During the last Stakeholder meeting, there was some debate (and potentially confusion) about how internal loading is being modeled and represented in the TMDL. Attached is a summary of the internal load modeling and final TMDL equation.

**Modeling Surface TP using BATHTUB**
Internal load is being estimated using results from the BATHTUB model(s) for years 2004-2007. BATHTUB estimates in-lake total phosphorus (TP) concentrations using a series of calculations (an algorithm) developed by Canfield and Bachmann, 1981. The Canfield-Bachmann algorithm was developed by establishing a relationship between in-lake TP concentrations, watershed load, atmospheric load, lake morphology (shape) and sedimentation rates using data from a wide range of lakes in North America. The ability of the Canfield-Bachmann algorithm to predict in-lake TP is depicted below (Figure 1). Because this model was developed using field observations (i.e., empirically), and all lakes have some natural internal loading (i.e., sediment release of phosphorus), the Canfield-Bachmann algorithm implicitly accounts for some level of “background” internal loading. However, to account for lakes that have internal loading at levels higher than would be considered background (e.g., phosphorus from curlyleaf pondweed senescence and multiple mixing events), the BATHTUB model allows the user to input additional internal sources of phosphorus.

![Replication of the Canfield-Bachmann Model Predictions](image)

*Figure 1* Is a scanned copy of Figure 2 from the original Canfield and Bachmann, 1981 paper (Can. J. Fish Aquat. Sci. 38:414-423) that compares the measured and predicted TP concentrations from 1330 lakes (both natural and artificial). Presumably, some of the uncertainty associated with Canfield-Bachmann predictions can be attributed to variations in internal loading.
Accounting for Internal Load in BATHTUB

In the process of modeling Medicine Lake from years 2004-2007, two distinct patterns emerged. In 2005 and 2006 (years where there was little internal loading from either curlyleaf pondweed or multiple mixing events), the BATHTUB model reliably predicts in-lake TP concentrations. However, in 2004 and 2007 (years where curlyleaf was observed at high densities and/or multiple mixing events were noted), BATHTUB underpredicted in-lake TP concentrations – presumably from increased internal loading (Figure 2A).

To account for the underprediction of TP concentrations in 2004 and 2007, the BATHTUB model was modified by adding additional internal loading at an average rate of 1 mg P/m²/day (an average of 3308 pounds of phosphorus per year). Following the modification to account for additional internal loading in 2004 and 2007, the model accurately predicts in-lake TP concentrations (Figure 2B). The 3308 lbs P/year value is being used to describe the internal load (above and beyond the background levels represented in BATHTUB) that will need to be addressed to meet water quality goals in all years.

**Figure 2** Graph A depicts results from the BATHTUB model simulations of in-lake TP concentrations from 2004-2007 using only the background internal load implicitly represented in the model. Graph B depicts results from the BATHTUB model simulations of in-lake TP concentrations from 2004-2007 with an additional average internal loading rate of 1 mg/m²/year for 2004 and 2007. In both graphs, the solid bars represent total watershed loads, and correspond to the primary y-axis on the left. The lines represent observed and modeled TP concentrations, and correspond to the secondary y-axis on the right.
Calculating the Components of the TMDL Equations

As has been discussed at the Stakeholder meetings, the TMDL number (i.e., the maximum amount of phosphorus that can enter the lake without impairing water quality) is described based on the Wasteload Allocation (WLA; the maximum amount of phosphorus that can be discharged by point sources – MS4s), Load Allocation (LA; the maximum amount that can come from non-points sources – the atmosphere and internal loading), Margin of Safety (MOS; to address uncertainty) and Reserve Capacity (RC; to account for future development). *Note that “∑” means sum, so that if/when wasteloads are allocated individually, the ∑WLA value equals the sum of all of the individual WLAs that are assigned to each MS4. In a categorical TMDL, the ∑WLA represents the entire allowable watershed load.

*$\text{TMDL} = \sum WLA + \sum LA + MOS + RC$

Based on discussions at the Stakeholder meetings, the MOS and RC values were identified. The MOS was set at 290 lbs P/year (the difference between an in-lake goal of 38 and 40 µg P/L) and the RC was set to 0 lbs P/year (based on the existing level of watershed development and/or non-degradation requirements).

The BATHTUB model (with inputs from P8) was then used to determine the WLA and LA values (the maximum phosphorus loads from point and non-point sources that will meet water quality goals). 2006 was chosen as the model year to identify WLA and LA values because it represents average levels of precipitation and had limited phosphorus input from curlyleaf pondweed and multiple mixing events. Based on the 2006 model, the WLA was identified as 3280 lbs P/year (Figure 3) and the LA was identified as 253 lbs P/year. (The LA value represents 253 lbs/year from the atmosphere and 0 from internal sources*). *Note: setting the internal load value in the TMDL equation to 0 does not imply there is no internal load. Instead, the 0 value indicates that the internal load that will allow Medicine Lake to meet water quality goals can be no higher than the background levels of internal loading already represented by the BATHTUB model.

![2006 Watershed Load Estimates](image)

Figure 3 Depicts the Watershed Load and corresponding in-lake TP concentrations for 2006. The current watershed load (4501 lbs) is compared to the watershed loads that correspond to 40 and 38 µg/L concentrations to describe the necessary wasteload reduction to achieve water quality goals.
Completing the TMDL Equation
Values for the WLA, LA, MOS and RC were then summed to arrive at the overall TMDL goal for Medicine Lake.

Completed TMDL Equation for Medicine Lake (lbs P / yr)

\[
\text{TMDL} = \Sigma \text{WLA} + \Sigma \text{LA} + \text{MOS} + \text{RC} \\
3823 = 3280 + 253 + 290 + 0
\]

Current conditions (based on 2006 data) were then compared to the TMDL goals to identify the phosphorus reductions necessary to achieve water quality goals for Medicine Lake (Table 1).

Table 1 - Phosphorus Sources and Required Reductions

<table>
<thead>
<tr>
<th>TP Source</th>
<th>Current TP Load (lbs/yr)</th>
<th>TMDL TP Load (lbs/yr)</th>
<th>Reduction Needed TP Load (lbs/yr)</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watershed</td>
<td>4,501</td>
<td>3,280</td>
<td>1,221</td>
<td>27%</td>
</tr>
<tr>
<td>Atmospheric</td>
<td>253</td>
<td>253</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Internal</td>
<td>3,308</td>
<td>0</td>
<td>3,308</td>
<td>100%</td>
</tr>
<tr>
<td>Margin of Safety</td>
<td>--</td>
<td>290</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Reserve Capacity</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Total</td>
<td>8,062</td>
<td>3,823</td>
<td>4,529</td>
<td>56%</td>
</tr>
</tbody>
</table>