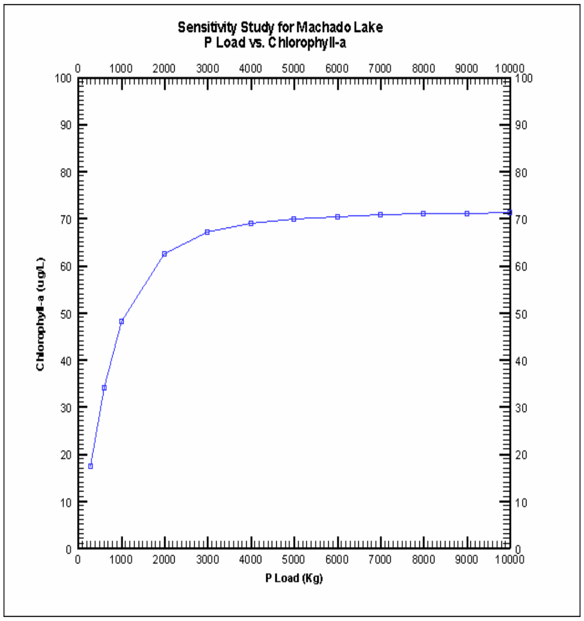

Figure 13 Concentration of Chlorophyll-a vs. P-Load for P-Load Sensitivity Analysis

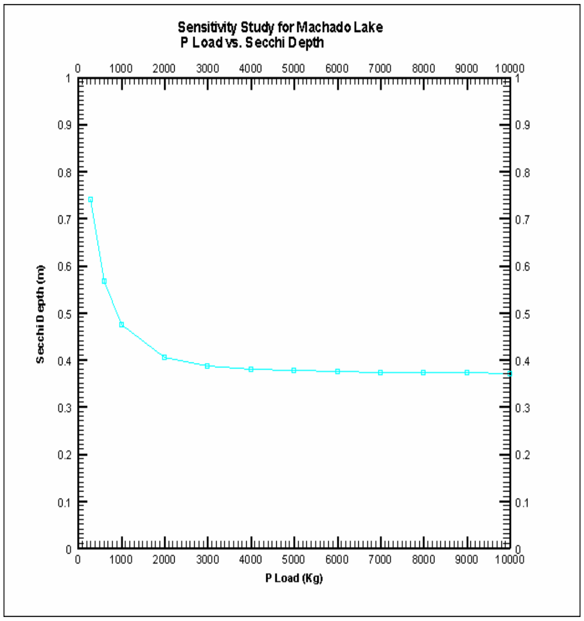

Figure 14 Secchi Depth vs. P-Load for P-Load Sensitivity Analysis

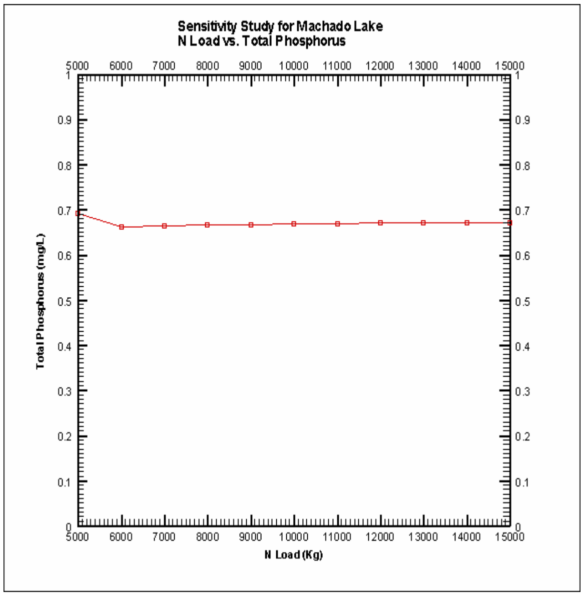

Figure 15 Concentration of Total Phosphorus vs. N-Load for N-Load Sensitivity Analysis

