

## Research Category I

# Hydrology, Climatology and Hydraulics

This category encompasses the physical processes governing water transformations through the atmosphere, over land, in the vadose zone, and in natural water bodies, aquifers and man-made conduits. Examples of investigations include studies of precipitation and stream flow; weather patterns; climate modification; micrometeorological processes linking atmospheric water, solar energy, water use by plants (commercial, exotic and native), and available soil moisture; modeling of hydrologic and hydraulic processes; and the development of databases.







# Monitoring California Water Resources from Space

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*A comprehensive monitoring system for California water resources would be greatly enhanced by the large-scale view afforded by satellite remote sensing. Several current and near-future satellite missions have now demonstrated the capability for monitoring soil moisture, snow water equivalent, heights of inland water bodies (e.g. rivers, lakes, reservoirs) and changes in total water storage. The goal of this work is to exploit these current and emerging capabilities to develop a framework for monitoring California water resources from space.*

A comprehensive monitoring system for California water resources would be greatly enhanced by the large-scale view afforded by satellite remote sensing. Several current and near-future satellite missions have now demonstrated the capability for monitoring soil moisture, snow water equivalent, heights of inland water bodies (e.g. rivers, lakes, reservoirs) and changes in total water storage (i.e. the aggregate of all of the snow, surface waters, soil moisture and groundwater). The goal of this work is to exploit these current and emerging capabilities to develop a framework for monitoring California water resources from space. The focus of our work is on statewide remote sensing of soil moisture, inland water bodies, changes in the mass of the snowpack, and changes in groundwater and total water storage. Specific objectives are to 1) prepare statewide maps of surface soil moisture using the AMSR-E satellite; 2) Estimate monthly changes in the mass of the Sierra snowpack using data from the GRACE satellite; 3) Estimate monthly changes in total water storage for state's the major watersheds using GRACE; 4) Explore the performance of the current generation of ocean (e.g. TOPEX/Jason) and ice (e.g. ICESat) altimeters to monitor the heights of the state's major rivers, lakes and reservoirs; and 5) Estimate changes in

groundwater storage by combining GRACE water storage change estimates with AMSR-E soil moisture estimates and state-of-the-art land surface models.

Our first year of research has seen important progress towards goals 1, 3, and 5. Our first surface soil moisture maps prepared from the AMSR-E data have pointed to problems with the inversion algorithm used to derive soil moisture from observed brightness temperature. We have been in contact with the JPL, USDA-ARS and Princeton groups who are working on better soil moisture retrievals. We will repeat this process when the new data become available later this year and complete the mapping and analysis of surface soil moisture variations across the state.

Research on the use of GRACE data for estimating changes in total water storage is progressing well. A key step towards application of the GRACE data towards water resources problems at the relatively small spatial scale of California (by GRACE standards) has been the development of new techniques for utilizing GRACE data at these higher resolutions. This work will now allow, for the first time, monitoring of water storage changes within the major drainage basins and mountain ranges of the state. We are currently working on delineating these GRACE-compatible regions for the

state so that we can map the GRACE data to the Sierras, the Central Valley, the coastal regions, etc.

We have also made important progress towards remote sensing of groundwater using GRACE, AMSR and in situ data. In a preliminary study using the hydrologically data rich area of Illinois, we used GRACE and observed soil water to successfully estimate groundwater storage variations. This work opens the door for groundwater remote sensing in the Central Valley aquifer and the Coastal Plain aquifers, which we are now ready to attempt.

#### Year 2 Plans

Goals for year 2 will be to complete the major objectives of this work. Our plan is to map the total water storage, snow water equivalent and soil moisture to the major drainage basins of the state, to explore the potential of satellite altimetry to monitor surface water variations, and to attempt to monitor groundwater storage variations using the methods from the preliminary study in the Central Valley. An implicit goal is to demonstrate the utility of these data at spatial-temporal scales that are relevant to statewide water resources management.

#### **Publications**

Swenson, S. C., P. J.-F. Yeh, J. Wahr and J. S. Famiglietti, A comparison of terrestrial water storage variations from GRACE with in situ measurements from Illinois, *Geophys. Res. Lett.*, 33, L16401, doi:10.1029/2006GL026962, 2006.

Yeh, P. J.-F., S. C. Swenson, J. S. Famiglietti and M. Rodell, Remote sensing of groundwater storage changes in Illinois using GRACE, accepted, *Wat. Resour. Res.* 2006.

#### **Professional Presentations**

Ryu, D., J. Famiglietti, T. H. Syed and S. C. Swenson, Basin-scale hydrological cycles from AMSR-E and GRACE, AGU Fall Meeting, San Francisco, CA, Dec. 5-9 2005.

#### **Collaborative Efforts**

Our UCI group collaborates with John Wahr and Sean Swenson from the University of Colorado, and with Victor Zlotnicki from the Jet Propulsion Laboratory on GRACE hydrology research. We work with Eni Njoku from JPL, and Tom Jackson and Dongryeol Ryu from the USDA ARS Hydrology Laboratory in Beltsville, MD on AMSR-E soil moisture. We will be working with Tom Painter from the National Snow and Ice Data Center in Boulder on AMSR-E snow water equivalent.

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# Feasibility of Snowpack Characterization Using Remote Sensing and Advanced Data Assimilation Techniques

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*The implemented snow data assimilation scheme is able to merge multi-scale multi-frequency remotely sensed observations with a distributed snow model to estimate basin-wide snow water equivalent in conditions with deep/wet snow and with light to moderate vegetation cover, factors which generally confound commonly used snow remote sensing retrieval algorithms.*

Many semi-arid regions of the world, including California, depend on annual snowmelt for the majority of their water supply. However the primary method for estimating the amount of water stored in the snow pack (snow water equivalent, SWE) is still most often done by field snow surveys. This approach is extremely limited because the survey data are sparse point estimates and because they rely upon regression and comparison to historical measurements.

New methods for estimation of SWE have been developed recently. For the past several decades, inversion of remote sensing data and application of snow models have been used to estimate SWE. However SWE estimates based solely on either remote sensing inversion or snowpack modeling techniques contain large uncertainty. For retrieval methods, the uncertainty lies primarily in the relationship between the snow states and the remote sensing observations. For modeling, errors occur primarily as a result of the propagation of uncertainty in model inputs (e.g., precipitation) to the SWE estimates. It is this uncertainty that motivates the development of the data assimilation approach used in this project.

Data assimilation methods, such as the Ensemble Kalman Filter (EnKF) are used to merge remote sensing observations into a hydrologic model to produce estimates of

SWE over the entire basin. The EnKF weighs the relative uncertainty of the model and of the observations and provides an estimate of the state variable as well as an estimate of its uncertainty. This project constitutes a feasibility study for estimating SWE through the incorporation of remote sensing observations in the microwave, visible, and thermal infrared parts of the spectrum into a physically-based snow model.

The first phase of our work focused on the selection and development of the required snow and remote sensing models needed in the data assimilation approach. We have chosen two widely accepted models as the foundation of the data assimilation framework. During the preliminary testing phase we have incorporated more realistic models for the snow grain diameter evolution and snow albedo (reflectivity) that were found to be extremely important parameters in the radiative transfer (remote sensing) model. These model refinements should ultimately significantly improve the SWE estimates. We have applied the model to data in the Mammoth Mountain region in the Sierra Nevada as well as the Rocky Mountains in Colorado. These models have been embedded in a data assimilation framework (EnKF) to test the ability to estimate SWE from remotely sensed microwave radio-brightness observations.

In this study, synthetic experiments were first performed at the point-scale to test the feasibility of the approach. In these tests, synthetic realizations of the remotely sensed observations were used in the assimilation scheme to test whether the true snowpack characteristics could be recovered under conditions of uncertain initial conditions and precipitation. The methodology was shown to outperform commonly used retrieval methods and overcome significant biases often seen in precipitation that is directly propagated to model estimates. Based on the successful point-scale experiments, the method was then applied over a 625 km<sup>2</sup> region and showed similarly positive results (Figures 1 and 2).

The primary findings in this study are that the assimilation approach is capable of providing estimates of SWE in cases with i) deep snow, ii) wet snow, and iii) light to moderate vegetation cover. These are three of the primary confounding problems with traditional snow retrieval algorithms. Furthermore the method allows for improvements over traditional modeling approaches that are subject to large input errors due to sparsely collected data in remote mountainous regions. The flexible method developed in the project has the potential to significantly improve water resource characterization and management in California.

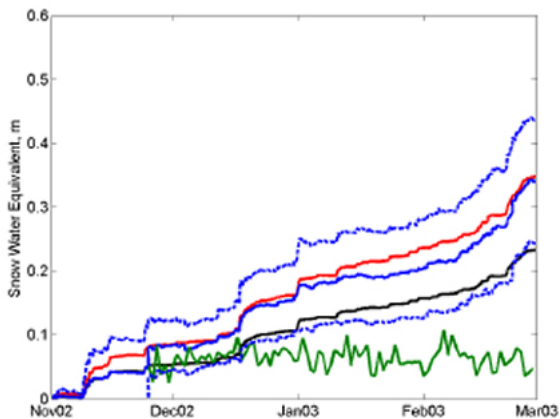


Figure 1. Comparison of the true (red line) spatially-averaged snow water equivalent over the course of the accumulation season to the EnKF ensemble mean/spread (solid/dashed blue lines), the open-loop (black line), and retrieval algorithm (green line) estimates.

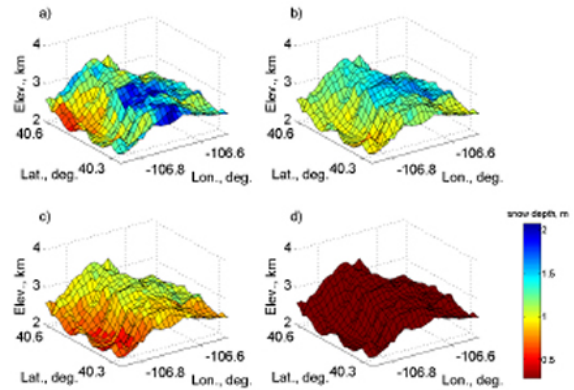


Figure 2. Comparison of spatial maps of snow depth on March 1<sup>st</sup> for the a) truth, b) ensemble mean from EnKF, c) open-loop simulation, and d) a common retrieval algorithm. The EnKF provides a significant improvement over the open-loop and retrieval estimation approaches.

## Publications

Durand, M. and S.A. Margulis, Feasibility test of multi-frequency radiometric data assimilation to estimate snow water equivalent, *Journal of Hydrometeorology*, 2006, 7(3), 443-457.

Durand, M. and S.A. Margulis, Large-scale SWE Estimation: Optimal Use of Remote Sensing and Snow Modeling, *Southwest Hydrology*, 2005, 4(2), 20-21, 32.

## Professional Presentations

Durand, M., and S. Margulis, Feasibility of snowpack characterization using radiometric data assimilation: an example of a multi-scale, multi-frequency approach, American Geophysical Union, Spring Annual Meeting, Baltimore, MD, May 2006.

Durand, M., and S. Margulis, Feasibility of snowpack characterization using multi-frequency remote sensing and advanced data assimilation techniques, American Meteorological Society Annual Meeting, San Diego, CA, January 2005.

Durand, M., and S. Margulis, Feasibility of snow water equivalent estimation using the Ensemble Kalman Filter, American Geophysical Union, Fall Annual Meeting, San Francisco, CA, December 2004.

