Lake Tahoe Clarity Workshop

In May 2025 the Tahoe Science Advisory Council hosted a two-day workshop focused on the current understanding and status of the modeling of Lake Tahoe's mid-lake clarity. The workshop provided a venue for managers and scientists to improve mutual understanding of recent scientific reports and management issues. The workshop combined presentations with robust discussion.

In preparation, a series of meetings were held to coordinate content. Several reports were distributed with the expectation that participants would review material prior to the workshop.

After the workshop, two products were developed:

1. A memorandum outlining general steps to develop clarity predictive tools.
2. An executive summary of workshop actions appropriate for presentations to the Tahoe Interagency Executive Steering Committee and other interested stakeholders.

During the workshop, participants identified a need for a complementary workshop focused on particle and nutrient loading estimates and associated modeling. There are ongoing discussions regarding workshop needs and next steps.

Attendees included academic scientists and management agency staff.

Science Participants: John Melack (UC Santa Barbara), Steve Sadro, Geoff Schladow, Alex Forrest, Adriane Smits, and Stephanie Hampton (UC Davis), Sudeep Chandra and Carina Seitz (UNR), Alan Heyvaert (DRI), Ramon Naranjo (USGS).

Management Participants: Dan Segan (TRPA), Jason Kuchnicki and Chris Fristen (NDEP), Laurie Scribe, Ed Hancock and Brian Judge (Lahontan), Dominique Fellers (Nevada Tahoe Conservation District), Andrea Buxton (Tahoe Resource Conservation District), and Darcie Collins (League to Save Lake Tahoe)

Sponsorship: The workshop was sponsored by the Nevada Division of Environmental Protection, the League to Save Lake Tahoe, and the University of Nevada, Reno. Additional funding was provided by a grant from the Southern Nevada Public Lands Management Act.

Presentation and discussion notes

TMDL overview

Geoff Schladow provided an overview of the clarity modeling work conducted in support of the TMDL, including Lake Clarity Model calibration, validation, and operational time scale.

Brian Judge, Dan Segan and Jason Kuchnicki outlined the TMDL implementation, tracking, and adaptive management structures.

Underlying the TMDL overview is a critical management question:

> *If watershed restoration and stormwater treatments have reduced fine sediment and nutrient loading, why is the lake not responding as anticipated by the TMDL analysis?*

Possible reasons include:

- Anticipated clarity response to loading and/or load reduction were not correct or have changed.
- Fine particles may remain in suspension longer than anticipated.
- The clarity-impacting size range of particles were not removed to the degree assumed.
- The response time to load changes is different than expected.
- Ecological factors have influences on clarity not modeled or anticipated.
- Physical dynamics have changed.
- Initial loading estimates were not correct.
- Load reduction estimates associated with restoration and BMP implementation are inaccurate.
- Climate and hydrologic conditions are different than those used in previous estimates and predictions.

Other key points:

- Re-running the 2010 version of the clarity model is not practical or recommended.
- Data on load reductions associated with management activities are not collected; the only metric against which clarity can be evaluated is an estimate of benefits associated with various implementation activities.

- Urban jurisdictions have achieved an estimated 35% particle load reduction based on established tracking and accounting tools.

Issues discussed:

- Need to evaluate urban implementation and tracking methods and associated metrics (PLRM, RSWMP, Crediting).
- Need for a unified methodology between how management activities are evaluated and necessary model inputs (modeled vs. actual measurements of sediment load).
- There is ongoing uncertainty regarding the original clarity model's assumed relationship between loading and clarity.
- Are other drivers (internal mixing dynamics, particle dynamics, changes in picoplankton) overshadowing watershed loads?
- Can we integrate load reduction estimates into statistical models to test for an effect?

<u>Clarity status and trends</u>

John Melack summarized available data sets.
Steve Sadro reviewed recent statistical analyses performed by Naranjo and Smits.

