Review of Lake Tahoe Total Maximum Daily Load

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The following material was read as the basis of the review of the Lake Tahoe Total Maximum Daily Load:

- Draft (June 2009) Lake Tahoe Total Maximum Daily Load
- Technical Report (June 2009) Lake Tahoe Total Maximum Daily Load
- Lake Tahoe TMDL Pollutant Reduction Opportunity Report (March 2008)
- Integrated Water Quality Management Strategy Project Report (March 2008)
- Appendices:
  - Urban and Groundwater Appendix A: PSC Performance Review
  - Forest Uplands Appendix B: Fire Literature Review
  - Appendix A: Stream Channel Erosion Nutrient Framework Analysis
  - Appendix B: Stream Channel Erosion Pollutant Control Options
  - Appendix C: Stream Channel Erosion Bank Stability Modeling
  - Appendix D: Stream Channel Erosion Load Reduction Analysis
- Appendix A: Packaging and Assessment Tool Description
- Appendix B: Information Supporting Chapter 3
- Appendix C: Supporting Tables and Figures
- CARB (2006)
- Tetra Tech (2007)

NB: Over the years I have read many of the papers published on Lake Tahoe, have heard numerous presentations at professional meetings by researchers from the area, and have visited the Lake Tahoe basin in all seasons.
In addition, several key journal articles were examined as part of the TMDL review; if specific publications are cited, they were read.
Supporting material was read less intently than primary TMDL text, in part, because the text was less focused on the key issues and many of the tables and figures were not sufficiently well described or were difficult to read given their size.

General comments

The process of developing the Lake Tahoe TMDL and the product is scientifically sound and credible. By building on a long period of research with many peer-reviewed publications and by conducting focused studies to augment and synthesize prior information, the TMDL is well supported. Modeling plays a significant part in the determination of the TMDL and is based on established approaches; the models are examined with appropriate sensitivity analyses.

One weakness in the Draft TMDL report is the lack of convincing evidence for the criteria used as the basis for the TMDL. Though Swift's thesis may contain the necessary level of analysis of underwater optical conditions and their relation to Secchi transparency, particles and phytoplankton, the Draft TMDL does not. Similarly, the case that N and P are the key nutrients influencing changes in phytoplankton abundance is not well documented.

The inclusion of the nearshore waters and bottom in the scope of a follow-on TMDL is recommended given the documented reductions in habitat quality nearshore, the region that most people experience.

Specific issues

Were sound scientific knowledge, methods and practices applied to the following determinations and actions in the TMDL?

1. Determination of fine sediment particles (<20 micrometers) as the primary cause of clarity impairment based on interpretation of scientific studies, available data, and the Lake Clarity Model.

The Ph.D. thesis by Swift (2004) as published in Swift et al. (2006) provides a theoretically and empirically sound basis for the 'determination of fine sediment particles (<20 micrometers) as the primary cause of clarity impairment'. More precisely, Swift's results demonstrate that most of the light scattering occurs because of inorganic particles less than 10 micrometers in size and with a significant contribution to light attenuation by algal cells. Swift developed an additive semi-analytic model of water clarity to calculate apparent optical properties of diffuse attenuation and Secchi depth from inherent optical properties due to water, algal cells, suspended inorganic sediments and colored dissolved organic matter. His modeling approach is based on recognized optical theory and uses measured properties of particles and algae in Lake Tahoe. Though the TMDL cites several additional sources of supporting information in support of the determination, this evidence is in Master's theses that were not provided for review.

2. Identification of the six sources of pollution affecting lake clarity of which urban upland areas was found to be the primary source of fine sediment particles causing Lake Tahoe's clarity loss.

The six sources areas considered include urban areas, forested areas, groundwater, stream channel erosion, atmospheric deposition and shoreline erosion. Each was evaluated with detailed measurements and extrapolated to the whole lake using GIS techniques and/or modeling (see following sections for evaluation of these models). In each case, the approach used, the analyses done and the conclusions reached are well supported and scientifically sound. A critical aspect of such calculations is that the uncertainty in the estimates be discussed, and this was done reasonably well. The results from these analyses clearly identify urban uplands as the dominant source of fine particles.

3. Determination that the Lake Tahoe Watershed Model was an appropriate

model to estimate upland pollutant source loads.

Several models are available with which to calculate inputs of pollutants for uplands, and the selection of the USEPA's LSPC modeling system as the basis for the Lake Tahoe Watershed Model is a reasonable choice. This modeling system includes simulations of watershed hydrology, erosion and processes influencing water quality and in-stream transport processes. The material available in the Technical Report (June 2009; Lake Tahoe Total Maximum Daily Load) is sufficient to judge the veracity of the model. To fully evaluate the version of LSPC being applied to Lake Tahoe required examining Tetra Tech (2007).