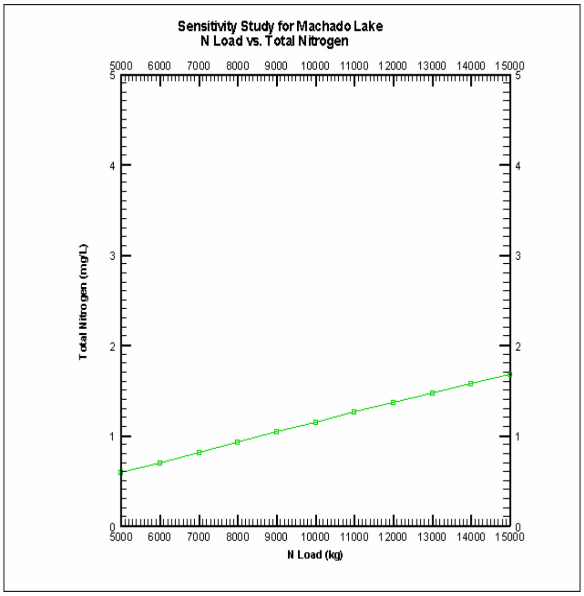

Figure 16 Concentration of Total Nitrogen vs. N-Load for N-Load Sensitivity Analysis

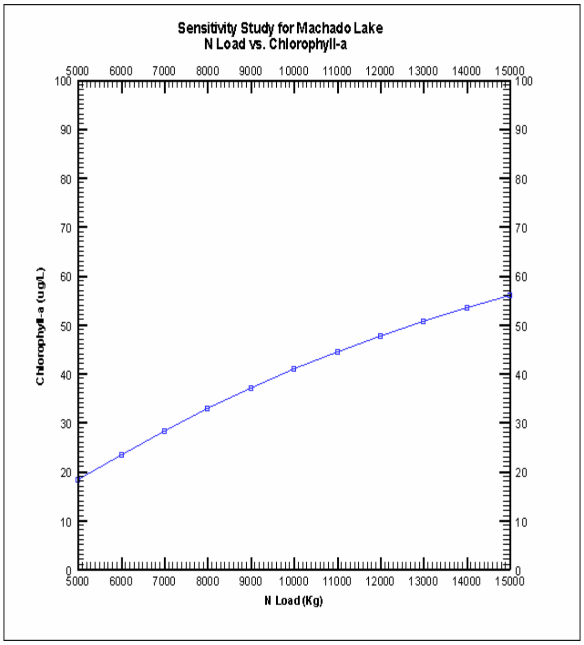

Figure 17 Concentration of Chlorophyll-a vs. N-Load for N-Load Sensitivity Analysis

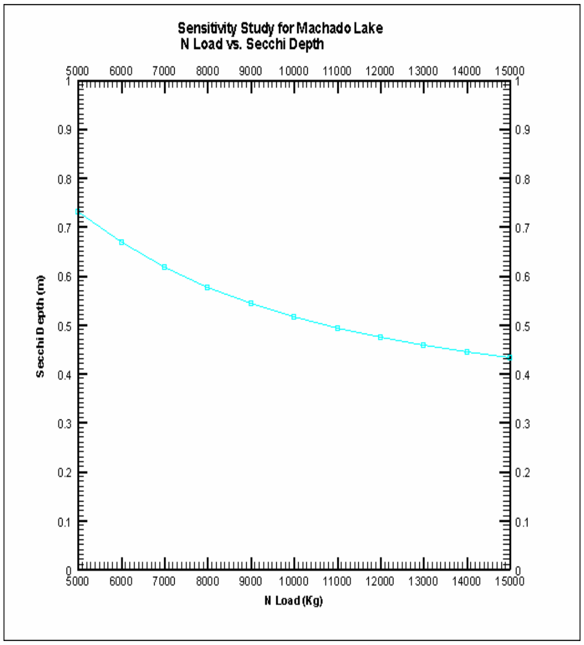

Figure 18 Secchi Depth vs. N-Load for N-Load Sensitivity Analysis

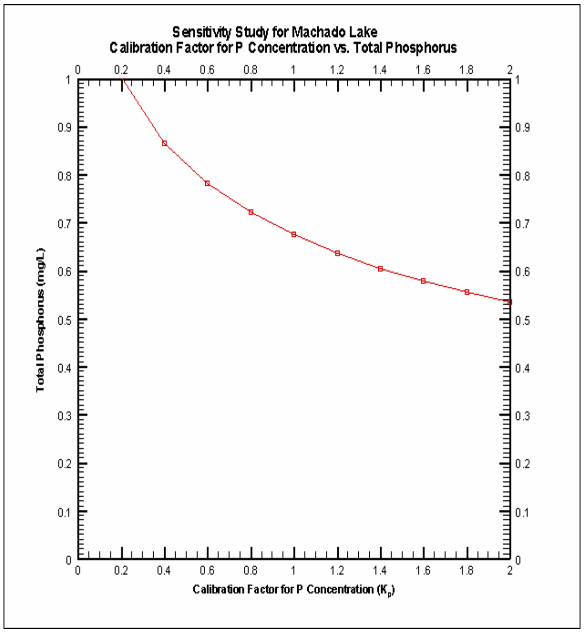

Figure 19 Concentration of Total Phosphorus vs. Calibration Factor for P Concentration

