LAKE TAHOE NUTRIENT AND SEDIMENT TOTAL MAXIMUM DAILY LOAD

SPRING 2003 NEWSLETTER

The previous Lake Tahoe Total Maximum Daily Load (TMDL) newsletter introduced the concept of mathematical water quality models and described how they simulate a waterbody's past and predict its likely future response to pollutant inputs. These critical tools will allow us to calculate sediment and nutrient load reductions that protect and restore Lake Tahoe's famous clarity. The first model we presented is the Watershed Model, which in turn integrates a number of other supporting models (see http://www.swrcb.ca.gov/rwqcb6/TMDL/Tahoe/Winter_2002-03_TMDL_Newsletter.pdf). This issue describes two additional models that play equally important roles in the process: one that uses the Watershed Model's output to determine Lake Tahoe's clarity and to calculate the TMDL itself, and the other that provides the meteorological data that drive both the Watershed and Lake Clarity Models. We hope that you'll brave the somewhat dry and technical nature of these discussions and recognize the sophistication of the tools we're applying to achieve our simple goal: to protect Lake clarity!

MODELING LAKE TAHOE CLARITY

The challenging task of modeling Lake Tahoe clarity has been assigned to a team of researchers at University of California at Davis under the leadership of Dr. Geoff Schladow, who has been developing the Lake Tahoe Clarity Model since 1997. The Lake Tahoe Clarity Model is a unique combination of sub-models including a hydrodynamic model, an ecological model, a water quality model, and an optical model. Each sub-model is based on an inter-related set of equations that describe the underlying physical transport, biological growth, chemical transformation and light attenuation processes occurring in the lake. As a result, the model has the potential to provide meaningful predictions for combinations of weather and runoff conditions that may not have been previously experienced (or at least recorded) at the lake. When conditions change, for example a summer thunderstorm occurs, the changes in climate and in sediment and nutrient loads into the lake (which the meteorological and watershed models will describe) provide input to the clarity model. Using these types of inputs, the clarity model calculates the amount of pollutant mixing and transport that occurs in response to the storm, the change in algae growth (resulting from the changed light and nutrient environment), and the change in the distribution of fine particles. It then combines all these processes to estimate the change in lake clarity (measured by the depth to which a dinner-plate-sized Secchi disk can be lowered before it is no longer visible from the surface).

While changes due to an episodic event like a thunderstorm are important to represent correctly, our real interest for purposes of calculating the nutrient and sediment TMDL is in knowing how the lake will respond to the continuum of meteorological events and associated pollutant inputs that occur over periods of years or even decades. We are especially interested in pollutant loads that are amenable to intervention or control. Using the model, we can predict what the effect would be of better managing each of those inputs. Or, working in reverse, the model predicts what level of pollutant reduction we will need to achieve Lake Tahoe's numeric clarity target or standard (which is a Secchi depth of 97 feet, the 1967-1971 average annual clarity). There will likely be numerous combinations of reduced fine sediment, phosphorus, and nitrogen loads that will satisfy this requirement, from which the TMDL will be selected. The model will also predict how quickly the lake will respond to the reduced loads.

❖ WHAT CONTROLS LAKE CLARITY?

The clarity of water, measured by how far down we can see, is dependent upon the sum of light *absorption* and light *scattering*. The principal light absorbing components of water are phytoplankton (or algae) and dissolved organic material. The amount of dissolved material in Lake Tahoe is still quite low, so most of the light absorption is by phytoplankton. The more phytoplankton there are, the higher the light absorption. Therefore, in order to model clarity, it is necessary to model the growth (and demise) of phytoplankton. Like any plants, phytoplankton need nutrients to grow, so the variation of nitrogen and phosphorus with depth must also be modeled. Phytoplankton also need light, so the clarity itself feeds back on one of the clarity controlling factors!

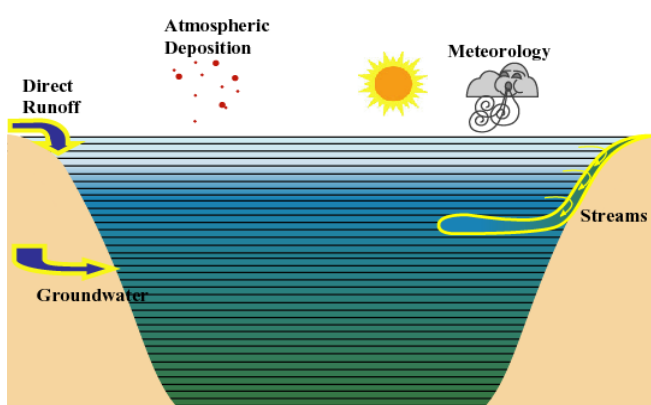
Light scattering is produced by fine particles (smaller than one-tenth the width of a human hair). Most of these particles are believed to be inorganic, and are added to the lake via stream inflows, direct runoff and by atmospheric deposition. Small particles can stay in suspension for many years in a lake as deep as Tahoe, so modeling the settling rate of these fine particles is a key factor of our present research.