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# Ecohydrologic Effects of Stream Restoration

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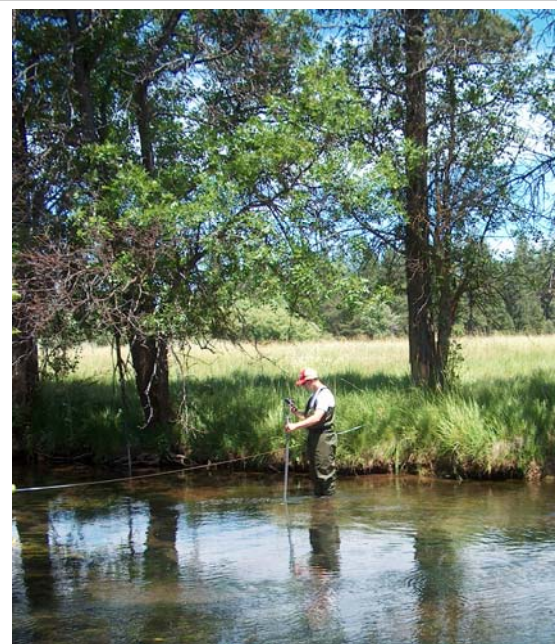
*Stream restoration activities throughout California are numerous; however the hydrologic and vegetation responses of these restored systems are poorly understood and rarely documented. The goal of this research is to quantify the hydrologic and ecologic effects of a “pond and plug” stream restoration of a meadow system, in order to improve future design efforts.*

Rivers and streams, and their dependent floodplain ecosystems have experienced dramatic degradation throughout California, and much of the world. The growing appreciation of the functions and services that riverine-floodplain wetlands provide and a realization of the need to rehabilitate these degraded systems has led to a blossoming industry of stream restoration. While stream restoration activities are plentiful, sound scientific basis for various actions, protocols for design, and post-project monitoring and assessment are generally lacking. Specifically, the effects of the popular “pond and plug” channel restoration method upon river-floodplain hydrology and wetland vegetation remain poorly documented. Given the proliferation of these projects, an improved understanding of the ecohydrologic effects of stream manipulation is vital in improving the methods used to design and assess them.

Through post-project monitoring and assessment, in combination with numerical modeling of an exceptionally well-documented “pond and plug” stream restoration project, this research seeks quantitative answers to two fundamental questions. First, what is the hydrologic response of surface water and groundwater to stream restoration? Second, how will these hydrologic changes impact the distribution of native wetland plant species? This research is focused on a 2.2 mile restored meadow reach of Bear Creek, the

largest ephemeral tributary to the Fall River, Shasta County, California. The research plan involves two linked programs, hydrology and vegetation response.

To quantify the impact of the “pond and plug” stream restoration activities on various components of the meadow’s hydrology, a hydrologic model of the restored meadow has been constructed, and is currently undergoing calibration. This numerical model consists of a two-dimensional hydraulic model to simulate inundation of the meadow surface coupled with a three-dimensional subsurface model to simulate



Monitoring streamflow

the complex temporal and spatial movement of groundwater throughout the meadow. Atmospheric exchanges due to precipitation and evapotranspiration are also included within the hydrologic model. The first year of UC Center for Water Resources funding allowed for the development/construction of the numerical hydrologic model, in addition to various crucial data collection activities which included, stream flow and water table elevation monitoring, geochemical boundary condition characterization and the refinement of the post-project digital elevation model. During the second year of UCWRC funding, the calibrated and validated hydrologic model will be used to simulate and compare the stream-meadow hydrology under pre- and post-restoration topographic conditions. Expected results include simulation of changes to the: outflow hydrograph (flood peak reduction and delay), depth to groundwater, extent of inundation, floodplain and subsurface storage, as well as evapotranspiration. Preliminary modeling results suggested a significant change to each of these hydrologic components, due to the restoration.



Measuring depth to the ground water table.

The restoration of this reach of Bear Creek caused significant changes to inundation of the meadow surface and depth to groundwater through much of the meadow. These hydrologic changes drove changes in the distribution of wetland plants. In the summer of 2005, data documenting the diversity and

abundance of herbaceous vegetation within 185 plots distributed throughout the restored meadow was collected. This vegetation data has been analyzed and several communities (wet meadow, moist meadow, dry meadow, and vernal pool) identified. A predictive vegetation model statistically linking these identified plant communities to the temporal trends in inundation and availability of shallow groundwater is under development. Once complete, this model will be used in combination with the hydrologic model to simulate the areal extent of various vegetation communities present under pre- and post-restoration hydrologic conditions. Expected results include an increase in the distribution of wet and moist meadow communities and a reduction of the dry meadow community type, in addition to an increase in the habitat available for species specializing in vernal wet environments.

The results of this study will aid in many elements of similar stream restoration activities. The integrated ecohydrologic methods utilized will benefit land managers, restoration practitioners and regulators by establishing baseline information regarding the potential benefits of similar projects, as well as developing a new predictive tool to assess potential design considerations. As stream restoration projects increase, and the need to balance the multitude of demands on the precious water resources within the state continues to grow, a better understanding of the hydrologic and ecologic effects of such restoration activities is crucial.

### **Collaborative Efforts**

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# Plant Water Use in Owens Valley, CA: Understanding the Influence of Climate and Depth to Groundwater

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*There is a long standing controversy in Owens Valley, California about the role of water exports in local vegetation change, particularly the loss of grasslands and the expansion of shrublands. While previous studies have focused on water availability as a primary mechanism of shrub expansion, our measurements of soil organic matter and nitrogen availability indicate that nutrient cycling may be a key variable linking ecology and hydrological processes in the valley.*

Owens Valley, California has been the site of redistribution of groundwater for almost 100 years. There is a long standing controversy in the region surrounding the potential influence of groundwater exports on the local vegetation of the valley, which is at the transition between the Mojave and the Great Basin Deserts. In 1991, Inyo County, where Owens Valley is located, and the Los Angeles Dept. of Water and Power signed an agreement stating a goal of water management in the valley must be to avoid changes in local vegetation cover that cannot be acceptably mitigated. To reach this goal, the linkage between hydrology and ecological processes in semi-arid but shallow groundwater ecosystems must be greatly improved, as the impacts of altered hydrology on vegetation is still quite poorly understood.

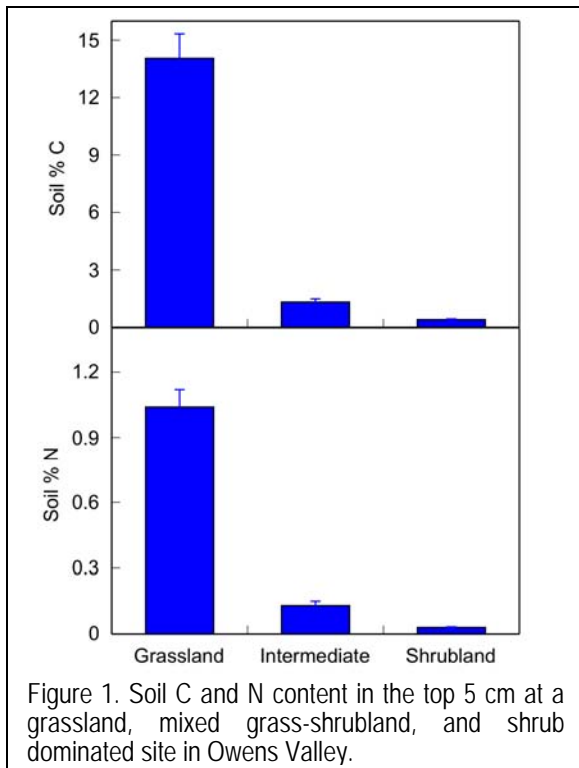
In this study, we evaluated plant access to groundwater in both grass and shrub species at grass-dominated and meadow-dominated sites in Owens Valley near Bishop, CA. Of particular concern is the loss of grasslands due to encroachment of shrub species such as *Atriplex torreyi* (Torrey's saltbush), *Sarcobatus vermiculatus* (greasewood), and *Ericameria nauseosa* (rubber rabbitbrush). It has long been assumed

that grass species in the valley are more shallowly rooted than shrub species, and are out-competed by shrubs when the water table is lowered beyond the rooting zone. However, the maximum rooting depth of the common species in Owens Valley is unknown. In addition, woody encroachment is a global phenomenon that has been documented in many ecosystems worldwide that do not have shallow water tables. Rather, grazing and climate change are commonly cited reasons for the expansion of shrubs into grasslands. It is not clear if altered hydrology has or will in the future cause a loss of grasslands in Owens Valley.

The isotopic composition of plant stem water can be used to determine if plant water sources are dominated by deep soil/groundwater or shallow surface water. This is because shallow surface water is isotopically enriched (meaning it contains more of the heavy vs. light isotope) due to evaporation. We measured the isotopic composition of grass and shrub stem water along a gradient of decreasing grass cover. We found that grasses do indeed appear to lose contact with the water table in late summer, which corresponds to a reduction in grass transpiration. However, the correlation between access to groundwater and

transpiration is not as great as we expected. Grass transpiration is low at our shrub-dominated site regardless of access to groundwater, and shrub transpiration shows spatial and temporal patterns that do not correspond well to access to groundwater. Clearly, factors other than groundwater depth and plant access are limiting transpiration in Owens Valley.

Our measurements of soil organic matter (SOM) and nutrient availability indicate that nutrient cycling may be a key variable linking ecology and hydrological processes in the valley. There is a large gradient of soil carbon (C) and nitrogen (N) content across our grass to shrub gradient, with the highest SOM and total N at the grassland site and the lowest at the shrub site (Figure 1). This corresponds well to the pattern of gas exchange at the three sites. It is known that N availability may strongly limit gas exchange due to the high N requirement in synthesizing photosynthetic enzymes. For the shrub species at our sites, it appears that plants have constant access to groundwater but have less access to N at the end of the season and at more shrub-dominated sites.



This finding has led to a new direction in our work. We would like to quantify the link between groundwater depth, vegetation composition, and N cycling in Owens Valley. Nutrient cycling is rarely incorporated into hydrologic models, yet it is likely to be a primary limitation for transpiration. Our results imply that N cycling and availability may improve hydrologic modeling, which is critically important for water resource management. In addition, to explore the management implications of these findings we would like to address the question: does woody encroachment cause a reduction in N availability or do shrubs encroach sites that are already N limited? The answer will provide information about the causes and possible mitigation strategies for vegetation changes in Owens Valley.

### **Collaborative Efforts**

We are collaborating with S. Trumbore at UC Irvine to further explore differences in how grasses and shrubs allocate biomass belowground to roots. We are also collaborating with S. Billings at the University of Kansas to study the biogeochemistry and N cycling in soils from our sites to determine the underlying reasons for differences in N availability. We have written a proposal (currently pending) to NSF with Trumbore, Billings, and J. Famiglietti at UC Irvine to incorporate an improved understanding of ecosystem dynamics into a full hydrologic model of inflows, outflows, and groundwater depth in Owens Valley. The study would contribute to the field of ecohydrology at the interface between the two disciplines.

The Los Angeles Department of Water and Power (LADWP) gave us permission to establish study sites on their property. LADWP, their primary contractor MWH, Inc., and the County of Inyo have all been very helpful and have shared the results of their previous studies in the valley with us.

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## Estuarine Landscape Modeling of Suisun Bay

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*The long-term viability of estuarine habitats hinges on the successful prediction of geomorphic change and appropriate management response. Climate change in the 21st century is predicted to alter snowpack accumulation in the Sierra Nevada, rainfall in the Central Valley, and therefore sediment runoff to bay ecosystems along the Pacific Coast. We are developing a modeling tool which predicts the geomorphic response of Suisun Bay to climatic changes over decadal timescales.*

Suisun Bay, the farthest upstream embayment of San Francisco Bay, provides beneficial habitat to the entire the San Francisco Bay ecosystem. The main goal of this investigation is to develop a modeling tool capable of simulating long-term (>10 year) changes in the shape and depth (i.e. bathymetry) of Suisun Bay. Changes are inevitable as climatic forcing (rainfall, snowpack) is forecasted to become increasingly variable, and as water resource management will need to respond to increasing demand.