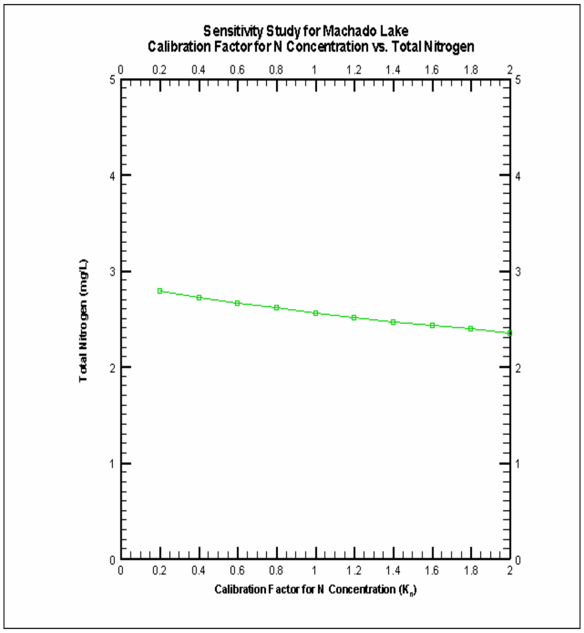

Figure 20 Concentration of Total Nitrogen vs. Calibration Factor for N Concentration

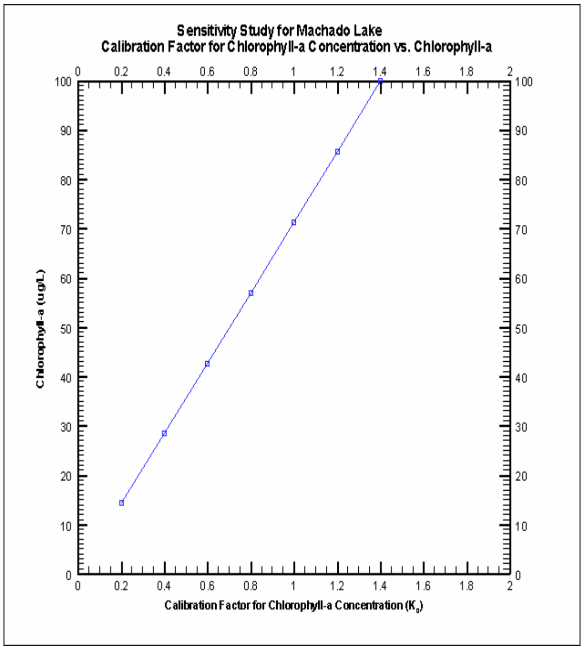

Figure 21 Concentration of Chlorophyll-a vs. Calibration Factor for Chlorophyll-a

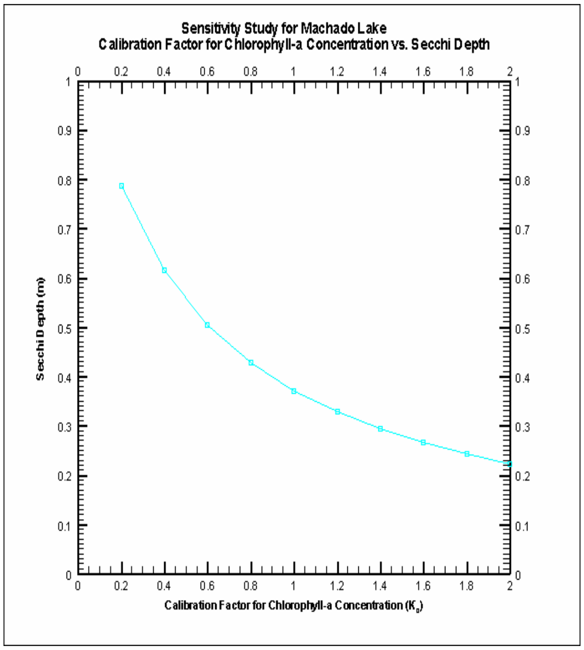

Figure 22 Secchi Depth vs. Calibration Factor for Chlorophyll-a