❖ WHAT ARE THE COMPONENTS OF THE MODEL?

The Lake Tahoe Clarity Model, which was originally developed with the support of a 1997 Environmental Protection Agency Watershed Research Grant, has the following key components:

Hydrodynamic sub-model

The lake is assumed to be composed of up to 500 horizontal layers, each of which has its own set of temperature, salinity, and other water quality variables. Horizontal variations across the lake are assumed to be much smaller than the vertical variations. The hydrodynamic sub-model predicts thermal stratification (or vertical layering of water in the lake) and mixing produced by climatic conditions. It then uses this result to account for the redistribution of lake properties. In addition, the sub-model routs stream inflows, which carry nutrients and fine particles, into the lake at a depth consistent with their temperature. It also directs inputs of these pollutants to the lake from other sources such as direct runoff, groundwater inflow, and atmospheric deposition.



Schematic of the hydrodynamic component of the Tahoe Clarity Model

Water quality sub-model

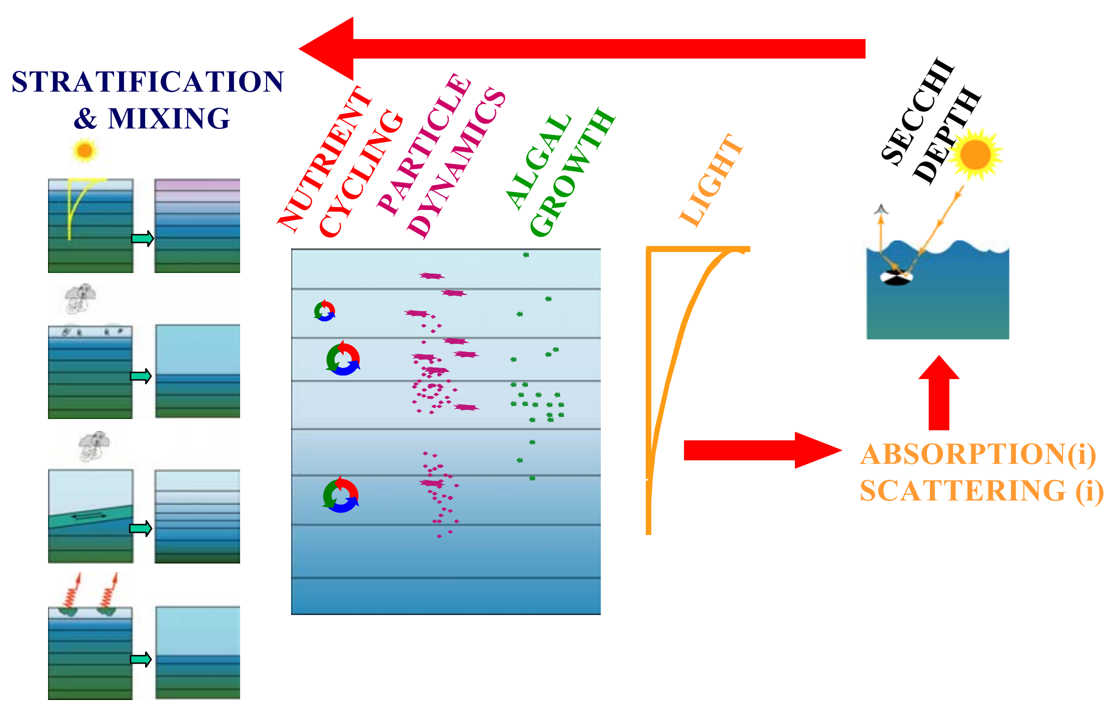
This component of the clarity model represents nutrient cycling and dissolved oxygen swings, as well as how seven size classes of inorganic particles aggregate and sink, within the lake. Nutrients enter the lake in different chemical forms, and are constantly undergoing transformations. Some of these transformations occur once the inorganic nutrients are taken up by the phytoplankton and converted to organic forms. Thus, the water quality sub-model is intimately linked to the ecological sub-model. Dissolved oxygen similarly affects nutrient transformations. One of the key sources of dissolved oxygen is from the action of wind at the surface, so this sub-model is also linked to the hydrodynamic sub-model. Outputs of the water quality sub-model include concentrations of oxygen, all chemical species of nutrients, and each particle size class at every layer and at each model timestep (three hours).