Our approach begins with calibrating a hydrodynamic/sediment transport computer model of Suisun Bay. Now that we have validated the model with short-term (<1 year) measurements of water depth, salinity, and sediment flux, we can determine the ideal method for simulating longer periods. These methods include reducing input data (e.g. ocean tides) to representative conditions, simulating only major episodic events (e.g. floods), and extrapolating time-averaged data. We are now in the process of validating the long-term simulations using historical measurements of bathymetric change, which span from 1867 to 1990. The public-domain hydrodynamic model (Regional Oceanic Modeling System, ROMS; <http://marine.rutgers.edu/po/>) was implemented for this effort. We

have made major simplifications to the configuration of the complex Sacramento-San Joaquin Delta (upstream of Suisun Bay). These simplifications appear to be satisfactory; and we can now use widely available historical flow data from the Central Valley watershed as our upstream boundary condition. This greatly simplifies both the hydrodynamic and salinity conditions at that boundary. The successful modeling of water years 1997-1998 and 2002-2004 are a major contribution to the modeling of long-term sediment transport in estuaries.

### Publications

Ganju, N.K. and D.H. Schoellhamer, Annual sediment flux estimates in a tidal strait using surrogate measurements. *Estuarine, Coastal and Shelf Science*, 2006, 69, 165-178.

Schoellhamer, D.H., N.K. Ganju, P.R. Mineart, and M.A. Lionberger, Sensitivity and spin up times of cohesive sediment transport models used to simulate bathymetric change, *Proceedings of the 8<sup>th</sup> International Conference on Cohesive Sediment Transport*, Institute of Lowland Technology, Saga University, Saga, Japan, in press.

### **Professional Presentations**

Ganju, Neil K. and David H. Schoellhamer, Lateral displacement of the estuarine turbidity maximum in a tidal strait, The 8th International Conference on Cohesive Sediment Transport, Institute of Lowland Technology, Saga University, Saga, Japan, September 20-23, 2005.

Ganju, Neil K. and David H. Schoellhamer, Calibration of an estuarine sediment transport model to measured cross-sectional sediment fluxes for robust simulation of geomorphic change, Physics of Estuaries and Coastal Seas, Astoria, Oregon, September 18-22, 2006.

### **Collaborative Efforts**

The validation data from 2004 was collected by the United States Geological Survey Hydrodynamics Group, Sacramento, CA.

Development of the ROMS model has been done in collaboration with Dr. John Warner, U.S. Geological Survey, Woods Hole, MA.

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# California-2100: Assessing Future Water Resources over California

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University of California, Davis

*The preliminary results indicate that summer irrigation has a strong effect on the differences between 1996 and 1901 in maximum temperature, surface latent and sensible heat fluxes, surface moisture and equivalent snow water.*

This project implemented the initial phase of California-2100 (Cal21), which is aimed at making and evaluating high resolution estimates of climate change over California out to the year 2100. The initial WRC component of this project has been focused on evaluating how well regional climate models reproduce the variations of important components of the water budget for California, and estimating the effects of the increases over the past century in irrigation in California on regional climate, especially snow accumulation.

The utilized regional model is the widely used MM5 running at 30km grid spacing and having 45 levels. There are three primary experimental runs. The modern run (labeled 1996) has boundary conditions from the ERA-40 reanalysis for the period August 1 1995 through September 30, 1996. The atmospheric carbon dioxide concentration is set at 365ppm. An important aspect of this run is that irrigation water is applied to all agricultural regions in a way that approximates irrigation practice. For the other two runs the irrigation rate is set to zero, and the default urban and agricultural land surface types have been modified such that physical characteristics of these types were converted to those of shrub land. For the run labeled Non-Irrig the boundary conditions and carbon dioxide concentration are the same as in the 1996 run. For the run labeled 1901 the carbon

dioxide concentration was set to the approximate observed 1901 value of 310ppm and the boundary conditions are constrained to represent the 1900-1901 time period. These boundary conditions are derived from the ERA-40 1995-96 values adjusted using the 1900-99 trends in the monthly means of the output of the highly respected HadCM3 global climate model.

Two major factors have influenced the climate of California in the past century. As elsewhere on the globe the first is global climate change. The second is regional land use changes, associated with the conversion of large blocks of natural vegetation to irrigated agriculture and urban areas. The modeled precipitation and maximum surface temperature difference between the 1996 and 1901 results generally agree with the observed winter and summer trends over the last century. The results also show in summer that irrigation has a strong effect on the differences between 1996 and 1901 in maximum temperature, surface latent and sensible heat fluxes, surface moisture and equivalent snow water.

## **Professional Presentations**

B. C. Weare, Modeling Climate Change in California: Land Surface Changes, Laboratory for Dynamic Meteorology Seminar, University of Paris, VI, July 5, 2005.

B. C. Weare, Climate Change in California: Land Surface Changes, European Geophysical Society, Vienna, Austria, April 5, 2006.

B. C. Weare, Modeling Climate Change in California: Updated Results, Laboratory for Dynamic Meteorology Seminar, University of Paris, VI, April 11, 2006.

### **Collaborative Efforts**

California Energy Commission collaborations: Modeling groups from UCSD (Dan Cayan, PI), UCSC (Lisa Sloan, PI), and UCB (Norm Miller, PI)

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## Research Category II

# Aquatic Ecosystems

This category encompasses basic observational, analytical and theoretical knowledge about aquatic environments and ecosystems. Research areas of interest include biological, chemical and physical mechanisms that govern the behavior of aquatic ecosystems, including the classification, transport and impact of pollutants. Also included are constructed ecosystems for water reclamation; wetland management; impacts of land use practices on aquatic habitats; role and effect of non-native species, and reconstruction ecology.







# Hydrological Regimes, Pond Morphology, & Habitat Use: Predicting the Impact of a Pathogen

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*We are investigating why populations of mountain yellow-legged frog in some parts of the Sierra Nevada are experiencing rapid die-offs as a result of chytridiomycosis, a newly-identified fungal disease of amphibians, while other populations are persisting with the fungus. Mark-recapture field surveys have shown that frogs at the persistent sites can survive with the disease, experiencing only mild infections. Laboratory experiments have revealed that this difference in disease outcome is unlikely to be due to differences in fungal virulence or frog susceptibility between areas.*

Declines in amphibian populations have been reported throughout the world in recent years. A number of factors have contributed to these population declines, including disease, introduced species, habitat loss and alteration, and climate change. Chytridiomycosis is a potentially fatal disease of amphibians caused by the chytrid fungus, *Batrachochytrium dendrobatidis*, which has appeared recently in the aquatic habitats of California and throughout the world. In portions of the Sierra Nevada Mountains of California, the disease is causing rapid die-offs of mountain yellow-legged frogs, *Rana muscosa*, a threatened native frog species. In other areas of the Sierra, infected populations of *R. muscosa* appear to be persisting with the fungus. In this study we are investigating why the fungal pathogen is having different outcomes on frog populations in different California watersheds.

**Laboratory Experiments:** A laboratory experiment conducted this year corroborated our previous years' findings that differences in fungal strain and/or differences in frog susceptibility are not responsible for the different population-level impacts of the disease at the different sites.

In this experiment we exposed subadult *R. muscosa* from either northern (persistent) sites, or southern (die-off) sites to *B. dendrobatidis* strains from each type of site. We found no difference between any of the source frog x source fungus location treatments in (a) the fractions of frog individuals that became infected from a standardized dose of the fungus, or (b) resulting frog mortality due to the fungus.

**Field Surveys:** During summer of 2006 we continued the field surveys started in the summers of 2004 and 2005 at sites in the Sierra Nevada experiencing *R. muscosa* die-offs due to chytridiomycosis, and sites with *B. dendrobatidis* present with persistent *R. muscosa* populations. We continued to use a non-destructive, quantitative PCR technique to determine the infection status (presence/absence of *B. dendrobatidis*) and infection level (fungal loads) of *R. muscosa* individuals. We marked adult *R. muscosa* and recaptured and re-swabbed the same individual repeatedly. We have found additional evidence that infected frogs at die-off sites carried very high fungal loads, while at persistent sites the infected frogs were experiencing only low to moderate infections. As in the previous year, we found that at the persistent infected sites, some

adult *R. muscosa* lost the infection through time, and many infected individuals survived over the long overwintering period.

Model Development: The results of our laboratory experiments and field surveys have led us to direct our future research efforts towards understanding the fungal load dynamics within individual frogs. We are currently developing mathematical models to investigate the effects of fungal load on population persistence.

### **Professional Presentations**

Briggs, Cheryl, and Lara Rachowicz, Quantifying the *B.d.* transmission function in *Rana muscosa*: An experimental/maximum likelihood approach, Integrative Research Challenges in Environmental Biology grant meeting, Arizona State Univ., Tempe, AZ, November 2005.

Briggs, Cheryl, Jess Morgan, and John Taylor, *B.d.* Population Genetics in the Sierras, Integrative Research Challenges in Environmental Biology grant meeting, Arizona State Univ., Tempe, AZ, November 2005.

Briggs, Cheryl, How do disease processes differ between persistent and non-persistent populations?, Workshop: Restoration Plans for the Mountain Yellow-Legged Frog, Yosemite National Park, CA, January 2006.

Briggs, Cheryl, Using mathematical modeling to understand disease impacts at the local and metapopulation scales, Workshop: Restoration Plans for the Mountain Yellow-Legged Frog, Yosemite National Park, CA, January 2006.

Briggs, Cheryl, Diseases in landscapes: Investigating the population-level consequences of two emerging infectious diseases in California, University of California, Santa Barbara, CA, March 2006.

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# Heavy Metal: Phytoplankton Interactions in San Francisco Bay

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*A study is being conducted to determine the interactions of heavy metals with phytoplankton blooms in San Francisco Bay, because some metals (notably copper) approach maximum water quality criteria and may be controlling primary productivity. Results from this study concur with previous copper speciation studies and indicate that most of the copper in the Bay is not available to the plankton, and is therefore not limiting its growth. Phytoplankton blooms, however, have been found to deplete other metals from the water (manganese, lead and nickel), and may thus help entrain those metals within the estuary.*

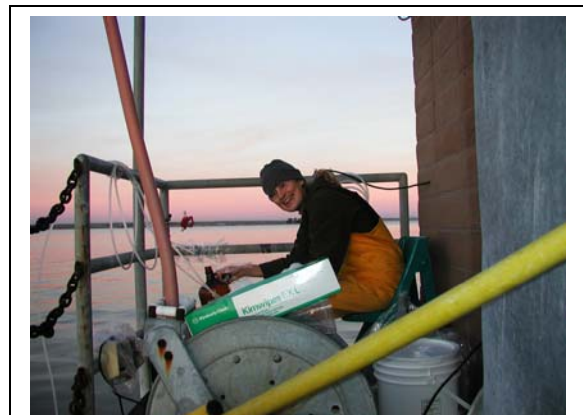
This project addresses one of the principal concerns with the health of San Francisco Bay: whether its primary productivity, or algal growth, is controlled by toxic levels of copper or other metals. Copper has been of special concern, since its concentrations in the Bay have been found to approach and sometimes even exceed both state and federal water quality criteria. Consequently, the influence of copper on algal blooms in the Bay is being analyzed.

Results from those analyses indicate that while copper levels in the Bay may be relatively high, they do not adversely impact primary productivity. This apparent inconsistency is attributed to the presence of dissolved organic material that strongly binds with the copper and makes it unavailable to phytoplankton. These findings are consistent with previous studies of the organic speciation of copper in the Bay. Consequently, this study adds to the evolving understanding that current water quality criteria for copper in estuarine waters need to be modified for San Francisco Bay.