Key points:

- Clarity trends have slowed but drivers remain uncertain
  - LOESS decomposition (Naranjo) found the slope of the trend to flatten after 2000
  - GAM model (Smits) found nonlinear decline in clarity at LTP through late 1990s, possible plateau in the 2010s.
  - Similar decline not seen at MTLP (although the number of data points at this station is lower by a factor of three)
- Outliers are identifiable using multiple approaches and especially evident in winter and spring
  - Outliers likely reflect episodic events, not just noise
  - Current data inputs do not attribute causality to outliers with confidence
- Seasonal and episodic variation in clarity are important
  - All models highlight the central role of seasonal and intra-annual variation in both clarity values, and how clarity responds to drivers

- GAM model (Smits) shows seasonality explains as much variation as interannual trends, and MARSS (Smits) shows residuals cluster by season
- LOESS (Naranjo) shows changing seasonal modes in the long term record, a shift from unimodal (through the 1960s) to bimodal (1970-2000) then back to unimodal (post 2000) with growing intra-seasonal variance
- EDM model (Melack) finds driver response relationships shift depending on system state, which includes seasonality

- Non-linearity, process noise, and unaccounted-for drivers limit predictive ability of statistical models

Issues discussed:

- Need for accessible database of monitoring data.
- Remote sensing products may be a source of data and need to be evaluated.
- Why has clarity not improved despite load reduction efforts?
    - Are observed trends being driven by the same external load tracked by TMDL crediting system? i.e. particle load size or particle load mass reduction
- What are driving residuals in the statistical model predictions?
    - Need to build more diversity of possible drivers into statistical models to capture more variation, then explore variation in residuals
- Are we reporting the correct variable, i.e., Secchi depths?
    - Other approaches to measuring light attenuation include on-going measurements of beam attenuation and attenuation of photosynthetically active radiation.
    - Other indices of optical properties of lake water to consider include on-going measurements of chlorophyll, colored dissolved organic matter, suspended particles.
    - Would high frequency sampling add a useful dimension to analyses?
- How can modeling and monitoring better align?
    - Managers ask for a way to link model outputs to decision making thresholds –tools that allow an exploration of observed vs expected Secchi under given load reduction scenarios
- What statistical output (figures/graphs) is most useful for managers?
- Need for monthly and seasonal values as well as annual averages.
- Are average annual Secchi depths time weighted to account for unequal sampling intervals? Yes.

- How do statistical analyses inform causes for variations in Secchi depths?
- MARSS by season is problematic - use monthly data sets.
- How do we interpret analyses outliers, and how are these effected by rare events, e.g. upwelling, deep mixing?
- Given the difference in trends, is the mid-lake station useful?

Predictive tool review

Geoff Schladow discussed UC Davis efforts to develop and implement a 3D model of Lake Tahoe's hydrodynamics and to improve ecological components.

John Melack discussed a recent project that used empirical relations to predict clarity conditions.

Key points:

- Clarity can vary at hourly time scales.
- The updated 3D model does not include a module for particle dynamics and optical conditions.
- The biological routines need to be improved and validated. Additional field and experimental data are required.
- Empirical Dynamic Modeling is similar to other AI/machine learning approaches.
- EDM and other data-driven forecasts are not mechanistic, though predictive, but dependent on available long-term data.

Issues discussed:

- How are clarity forecasts related to management activities?
- Computational constraints on modeling 3D hydrodynamics at decadal timescales.
- How would EDM forecasts change with more data?
- Consider combining EDM with downscaled climate modeling to forecast clarity as climate changes or coupling high frequency optical measurements of clarity with high frequency measurements of physical dynamics
- How is EDM affected by non-stationarity, such as with regime shifts or climate change?
- Can remote sensing data provide another data-rich input for EDM or other machine learning models?