Ecological sub-model

The ecological sub-model represents the photosynthetic growth of phytoplankton, their uptake and release of nutrients, their production of dissolved oxygen, and their loss through grazing by zooplankton and other higher trophic levels such as fish. Algae growth is regulated by the amount of light, nutrient concentrations, and temperature at the depth of each model layer. For example, at night, light drops to zero and algal growth ceases; however, other processes such as respiration, grazing, and sinking continue and are represented in the model. The output is the concentration of algal biomass at each layer and timestep.

Optical sub-model

The optical sub-model is a truly unique component of the Lake Tahoe Clarity Model. From the other sub-models' predictions of algal distribution and particle distribution, this sub-model calculates the amount of light scattering and absorption within each layer of the lake. Relationships between particle concentration, algal concentration and the inherent optical properties of lake water have been determined from analyzing over 2 years of data from Lake Tahoe. These relationships are then used to calculate the resulting Secchi depth or clarity of the lake.



Schematic of operations within each of the three-hourly timesteps of the Lake Tahoe Clarity Model. After stratification and mixing have redistributed layer properties (driven by meteorology and pollutant inputs as determined by the hydrodynamic model), nutrient cycling, particle settling, and algal growth occur. The absorption and scattering produced by the new distribution of algae and particles is used to calculate light attenuation and Secchi depth. The new profile of light attenuation is then used in the next timestep to calculate thermal stratification, or temperature-induced vertical layering within the lake.

❖ From Where does the Model Obtain Input Data?

The model is totally reliant on data to "drive" it. However, as it is to be used as a predictive tool for estimating clarity changes over the next 40-50 years, these data do not yet exist. This is where the Lake Tahoe Clarity Model interfaces with the Watershed Model (described in the previous newsletter) and where the synthetic meteorological record comes in (which is described later in this edition). Using the output from these models, the Lake Tahoe Clarity Model can be run using the best estimates of future conditions. These estimates will be varied and manipulated in an effort to quantify the associated uncertainties, and to ascertain the types of responses that may occur under future scenarios such as climate change, increasing drought duration, increasing storm occurrence and/or frequency of rain as opposed to snow storms, etc.

❖ How is the Model Calibrated and Validated?

For any model to be trustworthy, it has to undergo an extensive period of calibration where many of the unknown rate coefficients are adjusted to match local conditions by comparison with measured data. Equally important, the model has to be validated by comparing the results (using the best estimates of the adjusted coefficients) against a different set of data. The ongoing data collection program at Lake Tahoe is designed to provide the needed types of data, as well as to provide a basis for the continual upgrading and improvement of the model.

❖ Key Personnel

Geoff Schladow is a professor of Water Resources and Environmental Engineering at UC Davis. His research explores the connections between fluid mechanics and water quality parameters in lakes, reservoirs, streams and estuaries. He uses both field experimentation and numerical modeling to address these questions. DLM-WQ, the water quality model that forms the basis of the Lake Tahoe Clarity Model, has been under development by Dr. Schladow since 1991. It has been used to simulate toxic algal blooms in Australian reservoirs, fish kills under ice cover in Canadian lakes, CO_2 removal from explosive African lakes, and MTBE loading and volatilization in Californian lakes.

Joaquim Losada is post-doctoral researcher in the Department of Civil and Environmental Engineering at UC Davis. He completed his Ph.D. at the University of Girona, Spain, where he constructed the first version of the Lake Tahoe Clarity Model under the direction of Professor Schladow. In addition to his work at Lake Tahoe, Dr. Losada is an expert in the statistical analysis of model reliability, and in the use of Genetic Algorithm Techniques to calibrate complex models.

Joaquim Losada, collecting additional validation data for the model.

Ted Swift is a doctoral candidate in the Department of Environmental Science and Policy at UC Davis. His dissertation research has focused on the measurement and description of the clarity-defining parameters at Lake Tahoe. He has collected and analyzed much of the basic data needed to formulate and calibrate the Optical sub-model in the Lake Tahoe Clarity Model.