Conversely, the study has shown that algal blooms decrease, at least temporarily, dissolved concentrations of other potentially toxic elements, including manganese, lead and nickel. Lead appears to be sorbed onto

the plankton surfaces during a bloom, rather than assimilated within the plankton. However, after the algal bloom ends and the plankton decay, lead, manganese, cobalt, and zinc are released back to Bay waters. Consequently, the cycling of those and other heavy metals within the Bay are closely intertwined with the growth and decay of phytoplankton within the Bay.

Information being developed in this study will be of use in determining what factors are regulating both the primary productivity and the concentrations of toxic metals in San Francisco Bay.



Graduate student, Allison Luengen, sampling in San Francisco Bay.

## **Publications**

Luengen, Allison, Peter Raimondi, and Arthur Flegal, Contrasting biogeochemistry of six trace metals during the rise and decay of a spring phytoplankton bloom in San Francisco Bay. *Limnology and Oceanography*, (in press).

## **Collaborative Efforts**

The research is being conducted in collaboration with researchers at the United States Geological Survey, who provide ship time and in kind sampling and analyses, as well as comments on the interpretation of our results. Complementary data on trace metals in the Bay are being provided by the San Francisco Regional Monitoring Program, which is administered by the San Francisco Estuary Institute with guidance and support provided by the California State Water Resources Control Board, other state and federal agencies, industry, and environmental organizations.

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San Francisco Bay



# Investigating the Role of Nitrogen Fixation and Denitrification in a Highly Eutrophic Southern California Estuary

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*This project seeks to expand on our knowledge of nitrogen cycling and processing in highly eutrophic estuaries of southern California. Preliminary results of seasonal field surveys and three manipulative experiments suggest that the rates of nitrogen fixation are extremely variable and depend on both abiotic and biotic factors.*

Our research takes place in the Upper Newport Bay Ecological Reserve, a protected estuary in Newport Beach, California. Estuaries are critically important habitat to many species of plants, birds and fish, including several endangered and threatened species. They also perform ecosystem services such as protecting the coastline from erosion and filtering nutrient rich water that enters the system as runoff. These services are especially important as urban development continues, though few functional coastal marshes remain in southern California. The estuaries that do remain are threatened by eutrophication that results from excessive nitrogen loading from developed watersheds.

Our objective is to investigate the microbial processes of nitrogen fixation and denitrification that occur in the sediments of the estuary. Nitrogen fixation is a process by which nitrogen from the atmosphere can be converted to ammonium, thus becoming usable by plants. Denitrification can effectively remove nitrogen from the environment by converting nitrate into atmospheric nitrogen and releasing it back into the air. Since these processes can add or remove nitrogen, they have the ability to affect nutrients in the water and sediments and therefore can affect the presence of plants and algae in the estuary.

Surveys of the estuary took place in March 2005, Sept 2005, Feb 2006, and Sept 2006 and included sampling the intertidal mudflat along 5 locations in each of two tidal creeks. During each survey, sediment was taken for nitrogen fixation and denitrification measurements. Samples were also taken to determine other characteristics of the sediments, such as sediment type and nutrient content, organic material present, and water nutrients. This will allow us to determine any correlations between the nitrogen processing rates and ecosystem characteristics.



Graduate student, Tonya Kane, collects sediment samples during the September 2006 survey.

It is clear from the surveys that there is a great deal of variability within the estuary. Some sites exhibit high nitrogen fixation rates, while others show little to no nitrogen fixation activity. We expect to see that nitrogen fixation rates will correlate with abiotic and biotic factors. Rates are hypothesized to be higher in areas of decreased nitrogen supply from the water and surrounding sediments. Denitrification rates are not yet available, though they are expected to be highest in areas with higher nitrate concentrations and higher organic material content.

Three field experiments were also performed during the past year. In July 2005 we executed a nutrient experiment to test the response of nitrogen fixation and denitrification rates after exposure to nutrient enriched water treatments, including enhanced nitrate and phosphorus levels. This simulates estuary conditions as nutrient loading into the system continues to increase. In July – August 2005 we performed a sediment transplant experiment to investigate how microbial nitrogen processing rates are affected by differences in sediment types. In June – July 2006, a 40-day long field experiment investigated how the presence and density of green macro-algal mats, often a product of nutrient enrichment, affect nitrogen fixation and denitrification rates and other sediment and water characteristics beneath the algal mats.



A row of cages used for the algal mat experiment during low tide.

Initial analysis of the sediment transplant experiment shows an effect of sediment types on nitrogen fixation rates when sediments were transplanted to the same location and received the same tidal

flushing and exposure to water nutrients. Preliminary results of the nutrient experiment suggest nitrogen fixation rates vary based on nutrient treatment. No results are available at this time for the macroalgal mat experiment.

This research will contribute to our basic understanding of how nitrogen cycles through the Upper Newport Bay Estuary and will provide insight into other southern California estuary systems. It is important to understand these processes, as few estuaries remain and they may function differently than east coast estuaries, which are much different in structure and climate. Understanding nitrogen cycling in these systems could allow policy makers to make more informed decisions regarding the regulation of nutrient inputs into these systems. These processes that add and remove nitrogen from estuarine ecosystems are especially important as nutrient loading and subsequent eutrophication will only increase in the future.

### **Collaborative Efforts**

Determination of rates for nitrogen fixation and denitrification requires a Gas Chromatograph to measure gas concentrations obtained during assays. Dr. Doug Capone at the University of Southern California has allowed us to use his equipment. He and members of his laboratory have been very helpful in teaching us the techniques to measure these characteristics.

This work has also fostered collaboration with the Southern California Coastal Water Research Project (SCCWRP). In June 2006 a proposal was written to the San Diego Regional Water Quality Control Board to incorporate some of the questions we have been asking in the Upper Newport Bay Estuary to a more integrative project in San Diego Lagoon.

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# Understanding the Spatial and Temporal Patterns of Wetland Evapotranspiration and Primary Production

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*Both scientists and the public recognize the importance of wetlands, but understanding of the ecological processes that control the functioning of California wetlands is lacking. We are working at the University of California, Irvine's San Joaquin Freshwater Marsh to understand the ecological controls on wetland carbon, energy and water vapor exchange, and to explain why the marsh's vegetation varies dramatically from one year to the next.*

Both scientists and the public recognize the importance of wetlands. Economists estimate a hectare of wetland provides approximately \$14,000 in goods and services a year; the citizens of California have demonstrated support for wetland protection by voting for bond measures. At the same time, the biological, chemical and physical processes that control the carbon, nutrient and water cycles of California wetlands remain poorly understood. Searches of the scientific literature indicate a lack of research on the biogeochemical and hydrological cycles of California Tule Marshes. The disconnect is obvious: scientists and the public recognize wetlands as critically important, but understanding of the ecological processes that control the functioning of California wetlands is lacking.

We are working at UCI's San Joaquin Freshwater Marsh to better understand the ecological controls on wetland carbon, energy and water vapor exchange. The San Joaquin Marsh is an 82-ha *Typha latifolia* and *Scirpus californicus* remnant of a large historical wetland. The marsh is located on the UCI campus, allowing easy access and facilitating undergraduate and graduate student training. Our UCWRC-funded research has three goals. (1) To understand the rates of and controls on marsh evapotranspiration ( $E_t$ ) and to determine whether

wetlands have atypically high rates of evaporation. (2) To understand why wetland vegetation is capable of extraordinarily high rates of growth (Net Primary Production or NPP). (3) To understand why the marsh's  $E_t$  and NPP vary markedly from year to year.

Our research uses the eddy covariance technique to measure the exchanges of  $\text{CO}_2$  ( $F_{\text{CO}_2}$ ) and water vapor ( $E_t$ ) between the atmosphere and a few hectare patch of marsh. Measurements at the marsh indicate only moderate rates of  $E_t$ , which are broadly comparable to those of nearby grasslands, and very high rates of NPP, which are comparable to those of tropical forests. A longer-term look at the observations indicates that  $F_{\text{CO}_2}$  and  $E_t$  fluctuated dramatically from year to year, with high photosynthetic uptake of  $\text{CO}_2$  in summer 2000 and 2003, moderate uptake in 1999, low uptake in 2001, 2002, 2005 and 2006, and extremely low uptake in 2004. The midsummer rate of evapotranspiration also fluctuated dramatically, with high  $E_t$  in 2000 and 2003, moderate  $E_t$  in 1999, low  $E_t$  in 2001, 2002, 2005 and 2006, and negligible  $E_t$  in 2004. The interannual shifts in  $F_{\text{CO}_2}$  and  $E_t$  were only partially a result of variation in flooding. While the extremely low rates of  $\text{CO}_2$  uptake and evaporation observed in 2004 were a result of drainage to reduce mosquito habitat, the low rates

observed in 2001, 2002, 2005, and 2006 occurred despite the presence of ample water. We do not understand why the marsh's vegetation has varied dramatically from one year to the next.

In the last year, we started a series of field experiments to better understand why plant growth varies from year to year, and further investigated the use of remote-sensing to place the oscillations into a larger context. A continuous 20-year record of Landsat images for the marsh was assembled and calibrated. The images were then used to construct a 20-year record of the marsh's mid-summer Normalized Difference Vegetation Index (NDVI), a measure of vegetation density. The record of NDVI since 1999 shows excellent agreements with the simultaneous measurements of  $F_{CO_2}$  and  $E_t$  at the marsh – years with high  $F_{CO_2}$  and  $E_t$  also have a high NDVI.

Analysis of the longer time record of NDVI shows that the oscillations in marsh activity observed since 1999 occur throughout the Landsat time series. This analysis has provided evidence that the patterns observed since 1999 are not atypical for the San Joaquin Marsh. Moreover, a tool that will be used to determine whether other wetlands also show large year-to-year oscillations is under development. In the long term, our research will have practical implications for efforts to manage and restore wetlands, and possibly also for efforts to use wetlands for natural water treatment.

## **Publications**

Goulden, M.L., Litvak, M.E., Miller, S.D. Factors That Control Typha Marsh Evapotranspiration. *Aquatic Botany*, in press.

## **Collaborative Efforts**

Clara Tinoco from the Universidad Nacional Autónoma de México worked on the San Joaquin Marsh project while on sabbatical.

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## Using Marine-Derived Nitrogen in Tree Rings to Assess Nutrient Flux and Salmon Escapement

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*Our research uses long-lived riparian trees to determine historic inputs of salmon vectored marine-derived nutrients to individual watersheds. By examining the stable nitrogen isotope ratios of annual growth rings, we are able to infer changes in salmon abundance over time and reconstruct historic returns for periods where no such information exists.*

Although it is generally accepted that anadromous salmon and trout populations have declined throughout California, trends for individual watersheds are largely based on incomplete or unreliable data and provide little basis for estimating the true extent of the decline. This is especially true in small coastal basins where continuous records of salmon escapement (i.e., the number of fish that return to freshwater to spawn) rarely exceed 10 years and stock-specific population trends are generally unknown.

Our research uses long-lived riparian trees to examine current and historic inputs of salmon transferred marine-derived nutrients to coastal watersheds. A product of living and feeding in the Pacific Ocean is that the tissues of adult anadromous salmon are uniquely enriched with the heavier isotopic forms of many biologically important elements (e.g., nitrogen, carbon, and sulfur) relative to terrestrial or freshwater sources of these same elements. When mature salmon return to their natal streams and die after spawning, these heavy isotopes are liberated during carcass decomposition and ultimately incorporated into both aquatic and terrestrial ecosystems.

Riparian plants, in particular, may greatly benefit from annual inputs of marine-derived nutrients. Salmon carcasses contain many nutrients essential for plant growth and

often provide a large fraction of the nitrogen sequestered by riparian trees. By determining the annual growth and stable nitrogen isotope composition ( $^{15}\text{N}/^{14}\text{N}$ ;  $\delta^{15}\text{N}$ ) of riparian trees, we are able to infer changes in salmon abundance over time and reconstruct historic salmon returns for periods where no such information exists.

