Review of the Machado Lake Eutrophic, Algae, Ammonia and Odors (Nutrient) TMDL

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This is a review of the December, 2007 Draft Machado Lake TMDL (the TMDL)[2]. The review follows the general outline provided in Attachment 2 of the August 29, 2007 letter from Samuel Unger to Gerald Bowes.

Methodology for Assessing Sources of Nutrients

The TMDL required estimating the sources of nutrients to the lake. Three different sources were quantified: 1) watershed export; 2) atmospheric deposition; and 3) internal release. Sediment resuspension was also discussed as a source of nutrients.

The export from the watershed was based on watershed area, percent impervious, storm average annual rainfall, and land uses with associated mean runoff concentrations. That seems a reasonable approach, and is similar, if not slightly more conservative than mid-level urban water quality models. Because the lake volume is relatively small compared to the volume generated during many of the storms, much of the storm water passes through the lake. In contrast to many urban lake studies, the most critical aspect of the urban runoff may be the concentration that remains in the lake after the runoff event because that is the starting point for subsequent changes due to internal load.

The atmospheric deposition of nitrogen to the lake was also estimated. The estimating method seems reasonable, although this is a relatively minor nutrient contribution to the lake. The TMDL did not include an atmospheric deposition estimate for phosphorus, although I would anticipate it would likely also be relatively small compared to the internal and watershed loads so its omission is probably not critical.

The internal loading to the lake was estimated using measurements from sediment cores. The rate of nutrient release was evaluated as a constant rate during the short term experiments. That is a relatively common approach to estimating sediment contributions. The measured release rate for phosphorus was very high compared to other many other lake sediments. It was not clear if the release was measured under anoxic or oxic conditions, or the extent to which oxygen status was important. The TMDL proposed additional investigation to better understand the release of nutrients from the sediment. Because this nutrient source appears to substantially control the nutrient status of Machado Lake, it appears additional investigation into rates and reduction of nutrient release would be warranted.

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[2] *Including the Draft Machado Lake Eutrophic, Algae, Ammonia and Odors (Nutrients) TMDL report dated December, 2007, the Technical Memo for Machado Lake Eutrophic, Algae, Ammonia, and Odors (Nutrient) TMDL by C.P. Lai, and the August 29, 2007 letter from Samuel Unger to Gerald Bowes.*

Another source of nutrients to the lake that is described in the report is sediment resuspension. The report uses a discussion of wave height to describe conditions where wind mixing would likely reach the lake bottom and lead to a resuspension of sediment. To ultimately incorporate an estimate of resuspension impact on lake nutrient levels, it seems necessary to understand the rate of sediment resuspension (which will reflect sediment characteristics in addition to the wave height evaluation) and the exchange of nutrients between the resuspended sediment and the water column (which would likely require laboratory testing). Alternatively, the resuspension may be part of a net sedimentation rate and be reflected in a reduced sedimentation coefficient. The latter approach appears to be the method actually implemented in the TMDL through calibration coefficient adjustment in the BATHTUB model. That seems reasonable given the difficulty in actually quantifying directly the resuspension influence on nutrient levels.

The Numeric Target and Linkage Analysis

The TMDL uses a chlorophyll a as a numeric target. I believe chlorophyll a is an appropriate target as it is a measure of algal density and has generally correlated with user perceptions of lake water quality (Heiskary and Walker, 1995). If the target of 20 ug/l would be attained, that would likely provide a relatively high level of user satisfaction.

The TMDL uses a model simulation of phosphorus and nitrogen concentrations and the relationship between those nutrients and chlorophyll a in the development of the TMDL. Ultimately, nutrient levels are selected for the allocation without linking them directly to the 20 ug/l chlorophyll a concentration. While it is well established that nutrients influence chlorophyll a, the TMDL did suggest there is some uncertainty as to how the nitrogen and phosphorus together or separately influence trophic response. The TMDL presents figures showing simulation results for chlorophyll a with different phosphorus and nitrogen loads (Figures 12 and 13). Although the report concludes the lake is nitrogen limited based on those graphs, it seems that conclusion is really a reflection of Canfield correlation that is used in BATHTUB, not evidence from Machado Lake. Could the data that have been collected to-date be used to demonstrate the relationship between nutrients and chlorophyll a? The additional monitoring that is proposed will provide a better understanding of this relationship. Of course, the assumption in the TMDL that reductions in nutrient load will lead to reductions in algae is reasonable.