Ted Swift and family

The development of the Lake Tahoe Clarity Model is an ongoing effort that relies upon an extensive data collection and analysis program. Some of the team members involved in this work are, Back Row (L-R): Don Thompson, Sveinn Palmarsson, Stefan Wuertz, Geoff Schladow, Banu Sunman, Alan Jackman. Front Row (L-R): Peter Green, Rachel Terpstra, Arnie, Joaquim Losada, and Bob Richards.

CITIZENS COLLECT DATA FOR TMDL

On May 10, 2003, over 250 citizen volunteers collected water quality data at 125 locations around the Lake Tahoe and Truckee River watersheds as part of the annual Snapshot Day. Sponsored by the Tahoe-Truckee Clean Water Team and the Lake Tahoe Environmental Education Coalition, Snapshot Day is a one-day water quality monitoring event that provides citizen volunteers with the opportunity to sample and monitor water quality for several parameters including dissolved oxygen, conductivity, pH, temperature, turbidity, and fecal coliform bacteria.

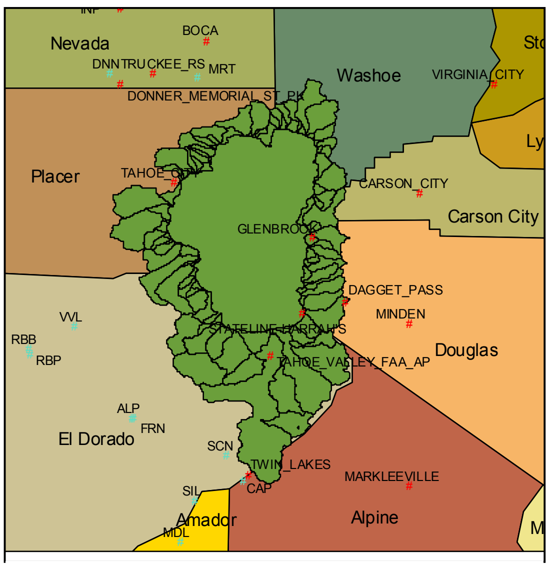
This year, volunteers also participated in collecting much-needed data for the Lake Tahoe TMDL. For the first time, water samples were gathered from the mouths of all 63 tributaries to Lake Tahoe in order to analyze sediment content. Dr. Geoff Schladow from UC Davis will analyze the quantity and size of sediment particles entering Lake Tahoe during spring runoff for use in developing the Lake Tahoe Clarity Model described above.

Citizen Volunteer Monitoring Burke Creek

Thank you to everyone who participated in Snapshot Day 2003. We hope to see you out there next year! If you would like to learn more about how you can participate in water quality sampling in the Lake Tahoe watershed, please contact Heather Segale at (775) 832-4138 or email her at segaleh@unce.unr.edu.

RECONSTRUCTION OF METEOROLOGICAL DATA IN THE LAKE TAHOE REGION

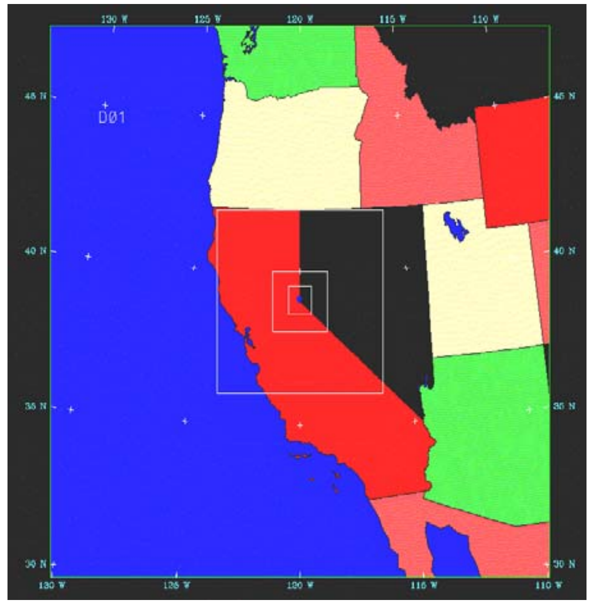
Running the Watershed and Lake Tahoe Clarity Models requires that the hydrology or movement of water through the watershed and lake be correctly characterized, which in turn requires accurately representing local weather conditions, or meteorology. Modelers use meteorological data from weather stations to build their mathematical water quality models, as described above and in the previous edition. The watershed and lake clarity models will likely be used to simulate water quality at least 50 years into the future, necessitating a corresponding meteorological record (including, among other things, precipitation, temperature, wind speed and radiation, at as fine a spatial resolution as practical). The strategy employed is to utilize the previous 42 years' weather data as a guide for extrapolating likely weather conditions into the future. The potential influence of global warming on hydrology and runoff will be incorporated to the extent possible. To do this requires obtaining actual meteorological information, if available, or if not, synthesizing it using a meteorological or climate model. Unfortunately, as shown in the adjacent figure, there are an insufficient number of meteorological stations available within the Lake Tahoe Region to provide directly collected weather data for each of Lake Tahoe's 63 watersheds and numerous intervening areas.