The estimation of sediment loads and parameterization of nutrient and TSS by land use, including an intensive stormwater study, represent a substantial effort with mixed results as illustrated in Tables 4-26 to 4-28 and Figures 4-27 to 4-29. While typical of comparisons between modeled and measured values for variables such as TSS, TN or TP, the scatter indicates the difficulty in modeling these items. The mean annual loading of TSS and N and P fractions calculated by LSPC falls within the standard deviations of the measured values in most of the 10 streams monitored. Based on the Lake Clarity Model inorganic particles less than 10 micrometer in size have the most influence on clarity, yet the fine sediment calculated by the Watershed Model is material less than 63 micrometers in size. This issue is dealt with in Chapter 5.

A few questions about the application of the model arise:

1. No in-stream transformations or biological interactions were simulated. While appropriate during maximum snow melt or major runoff events, during baseflow conditions it may not be appropriate.
2. What resolution DEM was used to delineate watersheds, subwatersheds and slopes?
3. How well validated is the National Hydrology Dataset for stream lengths in the Tahoe basin?
4. How were the rainfall and snowfall amounts distributed spatially from the eight SNOTEL sites?
5. Riverson et al. (2005) is cited as the basis for the selection of an evapotranspiration (ET) calculation, but this appears to be a presentation at a conference and is not available. ET and sublimation from snow are important aspects of the hydrological balance, and it would strengthen the report to provide more information about how these processes were determined.
6. Land –use is a key component of a watershed model, and several data sets apparently vetted by knowledgeable personnel were used. It would be helpful to have an overall assessment of the veracity of the land-use classification and the areas assigned to each class. When remote sensed data are used, such as the IKONOS data, formal procedures are usually applied to evaluate the validity of the product; however, Minor and Cabik (2004) is not available for review.
7. Metrics, such as the Sutcliff-Nash metric, are usually applied to evaluate model predictions, but these metrics are provided. Offering plots (e.g., Figures 4-18 and 4-19) with measured and predicted lines is not sufficient. The 'error statistics' in Table 4-15

help (though it is not clear if they are percentages or volumes), but are not really evaluated in the text.

8. Given the large amount of climate variability in the Tahoe basin, a four year calibration period seems short, especially since the model will be used to forecast conditions in the future as part of the overall TMDL.

4. Determination that estimates of groundwater nutrient loading rates are reasonable and accurate.

Groundwater movement and transport of materials is complex. It enters streams, where its influence is combined with other sources of runoff, and enters the lake directly. The USACE (2003) study (only summarized in the TMDL Technical Report) done as part of the TMDL work complements earlier investigations and used recognized, standard procedures, and provided spatially distributed estimates, which are relevant to mitigation options. The assumption of homogeneous aquifers and application of Darcy's Law is acknowledged as a simplification, and is asserted to provide reasonable estimates of groundwater flow. Since much more sophisticated, but data intensive, models, such as MODFLOW, exist and have been applied in other places, it would be valuable to have evidence offered to allow evaluation of the assertion. An indication of the considerable uncertainty in the estimates is noted in Table 4-5 where order of magnitude ranges from maximum to minimum values are listed. Given the acknowledged uncertainties, single values for basin-wide groundwater nutrient loading, as in Table 4-6, should not be listed. On page 4-15 under the subheading 'Ambient nutrient loading to Lake Tahoe from groundwater', it is stated that ambient groundwater represents approximately 46% and 34% of the P and N loading, while in Figures 4-1 and 4-2 groundwater is assigned 15% and 12.5% of the P and N loading. This apparent discrepancy should be clarified.

Estimates of groundwater nutrient loading should be described as reasonable estimates with wide error bars, hence the word accurate does not seem appropriate.

5. Pollutant loading rates from atmospheric deposition directly to the lake surface were quantified, and in-basin sources were found to be the dominant source of both nitrogen and fine particulate matter. Direct deposition of dust accounts for approximately 15% of the average annual fine sediment particle load.

Considerable effort was expended to quantify both wet and dry atmospheric deposition to the lake using established methods of measurement and calculation. The data on P deposition were quite difficult to obtain and special care was taken with the analytical methods. Dry deposition is a problematic measurement, and the two approaches used are complementary and have different sources of error. LTADS collected material from the air and then calculated deposition based on meteorological data and deposition velocities. LTIMP deployed bulk and wet/dry collectors; these bucket collectors are known to not represent true particle deposition. Snow sampling is also subject to errors if collected in buckets; this issue is not addressed. The transport models based on meteorological and compositional measurements were used to account for atmospheric deposition in the basin that originated outside. It is surprising that error bars are not shown for results since the text notes uncertainty. However, the considerable sources of fine particles and N identified within the basin support the conclusion that in-basin sources dominant. The overall percentage of fine particle load from atmospheric deposition depends on the values of all the other sources, all of which have uncertainties; hence it is difficult to assign a level of certainty to the approximation that direct deposition of dust accounts for approximately 15% of the average annual fine sediment particle load.