The TMDL describes a conceptual model for Machado Lake in which the lake receives large quantities of stormwater runoff from the largely urban watershed followed by long periods without water additions. The nutrient loading to the lake can be very large during the periods of heavy storm runoff, as expected because it has a relatively large watershed (~14,500 acres) compared to its size (~40 acres open water area). The result is a system where storms can replace much of the water in the lake. Between rainfall periods, there is little additional water input to the lake. Internal sediment release of nutrients is substantial however, and sediment release rates of phosphorus and nitrogen were observed to be quite large in laboratory studies. Measurements of nitrogen and phosphorus concentrations in the lake show they are highest after prolonged dry periods consistent with sediment release between runoff events. The TMDL provides a thorough discussion of the link between Machado Lake and the watershed, and the concentration data provided support this conceptual model.

The BATHTUB model (as part of a spreadsheet tool) was used to simulate water quality in the lake and the response to nutrient loading. While the BATHTUB model is a useful eutrophication analysis approach in many reservoir systems, it may not be a particularly powerful tool for evaluating Machado Lake where the water quality during critical periods is apparently controlled by internal nutrient release and not equilibrium with watershed loads. The BATHTUB model is commonly used with internal loading implicit in the empirical eutrophication formulas. In the Machado Lake TMDL, it was not clear if the internal load was included explicitly or only through adjustment to the calibration coefficient in the model. The calibration coefficient for phosphorus was reduced to 0.2 to match the average annual phosphorus concentration in the lake. When eventually evaluating the reduction requirements, the external loading was excluded from the calculation on the basis that it is essentially flushed through the lake. Because the BATHTUB model uses an average (across the averaging period) lake response to watershed loading and Machado Lake has a clear annual concentration pattern, the application of a model such as BATHTUB with its simple annual time-step, results in losing much of the information contained in the monitoring data.

A more dynamic model would allow a more specific exploration of the sediment release, sedimentation and watershed inputs. For example, I experimented with a very simple hourly time-step mass balance model within a spreadsheet as an alternative mass analysis for the lake. I calculated the nutrient mass in the lake each hour by adjusting to reflect additions from the watershed (using hourly precipitation from the LA airport, areas and impervious percentage and the flow-weighted average concentration from the TMDL), the internal loading rate (based on a 40 acre lake and constant release rate), and nutrient losses from the lake from both sedimentation and outflow. I used a simple first-order sedimentation term based on a settling velocity (10 m/yr). The mass lost in the outflow was calculated each hour by assuming the flow out of the lake is equal to the incoming water volume multiplied by the lake concentration in the previous hour. The concentration in the lake was calculated by dividing the mass in the lake by the lake volume (assuming a 1 meter deep lake with a modest adjustment for evaporation). Figure 1 below shows the results of this simple simulation and a comparison to the measured concentrations of nitrogen and phosphorus. I did find it necessary to use a lower rate of internal nutrient release than the mean described in the TDML (1.75 $mg/m^2/hr$ for TP) gave a better fit to the lake data. Overall, this simple model based on the conceptual model described in the TMDL seems to correlate somewhat with the measurements.

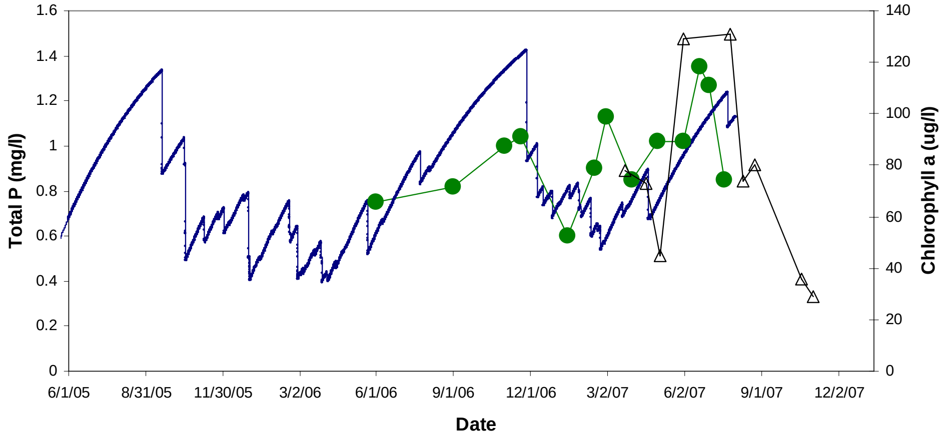

Figure 1. Results from a simple hourly mass balance model of Machado Lake for phosphorus. Solid circles show measured values approximately from a figure in TMDL and empty triangles show chlorophyll a measurements from the table in the TMDL.