Recent lake process research

Steve Sadro and John Melack summarized recent projects that investigated zooplankton populations (Chandra et al. 2025. Zooplankton ecology of Lake Tahoe: Composition, migration, and influence on plankton particle sizes) and particle dynamics (Heyvaert A, Buxton A. 2024. Characteristics, composition, and relative sources of very fine particles affecting water clarity in Lake Tahoe)

Key points:

- Concentrations of fine suspended particles (FSP; 0.5–16 µm) measured by computer-controlled scanning electron microscopy (CCSEM-EDS) had median values of 5,330 particles/mL in lake; 319,470 particles/mL in streams, and 4,138,750 particles/mL in urban runoff.
- About 50% of FSP numbers in lake, stream and urban samples in 1–5 µm size range. Most remaining FSPs in 0.5–1 µm size range. Only 3–11% of FSPs in 5–20 µm range.
- In contrast: 5–20 µm particles are 74–82% of the total FSP mass. Only 17–25% of FSP mass in the 1–5 µm range.
- Internal lake particle sources and transformations (e.g., from biota or in-lake aggregation) are not adequately tracked in current models.
- High seasonal and spatial heterogeneity found in zooplankton community structure across sits and between nearshore and offshore locations
- Emerald Bay is distinct from Lake Tahoe pelagic sites
- Nearshore zooplankton (dominated by Bosmina and Epischura) is distinct from offshore.
- Less variation found in rotifers.
- Vertical migratory patterns found across many taxa
- Need for a well-designed grazing experiment linked to particle sizes

Issues discussed:

- Particle fate, transport, and transformation processes are poorly understood.
  - The factors causing particle aggregation in Lake Tahoe need investigation.
  - What controls aggregation and disaggregation?
  - Are we focused on the right size fraction?
- Recent lakebed sediment cores suggest sedimentation rates have declined, but fine size fraction has increased.
- Role of biota in particle dynamics needs resolution
  - What are effects of zooplankton grazing and diel migration?

  - How does grazing affect size fractionation?
- What monitoring changes or improvements are needed to inform the clarity model, and make management decisions?
  - Can we resolve diel or vertical variability in particle dynamics coupled with zooplankton dynamics?
  - Should we be doing more night-time monitoring?
  - Is the timescale at which we're monitoring inherently missing the relevant timescale of dynamics?

<u>Predictive tool – next steps</u>

The discussion reflected a series of management questions and observations:

Clarity models need to be able to predict how lake clarity responds to different management actions:

- How does observed Secchi depth correspond to various load reduction percentages?
- What factors drive clarity dynamics and have they changed over time?
- How do the amounts of variation in clarity driven by within-lake and loading processes compare?
- What has been driving the apparent change in particle dynamics since 2017?
- If there had been no management action, what would be the clarity condition?
  - Are the TMDL model predictions for "no change" valid?

Multiple hypotheses for why clarity is not improving as expected can be tested with a variety of statistical or machine learning approaches or by deterministic models

- Time lag associated with particle dynamics or zooplankton dynamics not currently accounted for
- Tracking errors –our assumption about load reduction is not correct
- Wrong particle sizes –TMDL targets 16-micron material, but not the abundance of the smaller particles that matter the most for optical clarity
- Ecological changes –zooplankton community dynamics that affect grazing rates or phytoplankton community structure; importance of microbial autotrophs, i.e., picophytoplankton
- Changing physical dynamics

Additional technical considerations and needs

- 3D model effects are vital to understanding key interactions.
  - Littoral pelagic exchange

- Fate of inflows (streams, urban drains, atmospheric deposition)
  - Immediate and time lagged effects of upwelling
- Loading estimates should be revisited, especially for target particle size classes
- Computational challenges –how to overcome them?

There was productive discussion regarding two different methods for clarity prediction:

1. Forecasting tools driven from relations revealed by empirical data analyses.
2. Mechanistic models that attempt to describe relevant chemical, biological, and physical processes, along with impacts of management actions, critical for forecasting based on mechanistic understanding.

The group agreed there is value in both approaches and is interested in a framework that would pursue the two options in parallel.

1. Build on previous efforts to refine a processes-based model
2. Explore opportunities to develop data-driven forecasting tools.