Our previous research demonstrated that conifer trees growing adjacent to anadromous salmon streams readily sequestered and incorporated marine-derived nitrogen when available. In fact, annual tree growth, stable nitrogen isotope ratios and wood total nitrogen content were all found to positively correlate with the number of anadromous salmon that returned to spawn the previous year (i.e., a one year time lag existed between salmon-derived nitrogen delivery and tree response).

This past year we focused our research efforts on the Waddell Creek watershed (Santa Cruz County). In addition to supporting populations of both coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*), this coastal basin contains the necessary combination of mature trees and years of known salmon escapement that allow us to validate our reconstructions. Furthermore, the presence of two long-lived tree species at Waddell Creek (Douglas fir and coast redwood) provides the unique opportunity to evaluate and contrast annual

variation in marine-derived nitrogen incorporation among members of the same riparian community.

In the laboratory, increment core samples were prepared and processed using standard dendrological techniques. All cores were subsequently cross-dated and ring widths were measured using a digital image analysis system. In addition, we continued to refine methods for removing soluble forms of nitrogen (primarily those in sap residues) prior to stable isotope determination. Recent research suggests that nitrogen molecules may be extremely mobile in the xylem of some tree species and such mobility could potentially confound interpretation of marine-derived nitrogen availability at the time of ring formation.

The ability to reliably measure marine-derived nitrogen in tree rings has tangible

ecological significance for California's salmonid restoration efforts. Long-lived riparian tree species may potentially serve as valuable records of past biological events such as salmon declines or extirpations. Moreover, if predictable relationships between tree ring  $\delta^{15}\text{N}$  and salmonid escapement can be routinely derived, it then becomes possible to reconstruct historic salmon returns for the many watersheds where mature streamside trees still exist and escapement records do not.

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# Non-Native Fish in Mountain Lakes: Effects on a Declining Amphibian and Ecosystem Subsidy

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2006 was the final year of a 4-year ecosystem-level research project assessing the effects of fisheries management options on distribution and abundance of fish, amphibians, emerging aquatic insects, birds, reptiles and bats in wilderness lake basins. We found that non-native trout presence suppresses the numbers of the declining Cascades frog and other amphibians, as well as large-bodied aquatic insects such as mayflies and caddisflies. After trout removals, these groups show a marked increase in abundance.

Management of water resources in wilderness areas is a challenge to State and Federal agencies because of mandates to protect native species and ecosystems, while providing recreational and economic opportunities for the public. Sport fish have been introduced to many formerly fishless waters in public lands throughout the western USA. The resulting fisheries foster recreational use of wilderness, however, widespread fish introductions have been implicated in the decline of several amphibian species including sensitive species such as the mountain yellow-legged frog and the Cascades frog (a Species of Special Concern in California). Non-native trout prey upon amphibians and aquatic insects. The adult stages of aquatic insects and amphibians are major prey items for bats, birds, snakes, and other terrestrial insectivores.

Our goal is to better understand the consequences of agency fish stocking policies regarding impacts to the native fauna that live in the lakes or feed on the insects and amphibians that emerge from the lakes (Figure 1). Quantitative information on faunal changes and recovery will be supplied to agencies for use in wilderness water resource management planning.

2006 was the final summer of data collection for our 4-year research project assessing the effects of wilderness fisheries

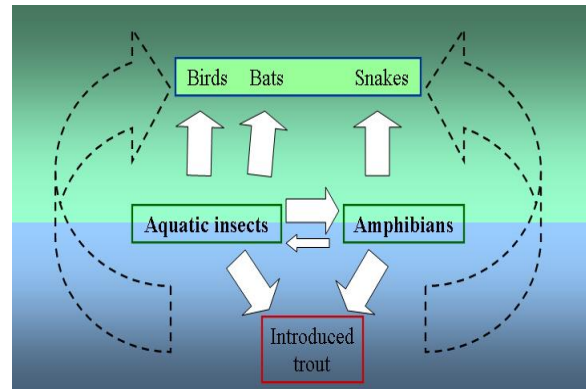


Figure 1. Schematic of wilderness lake study system. White arrows represent energy flow and dashed arrows represent potential indirect effects.

management options on distribution and abundance of fish, amphibians, emerging aquatic insects, birds, reptiles and bats.

We collected pre-treatment data in 2003 at all basins and began trout removal from four fish removal basins in the fall. In the following three summers we conducted repeat sampling of the 16 study basins.

In 2003, large-bodied insects, frogs, and garter snakes (*Thamnophis sirtalis*) were all less abundant in stocked sites compared with historically fishless 'control' basins. Over the following summers, the number of Cascades frogs increased in the fish removal basins (Figure 2). During the summer of 2006, we discovered fingerling brook trout in one fish-removal lake where

frogs did not significantly increase in abundance, suggesting that we did not eradicate trout in that lake and remaining fish successfully reproduced in the fall of 2005. Mayfly and caddisfly numbers have increased in the fish removal lakes in the years following fish removals. We did not see significant changes in abundance of common garter snakes at fish removal lakes in three years, but expect that numbers may increase in the future.

Our work will be vital to policy development for protecting and managing biodiversity in the extensive montane wilderness areas in the western United States. In addition, this project has great relevance to developing ecological theory. Ecologists have recently recognized the importance of 'ecosystem subsidies', which are flows of nutrients and organisms across the borders between adjacent ecosystems, such as water bodies and terrestrial habitats. This study will show whether a predator introduced into one community affects the level of subsidy flowing into an adjacent community.

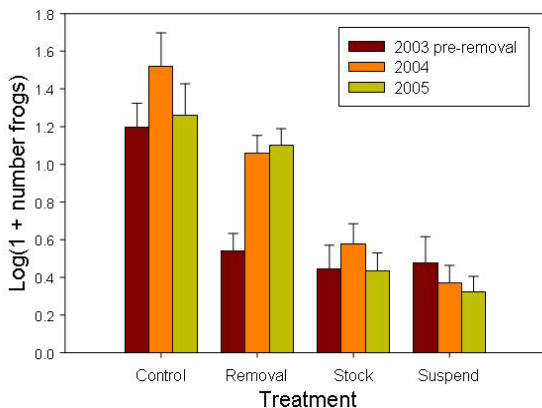


Figure 2. 2003-2005 yearly summary of Cascades frog counts (subadults and adults) collected during repeated summer visual encounter surveys. Error bars represent +1 standard error.

## **Publications**

Welsh, H. H., K. L. Pope and D. Boiano. 2006. Sub-alpine amphibian distributions related to species palatability to non-native salmonids in the Klamath mountains of northern California. *Diversity and Distributions* 12: 298–309.

## **Professional Presentations**

Pope, K. L. and S. P. Lawler. Introduced trout affect ecosystem subsidy and a threatened frog. Ecological Society of America Meeting, Montreal, Canada. August 8, 2005.

Pope, K. L., S. P. Lawler and H. H. Welsh. Effects of Fish Stocking and Fish Removal on Cascades Frog (*Rana cascadae*). Declining Amphibian Populations Task Force, Arcata, CA. January 12, 2006.

Pope, K. L., S. P. Lawler and H. H. Welsh. Introduced trout affect ecosystem subsidy and a threatened frog. Bay Area Conservation Biology Symposium, San Francisco, CA February 4, 2006 and Western Section of the Wildlife Society Annual Conference, Sacramento, CA. February 9, 2006.

Pope, K. L., S. P. Lawler and H. H. Welsh. Effects of trout stocking and removal on Cascades Frogs and other native species. Annual Conference of the California-Nevada Chapter of the American Fisheries Society, San Luis Obispo, CA. April 1, 2006.

## **Collaborative Efforts**

This large-scale project was a collaborative effort with UC Davis, California Department of Fish and Game (CDFG) and the US Forest Service (USFS), made possible by assistance from our granting agencies including CDFG, UC Center for Water Resources, National Science Foundation, and UC Davis Wildlife Health Center. Expertise, time and equipment were contributed to the project by: Dr. Hartwell Welsh and Dr. Don Ashton, USFS Redwood Sciences Laboratory; Betsy Bolster and Bernard Aguilar, CDFG; and John Alexander and Nate Seavy, Klamath Bird Observatory.

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# Nutrient Deposition and Food Web Alteration in High Sierran Lakes: Microbial Community Response

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*Growing evidence for ecosystem-scale impacts to remote lakes of the Sierra Nevada by nutrient deposition and fisheries manipulations demands an understanding of the role of microbes in these systems. Our initial research indicates a remarkably active and diverse bacterial community in lakes throughout the region. Recent experiments demonstrate that microbial communities in high-elevation Sierran lakes respond rapidly and strongly to phosphorus enrichment, indicating that continuing deposition of this nutrient may lead to significant changes in the rate of organic matter metabolism and overall ecosystem function of these lakes.*

High-elevation lakes of the Sierra Nevada, once considered isolated from human impacts, are increasingly experiencing the effects of human activities. Nutrient loading, the result of increasing atmospheric deposition, and the stocking of non-native trout, halted in National Parks but continuing on Forest Service lands, are major anthropogenic impacts to these remote ecosystems. The ecological impacts of both trout stocking and atmospheric pollutants have been studied in high-elevation lakes of the Sierra for nearly two decades, and have been shown to impose significant and lasting impacts at a regional scale, including loss of endangered species, alterations to algal productivity, and changes to zooplankton populations. Connecting these shifts to ecosystem function and biogeochemical cycling is necessary for understanding and predicting ecological impacts in these lakes, yet this has not yet been a focus, despite the documented sensitivity of alpine lake ecosystems to even minor changes in water chemistry or nutrient availability. In oligotrophic (low-productivity) aquatic ecosystems, including most alpine lakes worldwide, the microbial food web (bacteria and their protozoan grazers) is predicted to

dominate the metabolism of carbon, nitrogen, and phosphorus. Our research is investigating potential regional ecosystem impacts of eutrophication and trout introductions by examining the role of microbes in the structure and function of Sierran lakes.

Work in 2005-2006 focused on experimental assessment of the microbial response to predicted levels of atmospheric nutrient deposition. Experiments were conducted in Emerald Lake (Sequoia National Park) using *in situ* mesocosms amended with nitrate and phosphorus to examine how bacterial community composition and metabolic rates would be affected by increased availability of inorganic nutrients. Initial phylogenetic sequencing work to identify the species composition of bacteria in Emerald Lake was also completed. In addition, we continued year-round sampling of microbial and biogeochemical variables in Emerald Lake to establish a baseline understanding of bacterioplankton communities and insight into links between bacterioplankton dynamics and seasonal physical and chemical parameters. A second annual survey of six fishless and trout-stocked lakes in Humphrey's Basin

(Inyo National Forest) was conducted in mid-September of 2005 to evaluate differences in bacterioplankton and organic matter stocks attributable to the presence or absence of introduced trout.

Key findings from this second year of research include the following:

- 1) Bacterial communities in high-elevation Sierra Nevada lakes exhibit predictable annual successional patterns linked to the timing and magnitude of snowmelt.
- 2) Phosphorus strongly limits the metabolism of bacteria in Sierran lakes, suggesting that continued depositional enrichment will alter rates of respiration and organic matter cycling in high-elevation catchments.
- 3) Bacteria change the composition of their communities in concert with seasonal changes in the source of organic matter in alpine lakes: from terrestrial runoff in spring to phytoplankton-derived organic matter in autumn.
- 4) The phylogenetic identities of bacteria in high-elevation lakes are similar throughout the world, with Sierran communities closely related to studies conducted in Crater Lake (USA), the Austrian Alps, and Hawaii.

### **Professional Presentations**

Nelson, C.E., C.A. Carlson, J. O. Sickman, and J.M. Melack. Community composition and metabolism of high-elevation bacterioplankton linked to catchment inputs, landscape position, and seasonal limnological transitions. American Society of Limnology & Oceanography Summer Meeting, Victoria, British Columbia, Canada, June 4-9, 2006.