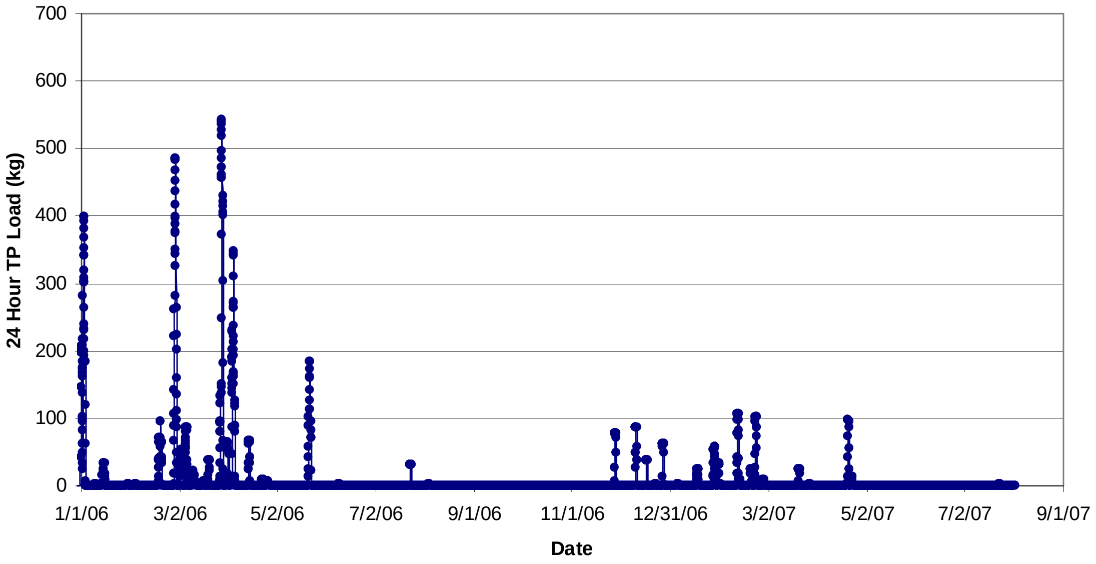

Figure 2. Twenty-four hour rolling average estimated watershed load to Machado Lake based on hourly precipitation and average phosphorus concentration from the TMDL.

The simple dynamic model did show some differences in the lake from year to year. Figure 2 shows the variation in estimated phosphorus loading over time. Clearly, much more phosphorus was input to the lake in 2006 than in 2007. The concentration measured in the lake does not appear to correlate well with the external load, but as described in the TMDL, is much more strongly influenced by the internal loading. In fact, based on the results of these simple simulations, the rate of internal loading seems greater in 2007 than in 2006. Using the same rate of release for both years leads to under-predicting the actual concentration in the lake in 2007 (Figure 1).

In summary, although the BATHTUB model can provide some insight into the relationship between loading and lake response, I believe that its annual average approach and incorporation of internal nutrient release in the eutrophication algorithms reduce its utility for simulating Machado Lake. I would suggest that the authors might find it useful to use even a simple dynamic model for evaluating the lake.

Estimating a Margin of Safety

An implicit margin of safety was assumed in the TMDL. This MOS is based on employing conservative assumptions in the evaluation. In the approach that was used to develop the TMDL, the implicit margin of safety seems reasonable.

Calculating Loading Capacity

The loading capacity and percent reduction required was estimated by developing a relationship between nutrient loading and average annual lake concentration using the calibrated BATHTUB model. It is my interpretation that the BATHTUB model was used to develop relationships between nutrient load and the nutrient concentration in the lake (Figures 17 and 18), and then the numeric target (1.0 and 0.1 for TN and TP, respectively) were used to identify the acceptable load. This leads to acceptable loads of 825 pounds of P and 8,800 pounds of N. The calculation of percent reduction required tried to accommodate the flushing of the lake that occurs during storm events. In effect, it seems to be allowing additional loading capacity by neglecting that portion of the load that occurs during the storm events. For example, if the allocation is met, then the TMDL assumes the phosphorus concentration in the lake will be 0.1 mg/l and the flushing of the lake that occurs during stormwater events will flush out 845 pounds of P so that is subtracted from the current estimated total annual load before relating it to the BATHTUB loading capacity of 825 pounds.