Daily meteorological stations in Lake Tahoe and surrounding areas. The blue crosses are California Data Exchange (CDEC) stations and the red crosses are National Climatic Data Center (NCDC) stations. Note the relatively few stations in this area, making meteorological data reconstruction necessary in order to run the Watershed and Lake Tahoe Clarity models.

A traditional way to overcome this difficulty is to statistically interpolate values between existing weather stations for which we have actual measurements. While this type of approach works well for a geographically dense monitoring network, it can be problematic for a network with rather low geographical density and great complexity, as is the case in the Lake Tahoe Region. This is because observation points are too far apart to accurately interpolate the values in between. Due to the large variation between areas of heavy precipitation in the western part of the basin and the "rain-shadow" to the east, and due to the mountainous topography, there are numerous distinct micro-climates in the basin. Here, the assumption that relative distances between observation points and the location of interest can determine the values at any location becomes less realistic.

A team from the Hydrologic Research Laboratory at UC Davis (UCDHRL) is taking a more sophisticated approach, rooted in physical principles. The team (profiled in the article below) is currently downscaling large-scale historical atmospheric data available from the National Center for Environmental Prediction (NCEP). This information includes records at 12-hour time intervals from 1958-2000 for a 2.5^{o} latitude x 2.5^{o} longitude spatial grid resolution, which corresponds to a box with approximately 285-kilometer-long sides over California and Nevada. Downscaling is done by means of a regional atmospheric model called MM5. The MM5 model is the fifth generation version of a state-of-the-art atmospheric model that was developed jointly by the National Center for Atmospheric Research (NCAR) and Pennsylvania State University. The model is particularly well-suited for steep mountainous terrain such as in the Lake Tahoe Basin, as it explicitly accounts for full vertical atmospheric motion and, as such, can satisfactorily simulate orography-induced precipitation. The MM5 model has been used by many universities and in hundreds of peer-reviewed articles. As a result of downscaling, UCDHRL will provide spatially distributed meteorological data at a 3-km resolution and at hourly time intervals over the whole Lake Tahoe Region.



Nested domains used by the atmospheric model MM5. MM5 scales historical data available for a 285 km. (177 mi.) grid covering much of California and Nevada down to 3 x 3 km. squares (too small to show on a map of this scale) throughout the Lake Tahoe Basin.