6. Pollutant Reduction Opportunity (PRO) analysis identifies fine sediment particle and nutrient reduction options that can be quantified. The PRO findings offer basin-wide pollutant load reduction estimates and costs for a range of implementation alternatives for reduction loads from urban uplands, forest uplands, stream channel erosion, and atmospheric deposition sources.

The material presented in the PRO analysis appears to thoroughly consider options and provide abundant documentation of costs for many options. The reduction options and costs evaluated are not sufficiently well known to this reviewer to allow critical appraisal.

7. Lake Clarity Model was the most appropriate for predicting the lake response to changes in pollutant loads.

The ‘Lake Clarity Model’ combined an optical model (Swift et al. 2006) with a hydrodynamic model derived from the widely used DYRESM model (Imberger and Patterson 1981), an ecological model related to a model described in Schladow and Hamilton (1997) and particle fate model. As such it includes the key processes and has algorithms verified by use in other systems as well as Lake Tahoe. However, to argue that it is the ‘most appropriate’ model is not possible unless it is compared to alternative models. In particular, while the optical and hydrodynamic components are grounded in optics and hydrodynamics, the ecological model includes many simplified expressions and numerical values selected from the literature. Hence, application of the ecological model requires very careful sensitivity analysis and has considerable uncertainty.

The validity and accuracy of model output depends on inputs, and the hydrodynamic model is being driven by readily available data. Though considerable information on nutrients and plankton exist for Lake Tahoe, the inherent complexity of the biological system leads to missing information required for the ecological model, a further source of uncertainty. These differences are evident in Figures 6-2 to 6-6 in which the close match between modeled and measured temperature profiles contrasts with the less good matches for chlorophyll, nitrate and bioavailable phosphorus. While simulated and observed annual average Secchi depths are close (Table 6-6), seasonal variations of simulated and observed values diverge considerably (Figure 6-7) and reflect the difficulty of modeling the dynamic processes the combine to influence transparency.

8. Allocation of allowable fine sediment particle and nutrient loads is based on the relative magnitude of each pollutant source’s contribution and the

estimated ability to reduce fine sediment particle and nutrient loads.

The logic of this statement is correct, and the information supporting it is discussed elsewhere. However, a general concern is that allocations are not stated as ranges or as estimates with uncertainty specified.

Comments on text of Lake Tahoe Total Maximum Daily Load – June 2009 Draft

Executive Summary

Page ES-1 Lake Tahoe is a subalpine lake not an alpine lake, as is stated elsewhere in the material.

The basis for the transparency standard of a Secchi depth of 29.7m as the annual average for the period 1967 to 1971 seems overly precise and the selection of years for this standard is not well supported.

The percentage reductions assigned to particular sources are too precise and do not include uncertainties.

The 'adaptive management' to be used to address issues such as climate change or wildfires is not formally described and seems difficult to implement in the context of the TMDL process.

1. Introduction

The possibility that nutrients other than N and P may influence the growth of algae is not mentioned. In ultra-oligotrophic waters, such as those in Lake Tahoe, trace elements can be important.

2. Basin and Lake Characteristics

Since Lake Tahoe does not mix thoroughly each year, it would seem appropriate to calculate a residence time for the water that considered differing volumes.

Optical Properties

The introduction and conceptual model of underwater light should note the dissolved organic matter is a constituent contributing to underwater light attenuation.

What are the sizes of the particles represented in Figure 3-2?

Section 3.4.1: Primary productivity by phytoplankton does not directly cause transparency decline. It is the resulting accumulation of phytoplankton, not their rate of photosynthesis, that leads to less transparency.

4. Problem Statement

Since Secchi transparency is the key criterion, more information should be provided about the nature of the measurement and its relation to instrumental measurements of underwater light attenuation.

What is the definition of the euphotic zone used as the basis of the statement that light penetrates as deep as 100 m?

How many measurements per year are represented in Table 4.1? Though the annual average may be calculated to mm precision, the accuracy of the Secchi transparency measurement is at the cm level. The values in the Table should be rounded to the nearest cm.

5. Water Quality Standards

Page 5-6: To interpret the vertical extinction coefficient (VEC; which should be called the vertical attenuation coefficient), the wavelength range of the sensor used for the measurements must be specified.

6. Numeric Target

Pages 6-1 and 6-2: VEC is not properly defined, and it is a concern that there appears to be no trend in VEC from 1971 to 2002 while Secchi transparency has a declining trend.

Page 6-3: If the numeric target is based on the annual average Secchi transparency, the number of measurements and their seasonal distribution must be stated.