The loading capacity evaluation appears consistent with the conceptual model of Machado Lake that was developed in the TMDL, but I would question what it says about the applicability of the BATHTUB model for computing the acceptable load. The BATHTUB model uses empirical algorithms relating lake response to watershed loads. It is based on reservoirs where watershed loads are related to in-lake response. In the case of Machado Lake, the ultimate loading capacity calculation essentially subtracts the watershed load before computing the loading capacity. As also suggested above, this seems like a complicated attempt to force the BATHTUB approach onto this lake system.

The TMDL does identify what are likely the critical aspects of attaining the targets for Machado Lake: reducing the runoff concentration and reducing the internal loading. It appears that there will be different combinations of external and internal loading that would allow those targets to be met and those decisions could have implications for identifying restoration alternatives. I used the simple hourly time-step model to compare with the loading suggested in the TMDL. For example, if the external P concentration is reduced to 0.075 mg/l and the internal P release reduced to a low rate (e.g., 0.15 mg/m^2/hr), the summer lake P concentration would probably be close to an average of 0.1 mg/l (Figure 3). In this case, the annual phosphorus load to the lake would be approximately 634 kg external (if adjusted to an annual precipitation of 10.6" precipitation from the 11.4" average during the simulation) and approximately 210 kg internal (assuming 40 acres), for a total of approximately 850 kg. This includes the event runoff and would therefore be approximately half the suggested loading in the TMDL (from the TMDL report Table 8 when computed as the sum of the load discharged in the outflow and the loading capacity). Some idea of the sensitivity to both the external concentration and the internal loading rate can be seen in Figure 4 where doubling the internal loading rate to 0.30 mg/m^2/hr and reducing the influent concentration to 0.05 mg/l (which would also lead to a TP loading of approximately 850 kg) would likely not meet a summer concentration of 0.1 mg/l. Because the best-fit sediment release rate (1.75 mg/m^2/hr) is lower than that used in the TMDL existing load calculation, the baseline P loading to the lake in this simple hourly model is only approximately 5750 kg. It would still, however, require an 85% P reduction to attain a load of 850 kilograms (a percent reduction that is similar to the 91% suggested in the TMDL). Of course, these simulations suggest it is necessary to divide that allocation appropriately between external and internal load.

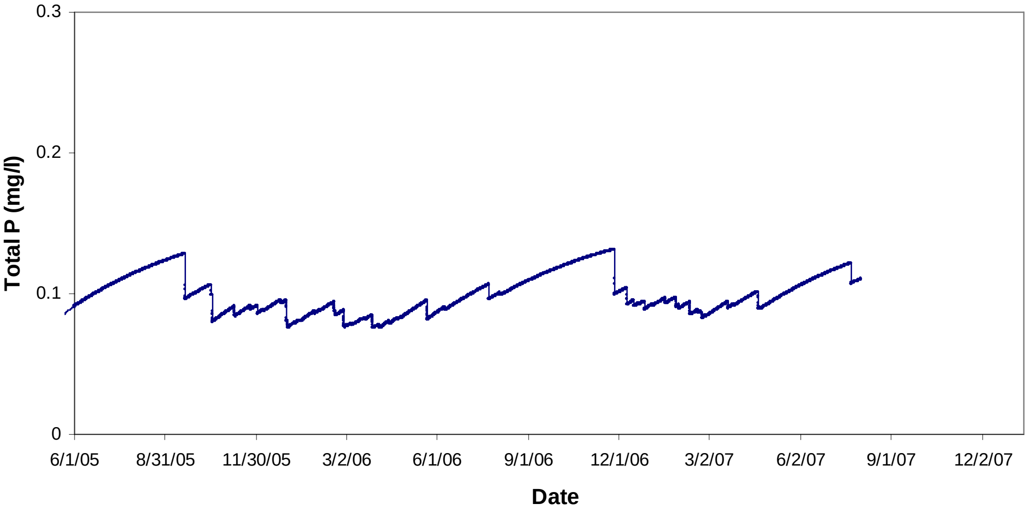

Figure 3. Predicted phosphorus concentration over time using a simple hourly time-step model with an external concentration of 0.075 mg/l, an internal release rate of 0.15 mg/m^2/hr and a settling velocity of 10 m/year.