### **Collaborative Efforts**

The interdisciplinary nature of this research has involved close collaboration with several research groups. Dr. Craig Carlson, a marine microbial ecologist at UCSB, has assisted with analyses of microbial parameters. Dr. James Sickman, a watershed biogeochemist at the University of Florida, has provided assistance with various analyses of organic matter composition. Drs. Roland Knapp and Orlando Sarnelle, respectively of the Sierra Nevada Aquatic Research Laboratory and Michigan State University, have provided access to and supporting data on lakes undergoing experimental fisheries manipulation.

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# Quantifying Sediment Resuspension Linkages to Nutrient Enrichment in the Existing and Future Salton Sea

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*The Salton Sea is a hyper-eutrophic water body characterized by low oxygen concentrations, massive fish kills, noxious odors and possibly related bird kills. Eutrophication in the Sea is driven primarily by nutrients associated with sediment resuspension. This research undertook a study at the Salton Sea to directly measure sediment resuspension. The measured data, in conjunction with existing UCD temperature instruments in the Sea and the CIMIS network, were analyzed for a relation between wind speed and turbidity, and will provide sufficient data to develop a new, process-based resuspension algorithm, and fully calibrate and validate it as part of the water quality model, DLM-WQ.*

The Salton Sea is a terminal lake located in the southeastern desert of California, and is the largest “lake” in California. It occupies the northern part of the Salton Trough that includes the Coachella and Imperial Valleys of California and the Mexicali Valley of Mexico. Its main source of water is irrigation return water from the Coachella and Imperial Valleys’ use of Colorado River water. Under the 2003 Colorado River Quantification Settlement Agreement and Salton Sea ecosystem restoration legislation, inflow to the Salton Sea is to be reduced by 20%, while at the same time part of the revenues raised by this historic transfer are to be used for the ecological restoration of the Salton Sea.

Currently the Salton Sea is a hyper-eutrophic water body characterized by low oxygen concentrations, massive fish kills, noxious odors and possibly related bird kills. Recent water quality modeling conducted by the University of California, Davis, indicated that eutrophication in the Sea is driven primarily by nutrients associated with sediment resuspension and suggests that inflow control alone will not produce the desired state. Sediment resuspension is a function

of wind speed, water depth, lake fetch (resulting in wave development) and the density (thermal) stratification. As the Sea recedes (due to the 20% inflow reduction) or if, as appears possible, a massive construction project is undertaken to change the physical construction of the Sea, the extent

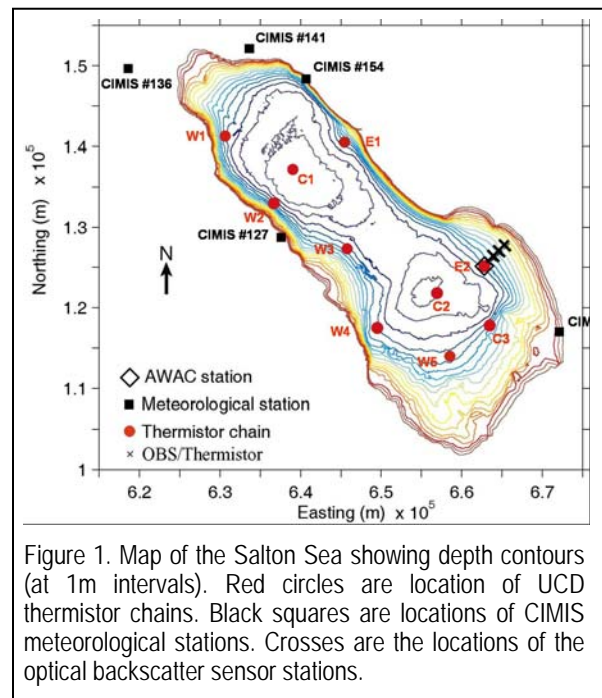


Figure 1. Map of the Salton Sea showing depth contours (at 1m intervals). Red circles are location of UCD thermistor chains. Black squares are locations of CIMIS meteorological stations. Crosses are the locations of the optical backscatter sensor stations.

and the effects of sediment resuspension will change.

This research undertook a 12 months study (including a four-month measurement program) at the Salton Sea to directly measure sediment resuspension using an array of optical backscatter sensors and a wave height and current profiling instrument. The data were provided by these instruments, in conjunction with existing UC Davis temperature instruments in the Sea and the CIMIS meteorological network (figure 1). The Sea was not strongly stratified for this research period, even though the surface of the Sea was weakly stratified. The time series data, including turbidity, wind speed, wave height and currents, were compared to one another to determine any relations among the measurements. The analysis of the time series reveals that the existence of a peak in wind intensity is associated with a peak in turbidity. These peaks of hourly wind speed seem to occur with quasi-invariant wave direction from the west. It also is interesting to see that important signal strengths are observed for day 252 – day 260 close to the bottom, which is compatible with wind speed at that period.

Based on the measured data, correlations between turbidity, which is assumed to be directly related with suspended solids in the water columns of the Sea, and wind speed are determined. These data also revealed that shear stress due to wave action was more dominant than that due to current. Non-linear relation between wind speed and turbidity were assumed and compared with other relations of sediment entrainment as a function of bed shear stress and the associated shear velocity.

In addition, sediment entrainment was calculated by two theoretical models, including Mian and Yanful (2004) for cohesive sediment and Garcia and Parker (1991, 1993) for non-cohesive sediment, and compared with measurements.

These two sediment entrainment models will be combined into the water quality model, DLM-WQ. The measured data fully calibrate and validate it.

The model can then be used to more fully explore the potential for ecological restoration of the Salton Sea, either under its present geometrical configuration or possible future configurations. The model, which is in the public domain, will also be applicable to many other lakes and reservoirs, where sediment resuspension or the nutrients and contaminants that are associated with the sediments, are an issue.

### **Professional Presentations**

Schladow, S. G., Rueda, F. J., Fleenor, W. E. and Chung, E. G. Three-Dimensional Hydrodynamic Modeling of the Salton Sea. California Water and Environmental Modeling Forum Annual Conference, Asilomar, CA, 2006.

### **Collaborative Efforts**

This research is providing input toward the ecological restoration the Salton Sea. This restoration is currently under investigation by the California Department of Water Resources and the US Bureau of Reclamation. We are working closely with staff from both these agencies, and their consultants. We are also collaborating with the USGS and NASA on Salton Sea related issues.

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## Research Category III

# Water Quality

Research in this category encompasses all aspects of water quality management. Topics include sources and the nature of contamination; effects of contamination on human health, plant and wildlife; wastewater treatment and reclamation processes; and retrospective evaluations of the effectiveness and impacts of different strategies utilized in California for improving water quality, in particular water reuse, and for preventing water quality degradation.







# Development of Biosensor for Real-Time Analysis of Perchlorate in Water

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*Perchlorate ( $\text{ClO}_4^-$ ) contamination of ground water is a widespread problem in the U.S., which can adversely affect human health and wildlife. We report the development of a highly sensitive method for real time detection  $\text{ClO}_4^-$  detection in water.*

Perchlorate ( $\text{ClO}_4^-$ ) contamination of ground water is a widespread problem in the U.S., which can adversely affect human health and wildlife. Current methods for detecting and quantifying  $\text{ClO}_4^-$  in water are time consuming, expensive, and subject to error due to complex procedures and various interferences. Thus, there is an urgent need to develop a method that can accurately detect and measure low concentrations of  $\text{ClO}_4^-$  in the field.

We constructed and characterized a  $\text{ClO}_4^-$  biosensor for rapid determination of  $\text{ClO}_4^-$  in water by employing a  $\text{ClO}_4^-$  reductase from a novel perchlorate-reducing bacterium (*Dechloromonas* sp. perc1ace). Using a 3 mm glass carbon electrode (GCE), we successfully constructed a  $\text{ClO}_4^-$  sensing bio-electrode by coating an aliquot of the enzyme on the nafion (ion-exchange matrix) layer pre-coated on the polished surface of the GCE. Amperometric [i/t] measurements revealed linear increases in current in relation to time and  $\text{ClO}_4^-$  concentration. The biosensor responded strongly to  $\text{ClO}_4^-$  at concentrations as low as 1  $\mu\text{g/L}$  and the sensor displayed a linear response to  $\text{ClO}_4^-$  concentrations in the range 25 to 100  $\mu\text{g/L}$ . Response time to  $\text{ClO}_4^-$  at 100  $\mu\text{g/L}$  was approximately  $111 \pm 28$  seconds. Kinetic evaluation of the sensor response to  $\text{ClO}_4^-$  at 25 to 100  $\mu\text{g/L}$  revealed a first order reaction ( $r^2 > 99\%$ ) with k values of 10.3,

24.2, 33.9 and 48.2 at 25, 50, 75 and 100  $\mu\text{g/L}$ , respectively. A strong linear correlation was established between biosensor response (nA) and ion-chromatography conductivity readings ( $\mu\text{S}$ ) in the 25 to 100  $\mu\text{g/L}$  linear domain of the biosensor. Biosensor response to  $\text{ClO}_4^-$  was maximal at applied potential range of  $-0.6$  to  $-1.0\text{V}$ .  $\text{ClO}_4^-$  reduction current increased with increase in pH and was maximal in the range of 7.6 to 8.0. The  $\text{ClO}_4^-$  biosensor displayed excellent stability after repeated use (24 analyses conducted on day 1 over a 10-hour period at room temperature). Nitrate concentrations below the drinking water regulatory limit ( $<45 \text{ mg/L NO}_3^-$ ) did not interfere with  $\text{ClO}_4^-$  biosensor performance. This study indicates great potential for the development of a portable and field deployable biosensor for real time analysis of  $\text{ClO}_4^-$  in water.

## Publications

Okeke, B. C., M. Guangyu, Q. Cheng, M. E. Losi and W. T. Frankenberger, Jr. (2006). Development of a Perchlorate Reductase Based Biosensor for Real Time Analysis of Perchlorate in Water. *J. Microbiol. Meth.* In Press (Available Online)

Okeke, B. C., M. Guangyu, Q. Cheng, M. E. Losi and W. T. Frankenberger, Jr. (2006). Perchlorate Detection in Water by a Microbial Enzyme-Based Biosensor.

Abstracts of the 106<sup>th</sup> General Meeting of the American Society for Microbiology, Orlando, FL.

### **Professional Presentations**

Okeke B. C., Guangyu Ma, Quan Cheng, Mark E. Losi and William T. Frankenberger Jr. Perchlorate Detection in Water by a Microbial Enzyme-Based Biosensor. 106<sup>th</sup> General Meeting of the American Society for Microbiology, Orlando, FL, May 2006.

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# Quantitative PCR Assays for Specific Host Sources of Fecal Pollution in Watersheds

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*The purpose of this study is to develop and validate Quantitative PCR assays for host specific and reference targets and apply the assays to the San Pedro Creek Watershed in Pacifica, CA in order to identify sources of fecal pollution. Year 1 of the project has demonstrated significant methodology development and validation. In addition, sites in the San Pedro Creek Watershed with anticipated fecal pollution have been sampled, and over 96% contained elevated levels of fecal indicators, suggesting these sites significantly contribute toward watershed pollution. These samples are being processed for future analysis by QPCR.*

The purpose of this study is to develop and validate quantitative polymerase chain reaction (QPCR) assays for host specific and reference targets and apply the assays to the San Pedro Creek Watershed in Pacifica, CA in order to identify sources of fecal pollution and focus remediation efforts.

Identifying the host sources of fecal pollution in watersheds is typically accomplished via microbial source tracking (MST), and is essential for effective remediation of watershed pollution. Host-specific microorganisms, which are found only or primarily in a single host species, are highly advantageous for MST. Since assays for host-specific microorganisms circumvent the need for the large host origin database that is required for most MST assays, they provide more specific, faster, and less expensive MST assays.

