

Monitoring Past, Present, and Future Water Quality Using Remote Sensing

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The final report of this Round 7 SNPLMA Science project was recently submitted to the USDA Forest Service Pacific Southwest Research Station. In broadest terms, the intent of this project was to demonstrate the use of Remote Sensing for measuring water quality parameters at Lake Tahoe. One of the major benefits of this approach would be that a whole-lake view of water quality changes would be possible, even extending into the nearshore where discrete sources of pollutants could be identified. Linked to this was the possibility that through using archived satellite data, long-term trends in other parts of the lake (beyond the two sites currently monitored by UC Davis) would be feasible. The system capitalized on the local infrastructure developed by NASA and UC Davis, the long-term dataset that was collected by UC Davis, and the numerous freely available satellite datasets.

Through this study we developed a semi-automated system to utilize remotely sensed and field measurement data to quantify water clarity and near-surface chlorophyll *a* concentration measurements over the entire lake. The system was based on the use of MODIS satellite data (1 km, 500 m, and 250 m) that are available several times per day for the period 2002 – 2010. These data were used to create maps of water clarity and chlorophyll *a* which extend sufficiently close to the shoreline to assess the impacts and fate of key point and non-point pollutant sources.

While the reader is referred to the full report to better understand the benefits and limitations of the work conducted to date, there are a number of important points that are summarized here.

1. Remotely sensed “measurements” are a combination of measurements and models. Spaceborne radiometers, such as MODIS, measure the spectral distribution of radiance exiting the top of the atmosphere. Only a small fraction of the radiance measured at the sensor is water-leaving radiance. Over oligotrophic waters, such as Lake Tahoe, the atmosphere can contribute as much as 90 – 99% of the signal received by the satellite sensor. In addition, there are influences from factors such as sun glitter, whitecaps, clouds and jet contrails. Therefore, atmospheric correction must be performed on each satellite image to remove these contributions and adjust for atmospheric attenuation. In the open ocean there are well-established methods for atmospheric correction, which benefit from negligible terrestrial contributions to the atmosphere and water. Lake Tahoe by contrast has a more optically complex terrestrial atmosphere, albeit a thinner one due to its altitude, and more optically complex waters, although its low chlorophyll concentrations are similar to the pelagic ocean. Uncertainties associated with the process of atmospheric correction (i.e. how the atmosphere is modeled) are an important limitation on the accuracy of remotely sensed water quality at Lake Tahoe.
2. As part of this project a web-accessible database of Tahoe remotely sensed imagery has been created. This is a living database, and images are being added to it as they are acquired by MODIS. These images are atmospherically corrected, using what we believe to be the

most appropriate “models” for Lake Tahoe. Instantaneous and monthly averaged Secchi disk depths and chlorophyll *a* values for locations corresponding to the long term UC Davis monitoring stations are calculated, as are similar values for 45 “virtual” offshore, coastal and nearshore stations around the periphery of the lake, and maps of these variables for the entire lake are produced.

3. Calibration of the satellite-derived Secchi depth and chlorophyll *a* concentration against the measured data for the lake gave a very good match, with both seasonal variations and year-to-year variations for the 8 years of data used being well represented. Annual average Secchi depth showed a slight bias, with the satellite derived values being about 1 m lower than the measured values. The cause of this bias is currently being studied.
4. Lakewide maps of Secchi depth and chlorophyll *a* concentration show significant variations. The largest variations occur closer to shore, and the lowest Secchi depth and highest chlorophyll *a* are frequently seen to be associated with stream mouths and to occur at times of spring runoff.
5. Because of the influence of nearshore features such as bottom reflection, and the relatively large pixel size associated with MODIS imagery, the “virtual sampling stations” that were established had their nearshore sites approximately 750 m from shore. While this was sufficient to see the influence of loading from the land, it cannot resolve finer-scale features closer to land such as details of turbidity plumes, distribution of macrophytes and clam beds, and the precise source of pollutants from the intervening zones. That type of information can best be acquired with the concurrent use of high resolution satellite imagery (as was acquired in summer 2010 by TRPA) by NASA airborne hyperspectral sensor in combination with field measurements of bottom reflectance around the nearshore.
6. An unexpected finding of comparing the 8-year, monthly averaged Secchi depth around the lake periphery is that Secchi depth is consistently lower on the east side of the lake (from Stateline Point to Tahoe Keys) than on the west side of the lake. This appears to hold true at all times of year, and is most pronounced closest to shore (at the nearshore sampling stations). Consistently the lowest clarity region is between Glenbrook and Marla Bay. The reasons for this are not fully understood, but it is most likely due to mixing and transport processes within the lake (i.e. physical limnology) than on watershed inputs in this region. Chlorophyll *a* on the other hand, did not show as clear a pattern from east to west.
7. The images in the report showed clearly that the distribution of clarity and chlorophyll *a* in the nearshore is very often controlled by the transport processes within the lake. This held true for both along shore effects, and onshore-offshore transport. Through a complex and poorly understood combination of upwelling, large-scale circulations, meso-scale spiral eddies, jets and flow reversals, pollutants are redistributed around the lake. This has very important ramifications for near-shore monitoring of water quality. In the first instance, a given measurement site may not be representative of a nearby land-use as water from pristine and polluted areas are potentially transported large distances. Second, as these transport mechanisms are likely to change their spatial and temporal distributions seasonally, annually and inter-annually in response to meteorological and climatic forcing, long-term trends will be difficult to ascertain until the transport is better understood.