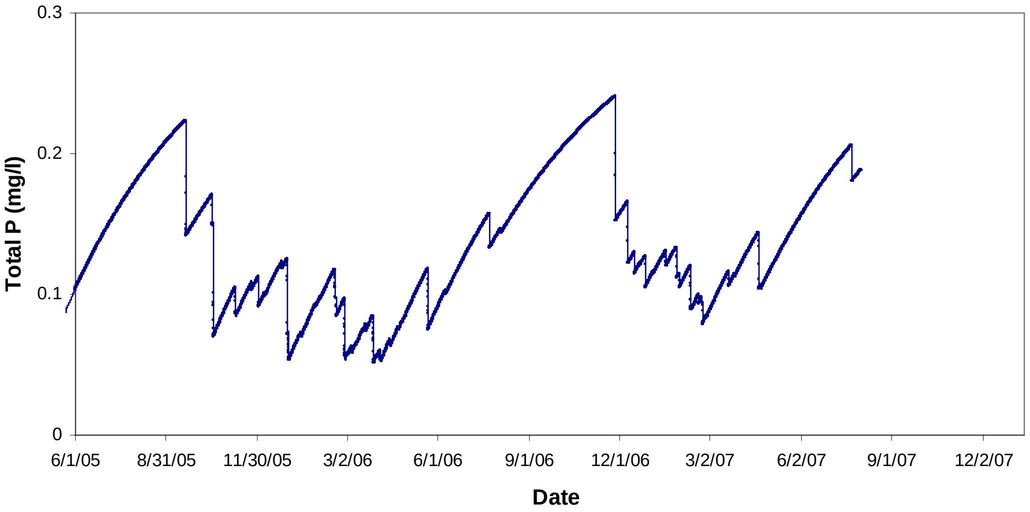

Figure 4. Projected phosphorus concentration over time using the simple hourly time-step model with an external concentration of 0.05 mg/l, internal release rate of 0.30 mg/m^2/hr, and settling velocity of 10 m/year.

The August 29, 2007 letter also requested comments on sedimentation rates and denitrification. I did not find discussions in the TMDL on sedimentation rates (except to the extent that they are in the empirical eutrophication algorithms of BATHTUB) or denitrification.

Monitoring Program and Special Studies

The TMDL proposed monitoring to measure the progress and special studies to refine aspects of the TMDL. The monitoring program appears sufficient (biweekly samples, nutrients, chlorophyll a, general water quality) to characterize the extent to which nutrient concentrations are being met. The program will also assist better characterizing the relationship between nutrient concentrations and algal density and how that might change with loading reductions. The special studies that are proposed appear appropriate and needed. The internal nutrient loading appears to be an important control over nutrient concentrations during the summer. I would suggest those studies be extended to explore the impact of different remediation strategies on nutrient release as it will be necessary to reduce those release rates substantially if the targets described in the TMDL are to be met.

Implementation Plan and Allocations

The TMDL presents a group of implantation options that would provide some reduction in nutrient loading and/or concentrations in the lake. The options look appropriate although they may vary considerably in their effectiveness in this situation. The reductions necessary to meet the load allocations are quite large, particularly for phosphorus, and I would suggest the reduction strategies be examined carefully with respect to how they will influence the lake. For example, vegetated swales have certainly been shown to provide large reductions in stormwater pollutants, but if much of that reduction occurs through infiltration, and concentrations of soluble phosphorus that remain after passage through the swale are still relatively high (e.g., 0.3 mg/l), that alternative is not going to effect the type of change which will help meet these targets because it is concentration in the lake after the runoff events that play a large role in controlling the growing season concentrations. Of course, the discussion of implementation options in the TMDL is preliminary and a more detailed evaluation of their impact on the nature of nutrient loading that will affect the lake is going to be necessary.

The TMDL established allocations are based on concentrations that are the same as the desired in-lake concentrations. That seems generally reasonable, although it is a simplification and the TMDL could include a more explicit acknowledgment of the dynamic nature of the nutrient loading in Machado Lake and the extent to which the two principal loads act in concert to determine the in-lake concentrations.

Summary and Conclusions

The TMDL does seem to present an appropriate conceptual model for Machado Lake and a concentration-based allocation approach that would move the lake towards the improved water quality. I do believe the modeling approach, while generally capturing the basics of eutrophication in watershed/lake systems, is unnecessarily cumbersome and not particularly powerful with respect to evaluating this lake and suggest it would be easier to evaluate the lake if the different components of the nutrient budget could be evaluated more dynamically. I believe that will be particularly important when evaluating the restoration alternatives as the different nutrient sources may influence nutrient loading and lake response in different ways.

References

Heiskary, S.A. and W.W. Walker. 1995. Establishing a chlorophyll a goal for a run-of-the-river reservoir. Lake and Reservoir Management 11(1):67-76.