The San Pedro Creek Watershed in Pacifica, CA, is an important local recreational resource, provides steelhead rookery, and has both rural and urban aspects. The watershed also has elevated levels of fecal pollution that contribute to coastal pollution and beach closures.

San Pedro Creek Watershed sampling focused on areas suspected of contributing fecal pollution to the main stem of the creek,

namely sites on the North Fork, above the Park Mall Shopping Center culvert (Figure 1, upper right corner - Big Bend area), and sites associated with tributaries that feed into the main stem from the South, primarily between Adobe and Highway 1 (Figure 1, lower left area).

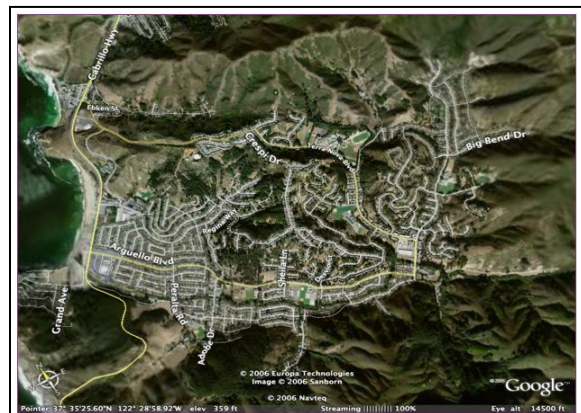


Figure 1 San Pedro Creek Watershed

Four methods for isolation of genomic DNA were applied to a representative sampling of *Enterococcus* and *E. coli* cultures and evaluated by DNA yield from bacterial cultures, and by assay cost, overall time and technical time.

Significant progress has been made in the development and validation of QPCR

assays for host-specific microorganism targets: (1) the esp gene of *Enterococcus faecium*, as a specific marker for human fecal pollution, and (2) two gene targets in *Enterococcus faecalis* as indicators for avian and human fecal pollution, plus two reference gene targets diagnostic for total *Enterococcus*, as indicators of total fecal pollution.

The QPCR assays were applied to fecal, sewage and environmental samples (Table 1). The human specific E. faecium target (Esp2b2) was positive for sewage and environmental samples with suspected human contamination, and did not react with avian, cow, dog, human or rabbit fecal samples. Furthermore, the human specific gene target identified 5 of 7 environmental samples with human fecal contamination (Table 2). All of the above data are fully consistent with the putative assay specificity, as the gene target is not found in all human individuals. The reference target (16Sb) reacted with all fecal, sewage and environmental samples, and exhibited similar levels of gene expression across all samples, confirming its efficacy as a reference marker for total Enterococci.

Table 1. QPCR Assays on Fecal, Sewage & Environmental Samples

Host	Human	Human/Avian	Total Entero
Gene	Esp2b2	Ace1a, Esp1a	16Sb
Positive	Sewage, Environmental	Bird, Cow, Dog, Human, Rabbit, Sewage, Environmental	Bird, Cow, Dog, Human, Rabbit, Sewage, Environmental
Negative	Bird, Cow, Dog, Human, Rabbit	None	None
Notes	>>250-fold differential	Lower Cts for non-target hosts	Similar Cts for all (20-21)

Blind environmental: Human contaminated watershed  
Assays at 0.4 and 10 ng DNA/ul; CVs 0.5-2%

In summary, the first year of the project has demonstrated significant progress in assay development and validation, and methodology development. In addition, sites in the San Pedro Creek Watershed with anticipated fecal pollution have been sampled, and a high percentage (96.2%) of these

watershed samples were found to contain elevated levels of fecal indicators.

Table 2. QPCR Assays on Environmental Samples with Human Fecal Contamination

Sample	Ct	Ct	delta Ct
	16Sb	ESP2b2	
B1Sewage	20.3	34.6	14.3
B2Sewage	21.6	19.6	14.3
FDI DEL	18.3	29.7	11.4
HCSewage	19.6	33.8	14.2
Sewage20 10/26	18.0	>40	>21.98
Sewage3 10/26	19.3	>40	>20.67
Sluice	20.1	38.9	16.5

CVs (0.001-0.70)

Final results of this study are anticipated to facilitate the identification of sources of fecal pollution in watersheds, and thus enable more efficient watershed management. In particular, the focus on development of assays for human fecal pollution will impact the sources of pollution from which humans experience the highest health risk.

### Publications

Ivanetich, Kathryn, Pei-Hsin Hsu, Kathleen M. Wunderlich, Evan V. Messenger, Ward G. Walkup IV, Troy M. Scott, Jerzy Lukasik, Jerry Davis, Microbial Source Tracking by DNA Sequence Analysis of the *Escherichia coli* malate dehydrogenase gene. *Journal of Microbiological Methods* 67, 507-526 (2006).

### Professional Presentations

Ivanetich, Kathryn, Status of California Watersheds and Novel Methods to Identify Host Sources of Fecal Pollution, California State University at Chico, Department of Chemistry and Biochemistry, April 2006.

### Collaborative Efforts

Troy Scott, Ph.D., and George Lukasik, Ph.D., Biological Consulting Services of North Florida, and University of Florida, Dept. of Microbiology and Cell Science, Gainesville, FL.

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# Do Constructed Flow-Through Wetlands Improve Water Quality in the San Joaquin River?

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*In the Central Valley, constructed wetlands can improve water quality of irrigation return flows by intercepting and/or transforming particulate organic carbon, nitrogen, phosphorous and sediment before it reaches the San Joaquin River.*

The primary goal of this study is to evaluate the efficacy of using constructed wetlands (CW) to improve water quality in irrigation return flows ultimately destined for the San Joaquin River. Two CWs were monitored during the 2005 irrigation season (April - Sept.), a new CW (W-1) and 12-year-old CW (W-2). No monitoring occurred in 2006 due to flood conditions that remained until August.

Sediment samples were analyzed for carbon, nitrogen, phosphorus and particle size; and intricate input/output flow monitoring systems were installed to calculate constituent loads. Input/output waters from CWs were collected on a weekly basis and analyzed for: total nitrogen (TN), total phosphorus (TP), dissolved organic carbon (DOC), particulate organic carbon (POC), total suspended solids (TSS), volatile suspended solids (VSS), and chlorophyll-a (a measure of algal biomass). High frequency sampling with autosamplers was also employed to better understand the temporal variability in water quality constituents. Carbon, nutrient and sediment retention efficiency was evaluated from input/output concentration data.

Particular emphasis was directed toward phosphorus cycling in 2005-2006. Suspended solids from input and output waters were processed through a sequential phosphorus extraction procedure in order to characterize the different P fractions.

## Results

The work has enabled us to compare the older CW with the newly constructed CW, but differences in size and irrigation water received may have complicated the results. Both CWs are clearly effective at capturing sediment and nutrients discharged from irrigated farmland.

Constructed wetlands have a potential to store carbon. After receiving tail water over the 2004 and 2005 irrigation seasons, the average soil organic carbon content of seasonally submerged soils increased almost five-fold at W-1 and approximately ten-fold at W-2.

In samples from 2004, chlorophyll-a tended to be higher in water at W-1 compared to W-2, especially at the input. In 2005, W-2 became a source of chlorophyll-a, while W-1 showed no differences between input and output. During spring 2005, CW-2 was not allowed to dry out. This prevented the germination of emergent vegetation, which allowed more light into the system over the irrigation season resulting in more algae.

While W-1 was generally a sink for DOC in 2004, W-2 was often a source, possibly due to leaching of DOC from vegetation and litter. In 2005, W-1 was a sink for DOC over 70% of the irrigation season; W-2 was a source roughly 50% of the season. A comparison of concentration and load data for DOC at input and output locations illustrates that although the concentration of DOC was greater at the outputs, the actual amount of DOC exiting the CW as a load

was much less than what entered. This was true at W-1 and to a lesser extent at W-2.

Both wetlands were effective in reducing bio-available phosphorus (BAP) throughout the season. Dissolved phosphorus (DP) removal was high in both wetlands although the average removal efficiency was higher in the older, larger CW than in the newer, smaller one. Removal efficiencies for particulate P were similar.

The retention of particle bound P is considered one of the primary retention mechanisms of constructed wetlands. Total suspended solids were significantly lower in both wetlands at the outputs relative to the inputs. This retention of suspended solids occurs primarily from the settling of particles due to decreased water velocities. As water flows through the wetlands and larger particles are deposited, the proportion of fine textured solids reaching the output increases.

### **Publications**

O'Geen, A.T., J.J. Maynard, and R.A. Dahlgren. Efficacy of constructed wetlands to mitigate non-point source pollution from irrigation tailwaters in the San Joaquin Valley California, *USA Water Science and Technology*, In press.

### **Professional Presentations**

Maynard, J.J., A.T. O'Geen and R.A. Dahlgren, Using Constructed Wetlands to Remove Water Quality Contaminants in Agricultural Return Flows. California Plant and Soil Science Conference, Modesto CA, Feb. 2005.

O'Geen Preliminary water quality monitoring in constructed wetlands. San Joaquin River Management Program Advisory Council, Modesto, Mar. 2005.

O'Geen, A.T., J.J. Maynard and R.A. Dahlgren, Strategies for Attenuating Hypoxia in the Lower San Joaquin River, California, World Water & Environmental Resources Congress, Anchorage AK, May 2005.

Maynard, J.J., A.T. O'Geen and R.A. Dahlgren, A Spatial Investigation of Bio-Available Phosphorus in Submerged Wetland Soils, Western Society of Soil Science Annual Meetings, Ashland OR, Jun. 2005.

Brauer, N, A.T. O'Geen, J.J. Maynard, and R.A. Dahlgren, Mineralogical Characterization of Seasonally Submerged Wetland Soils Western Society of Soil Science Annual Meetings, Ashland, OR, Jun. 2005.

O'Geen, A.T., Efficacy of constructed wetlands to mitigate non-point source pollution in the San Joaquin Valley California USA, Diffuse Pollution Specialist Conference, Johannesburg, South Africa, Aug. 2005.

O'Geen, A.T. and R.A. Dahlgren. Field tour for the Southwest States and Pacific Islands Regional Water Quality Program. Jun. 2006.

Maynard, J.J., A.T. O'Geen and R.A. Dahlgren, Transformations of Biologically-labile Particulate Phosphorus in Constructed Wetlands, Western Society of Soil Science Annual Meetings, Park City UT, Jun. 2006.

Maynard, J.J., A.T. O'Geen and R.A. Dahlgren, Effects of sedimentation on phosphorus retention in seasonally submerged wetland soils. World Congress of Soil Science, Philadelphia, PA. Jul. 2006.

### **Collaborative Efforts**

This project has fostered collaborations with the USDA-NRCS District Conservationist in Stanislaus County, Fish and Wildlife Service, Bureau of Reclamation, and the State Water Resource Control Board.

This project has also initiated a collaborative effort with the San Joaquin River Wild Life Refuge, one of the largest holdings of natural and constructed wetlands in the Central Valley.

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## Identification of Viable Cells of *E. coli* O157:H7 in Environmental Waters using Quantitative PCR

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*In the development of a microarray to identify pathogens, several preliminary points became evident. These were interference reducing the accuracy of quantification; viability; and effect of matrix on standard curves.*

Under the Clean Water Act, Total Maximum Daily Load requirements for fecal coliforms established by the US EPA and its state representatives are proving difficult to meet. Agencies and cities in charge of runoff from storm drains and other discharge points into environmental waters are investing large amounts of public funds to identify and control fecal sources. To aid water managers in identifying waste quickly and inexpensively, we propose to develop an oligonucleotide microarray that will identify four fecal waste sources (human, cow, pig and bird) and a major bacterial pathogen, *E. coli* O157:H7, simultaneously with results available within 48 hours.