❖ METEOROLOGICAL MODELING TEAM

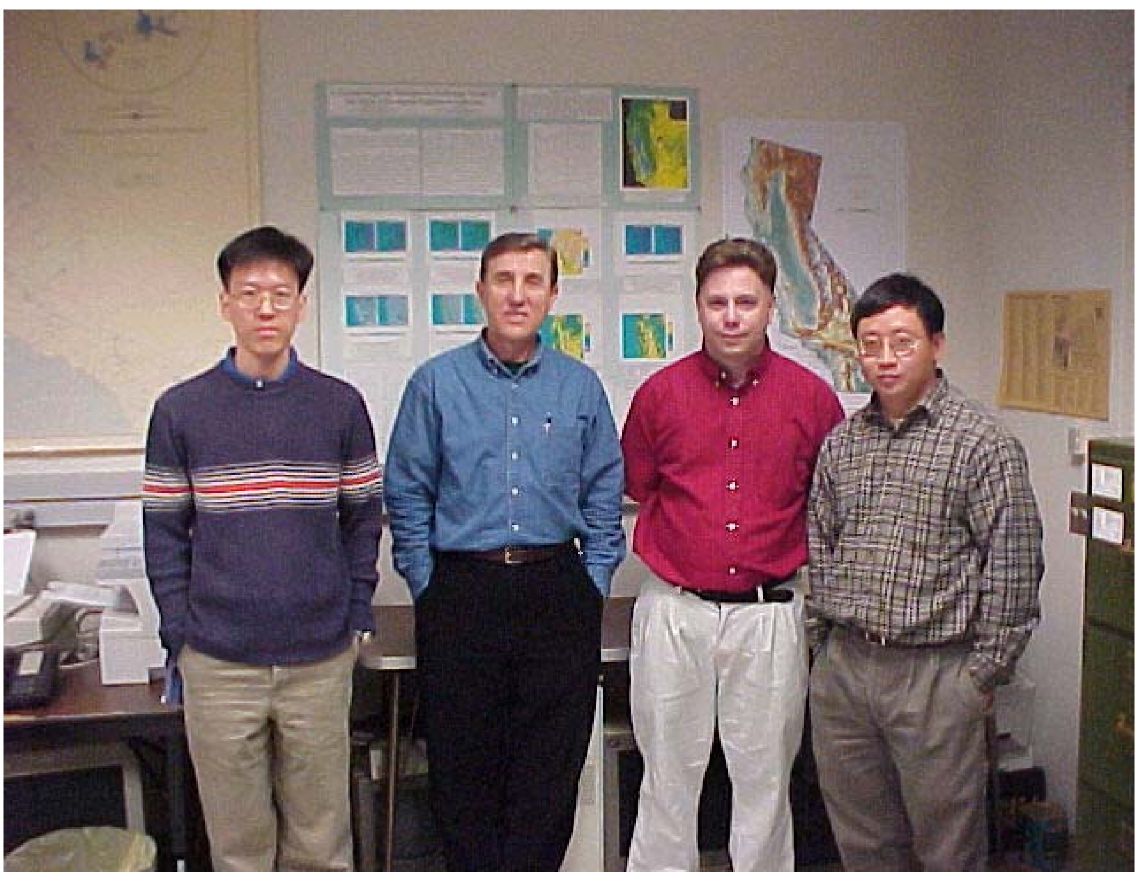
Hydrologic Research Laboratory team members reconstructing Lake Tahoe's historical meteorological data have more than 12 years of experience working on a variety of atmospheric modeling projects that involve downscaling large-scale atmospheric data, both in California and around the world. Study locations include the Calaveras watershed in California and the Greater Tokyo Region of Japan. Key team members include Professor M. Levent Kavvas, Zhiquing Chen, Michael Anderson, and Jaeyoung Yoon.

Dr. Kavvas is director of the Hydrologic Research Laboratory, a full professor in the Department of Civil and Environmental Engineering, and a member of the Graduate Group in Atmospheric Sciences at the University of California, Davis. He has also been co-director of the UC Center for Study of Hydroclimatology in the Pacific Rim. His areas of specialization include modeling of integrated hydrologic and atmospheric processes at global, continental, country and watershed scales. Such modeling is used to simulate and predict precipitation, wind, temperature and radiation (among other atmospheric measures), and hydrologic processes including sediment and other pollutant transport. In the last 14 years, he has worked as a consultant to the US Air Force, US Army Corps of Engineers, Japan Ministry of Construction, Malaysian National Hydraulic Research Institute, and Turkish Department of Water Resources on problems related to hydrometeorology, hydroclimatology and watershed hydrology.

Dr. Chen obtained his Ph.D. degree in Water Resources Engineering with two minors in applied mathematics and statistics from the Department of Civil and Environmental Engineering at U.C. Davis in December, 1992. He is currently working on watershed hydrologic modeling for Lake Tahoe and the Cosumnes and Feather Rivers as well as many other places outside the country. He is also active in supervising graduate students researching hydrometeorological and watershed modeling and environmental hydraulics.

Dr. Anderson has modeled atmospheric processes for seven years. Dr. Anderson's Ph.D. work included the development of a hemispheric climate model for the study of continental droughts. He has worked on several projects using MM5 including reservoir inflow forecasting for the U.S. Army Corps of Engineers and data reconstruction in ungaged basins for the United Nations World Water Assessment project.

Dr. Yoon has been working on a number of projects on physically based watershed hydrology, nonpoint source pollution modeling, and hydrometeorology. His specialty area is surface water modeling and GIS applications in watershed modeling. For the Lake Tahoe TMDL project, he is in charge of acquiring historical meteorological data and is verifying the model's simulations of downscaled atmospheric data. Dr. Yoon attended Korea University for his Bachelor's and Master's degree. He earned his Ph.D. in Civil and Environmental Engineering in 2001 at UC Davis.



Meteorological Modeling Team Members Jaeyoung Yoon, M. Levent Kavvas,
Michael Anderson and Zhiquing Chen of UCDHRL

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