In the development of a microarray to identify pathogens, several preliminary points became evident. These were interference resulting in a reduction of the accuracy of quantification; viability; and effect of matrix on standard curves. We have optimized a compound of bovine serum albumin for direct DNA extraction from sewage sludge, sediments, activated sludge, stream waters and raw sewage to remove interference in quantitative polymerase chain reaction (PCR). Additionally, if no interfering compound is present, this compound does not reduce the sensitivity of the assay. A DNA intercalating compound has been developed that can be used to develop a viability assay that can accompany any quantitative PCR assay prior to DNA extraction. This addition to quantitative

PCR testing means that for public health purposes viability can be incorporated into the assay.

To date, we focused on *Escherichia coli* O157:H7 because this organism is an important human pathogen that has been attributed as the primary cause of hemolytic uremic syndrome and hemorrhagic colitis in the United States. Many of the estimated 73,000 cases of *E. coli* O157:H7 infections have been a result of exposure to contaminated recreational waters or consuming contaminated drinking water or food, especially ground beef.

Our overall approach is based on quantitative PCR using dual labeled probes that would allow investigators to capture multiple genetic markers specific for a target pathogen from a complex matrix, as explained for *E. coli* O157:H7. This method promotes maximum flexibility because assays could be tailored to sample specific concerns. Molecular methods such as conventional quantitative PCR lack the ability to determine cell viability, but additional techniques may be employed to circumvent this obstacle. We adopted a method based on treating our samples with a nucleic acid stain that would prevent PCR amplification of nonviable cells. Therefore, if we observed quantitative amplification of our designated targets, we could be certain these are from live cells. This analysis provides a more accurate microbial

description of our sample. Our viability assay was screened and optimized using pure cultures while the environmental samples consisted of secondary effluent, cow feces, and cow waste lagoon waters.

Including the cell viability analysis appears to be very promising. Figure 1 indicates a 4 log reduction using quantitative PCR for the *flhC* gene of *E.coli* O157:H7 when treated with optimal nucleic stain concentrations. We have observed this compound to inhibit bacterial growth as shown by figure 2, but quantitative PCR is still able to detect the entire bacterial population prior to treatment with the nucleic stain. Additionally, in dealing with interference due to the environmental matrix we have included bovine serum albumin. This substance increased detection in the presence of interfering compounds and produced no ill effects in the absence of interference.

This research is important to water quality because *E. coli* O157:H7, as well as other pathogens, continue to pose a threat to public health regardless of the improved safety measures required by regulation agencies. This research method is robust in that it successfully deals with interference and cell viability. Our research will present a simple and efficient method to identify viable pathogens in the environment. As a tool it is important because it provides an accurate description of the microbial population from any given source.

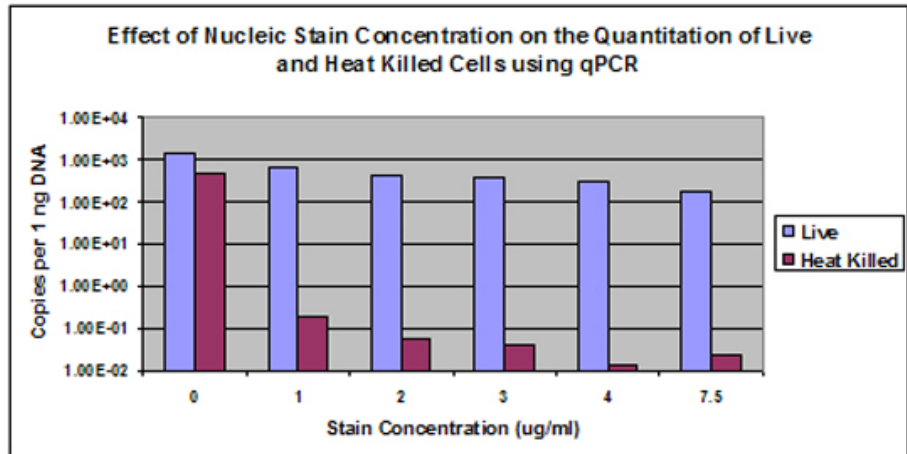


Figure 1.

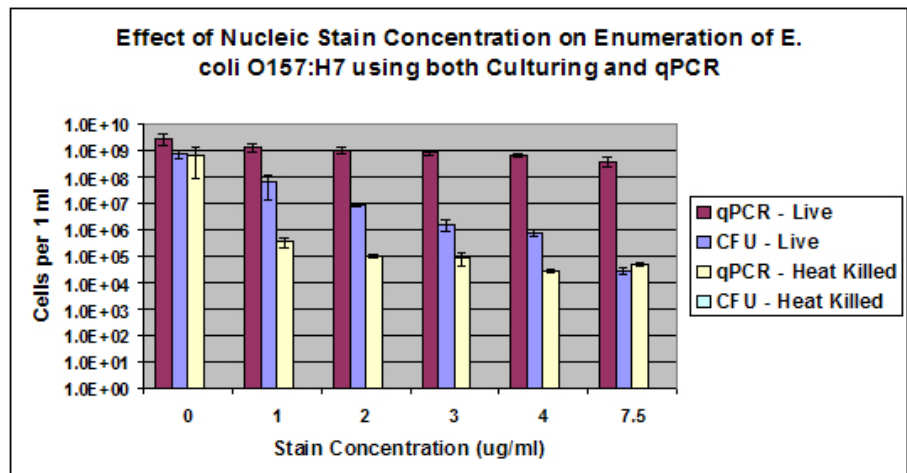


Figure 2.

### Professional Presentations

Phil Gedalanga and Betty H. Olson, Identification of *Escherichia coli* O157:H7 Specific Genes *flhC* and *stx1* in Environmental Matrices Using Quantitative PCR Coupled with Magnetic Capture Hybridization, American Society for Microbiology, Orlando, FL, May 2006.

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# Diuron in California's Water Supply: Transformations and Associated Risks

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*Diuron is the third most commonly used herbicide in California, and nearly all applications coincide with California's rainy season. Because diuron is moderately persistent in the environment, detection of the compound in California water supplies is common. Chlorination or chloramination of diuron, or similar compounds, during water disinfection has been shown to produce the potent carcinogen N-nitrosodimethylamine (NDMA). This project seeks to: (1) determine the rate and extent of toxic byproduct formation during chlorination or chloramination of diuron containing waters, and (2) assess the range of likely human exposures to these byproducts. Work in this first year confirmed that significant quantities of NDMA could be produced under some test conditions; actual human exposures, if any, remain unclear.*

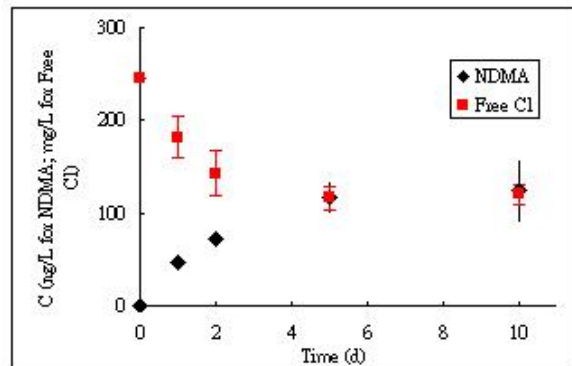
Diuron is the third most commonly used herbicide in California (over 1.5 million pounds annual usage in 2005). Nearly all applications (95%) are in late fall through early spring, which coincides with California's rainy season. Spot surface water monitoring, conducted by the Department of Pesticide Regulation between 1992 and 2002, frequently detected the presence of diuron. Monitoring of various organic compounds two or three times a year by the Department of Water Resources for the state water project has also resulted in frequent detection of diuron.

The primary reason for concern about diuron in source waters is the chance of forming carcinogens, such as N-nitrosodimethylamine (NDMA), from diuron directly or from its breakdown product, dimethylamine (DMA). In addition, the formation of other byproducts, such as chlorinated anilines, may also impart unacceptable risks.

The objectives of the project are to: 1) determine the kinetics of toxic byproduct formation during chlorination or chloramination of diuron containing waters from the California Aqueduct; and 2) assess, through a combination of field sampling and

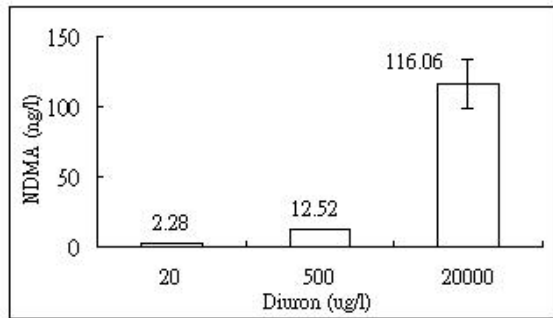
modeling, the range of human exposure to diuron's byproducts via treated waters derived from the California Aqueduct.

The first phase of the project has been to test the potential for NDMA formation during chlorination of diuron. The results acquired support the hypothesis that appreciable amount of NDMA can be produced from the chlorination of diuron (Figure 1). Similar experiments were also conducted to investigate the effects of different initial diuron concentrations and pH values.

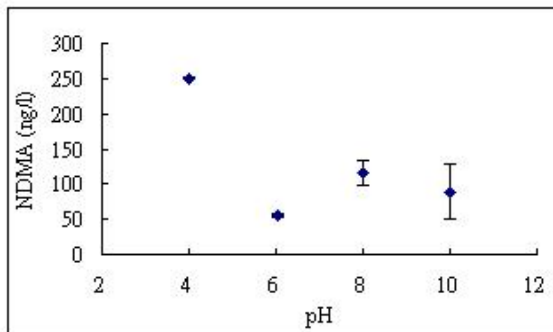


**Figure 1: Concentration of NDMA (♦, ng/L) produced in the diuron chlorination study, and of free chlorine as  $Cl_2$  (■, mg/L) at the end of reaction (The initial diuron concentration is 20 mg/L, and pH = 8). The point and bar represent the mean value and one standard deviation, respectively.**

Results indicate that lower concentrations of diuron produced lower concentrations of NDMA at the end of experiments (Figure 2), and the optimal pH range of NDMA formation from diuron is 6 to 10, which is similar to the proposed optimal pH range of NDMA formation from DMA (Figure 3).



**Figure 2: Concentration of NDMA produced in samples containing various initial diuron concentrations after 5 days (pH = 8). The number and bar represent the mean value and one standard deviation, respectively.**



**Figure 3: Concentration of NDMA produced in samples containing various pH values after 5 days (The initial diuron concentration is 20 mg/l; acetate buffer for pH 2, phosphate buffer for pH 6 and 8, carbonate buffer for pH 10). The point and bar represent the mean value and one standard deviation, respectively.**

Work during the next year of the project will clarify the formation kinetics of NDMA and other toxic byproducts during chlorination and chloramination of diuron, which is essential to determine the risk posed by diuron in any location where it is a contaminant of concern. Estimates of human exposure to diuron and its byproducts in drinking water will allow identification of specific regions in the California Aqueduct, if any, where the treatment plants should be modified.

### **Professional Presentations**

Wei-Hsiang Chen, Peter Green, and Thomas Young, Diuron in California's water Supply: Transformation and Associated Risks, California-Nevada Section, American Water Works Association, Reno, NV, August 2005.

Wei-Hsiang Chen, Peter Green, and Thomas Young, Diuron in California's Water Supply: Transformation and Associated Risks, UC Water Resources Coordinating Conference and Surface Water Quality Workshop, Woodland, CA, April 2006.

Wei-Hsiang Chen, Peter Green, and Thomas Young, Diuron in California's Water Supply: Transformation and Associated Risks, The Future of Agriculture: Science, Stewardship, and Sustainability, International Conference, Sacramento, CA, August 2006.

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