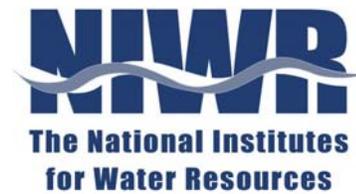


California Water Resources Center



Annual Project Progress Report 2004 – 2005

July 1, 2004 – June 30, 2005

Dr. Andrew Chang, Director
Dr. Laosheng Wu, Associate Director

UC Center for Water Resources

The University of California prohibits discrimination against or harassment of any person employed by or seeking employment with the University on the basis of race, color, national origin, religion, sex, physical or mental disability, medical condition (cancer-related), ancestry, marital status, sexual orientation, citizenship or status as a Vietnam-era veteran or special disabled veteran.

The University of California is affirmative action/equal opportunity employer. The University undertakes affirmative action to ensure equal employment opportunity for underutilized minorities and women, for persons with disabilities and for Vietnam-era and special disabled veterans.

University policy is intended to be consistent with the provisions of applicable State and Federal law. Inquiries regarding this policy may be addressed to the Affirmative Action Director, University of California, Agriculture and Natural Resources, 1111 Franklin Street, 6th Floor, Oakland, Ca 94607-5200 (510) 987-0097.

This publication is a continuation of the Water Resources Center Report series. It is published and distributed by the DIRECTOR'S OFFICE of the UC CENTER FOR WATER RESOURCES. The Center sponsors projects in water resources and related research within the state of California with funds provided by various state and federal agencies and private industry. Copies of this and other reports published by the Center may be obtained by contacting:

UC CENTER FOR WATER RESOURCES
RUBIDOUX HALL – 094
UNIVERSITY OF CALIFORNIA
RIVERSIDE, CA 92521
ATTENTION: PUBLICATIONS
(951) 827-4327

Copies of Center publications may be examined at:

Water Resources Archives
410 O'Brien Hall
University of California
Berkeley, CA 94720
(510) 642-2666

This publication is available on the website of the UC Center for Water Resources. The URL is:
<http://www.waterresources.ucr.edu>

Funding for this publication is provided by the University of California. It is available to the general public free of charge.



TABLE OF CONTENTS

RESEARCH PROJECT INDEX

Research Category I – Hydrology, Climatology and Hydraulics

Project Title	Principal Investigator	Location	Page
<i>Predicting Flow and Sediment Transport in Steep Channels: Field Study and Flume Experiments to Develop and Test Models</i>	William E. Dietrich	UC Berkeley	2
<i>Estimating the Water Stored as Snowpack Using Remote Sensing and Advanced Data Assimilation Techniques</i>	Steven A. Margulis	UC Los Angeles	3
<i>Estuarine Landscape Modeling of Suisun Bay</i>	David H. Schoellhamer	UC Davis	5
<i>Future Regional Climate Change in the Ten Hydrologic Regions of California: A Climate Modeling Investigation</i>	Lisa C. Sloan	UC Santa Cruz	6
<i>Mount Shasta's Glaciers: An Endangered Resource?</i>	Slawek Tulaczyk	UC Santa Cruz	7
<i>California 2100: Assessing California's Future Water Resources</i>	Bryan C. Weare	UC Davis	9

Research Category II – Aquatic Ecosystems

Project Title	Principal Investigator	Location	Page
<i>Nutrient Loading and the Invasion of Giant Reed (Arundo Donax), into California's Riparian Ecosystems</i>	Richard F. Ambrose	UC Los Angeles	12
<i>Hydrological Regimes, Pond Morphology, and Habitat Use: Predicting the Impact of an Emerging Aquatic Pathogen</i>	Cheryl Briggs	UC Berkeley	14
<i>Structure and Seasonal Changes of Nematode Communities from Vernal Pools of the Santa Rosa Plateau</i>	Paul De Ley	UC Riverside	16
<i>Pyrethroid Insecticides in Nursery Runoff: Transport and Impact on Aquatic Invertebrates</i>	Jay Gan	UC Riverside	18
<i>Spatial and Temporal Patterns of Wetland Evapotranspiration, Primary Production, and Nutrient Cycling</i>	Michael Goulden	UC Irvine	20
<i>Using Marine-Derived Nitrogen in Tree Rings to Assess Nutrient Flux and Salmon Escapement</i>	Michael Johnson	UC Davis	22
<i>Temporal and Spatial Linkages Between Watershed Land Use and Wetland Vegetation Response, Elkhorn Slough, Monterey County, CA</i>	Maggi Kelly	UC Berkeley	24
<i>Non-native Fish in Mountain Lakes: Effects on a Declining Amphibian and Ecosystem Subsidy</i>	Sharon P. Lawler	UC Davis	26
<i>Anthropogenic Nutrient Deposition and Alteration of the Food Web Structure in Alpine Lakes: Response by Microbial Communities</i>	John M. Melack	UC Santa Barbara	28

Research Category III – Water Quality

Project Title	Principal Investigator	Location	Page
<i>Cryptosporidium in Bivalves as Indicators of Fecal Pollution in the California Coastal Ecosystem</i>	Patricia A. Conrad	UC Davis	31

Research Category III – Water Quality (continued)

Project Title	Principal Investigator	Location	Page
<i>Development of Biosensors for Real Time Analysis of Perchlorate in Water</i>	William T. Frankenberger	UC Riverside	33
<i>Kinetics of Inorganic Arsenic Contamination in Surface and Ground Waters</i>	Michael McKibben	UC Riverside	34
<i>Detection of the Herbicide Atrazine in Freshwater Using DNA Aptamers</i>	Ashok Mulchandani	UC Riverside	35
<i>Development of a Real-Time Method for Enumeration of Host-Specific Fecal Bacteria Based on Quantitative Polymerase Chain Reaction</i>	Kara Nelson	UC Berkeley	36
<i>Do Constructed Flow-Through Wetlands Improve Water Quality in the San Joaquin River?</i>	Anthony T. O’Geen	UC Davis	37
<i>Development of a Microarray to Simultaneously Detect Fecal Waste Sources and a Major Pathogen, E. coli O157-H7, in Stormwater Runoff</i>	Betty Olson	UC Irvine	39
<i>Use of Bioassays to Assess the Water Quality of Wastewater Treatment Plants for the Occurrence of Estrogens and Anti-estrogens</i>	Daniel Schlenk	UC Riverside	41

Research Category IV – Water Development and Management Alternatives

<i>Imperial Valley Agriculture and Water: A Regional Economic Analysis</i>	Kurt Schwabe	UC Riverside	44
<i>Futures Markets for Water in California: Effective Management of Supply-Side Risk</i>	Jeffrey Williams	UC Davis	46
<i>Modeling and Optimization of Seawater Intrusion Barriers in Southern California Coastal Plain</i>	William Yeh	UC Los Angeles	47

Research Category I

Hydrology Climatology and Hydraulics

This category encompasses the physical processes that lead to water availability for human use on land, in lakes, streams and aquifers. Examples of investigations that logically fall in this category include studies of precipitation and stream-flow relationships, weather forecasting, climate modification, micrometeorological processes linking atmospheric water, solar energy, water use by plants (both commercial and native), and available soil moisture, hydrologic and hydraulic modeling and processes, and the development of databases.





Predicting Flow and Sediment Transport in Steep Channels: Field Study and Flume Experiments to Develop and Test Models

William E. Dietrich
Department of Earth and Planetary Science
UC Berkeley

Traditional bedload transport equations often over-estimate the sediment flux from streams draining mountainous terrain. We developed a transport equation for steep, rough channels to predict the timing and magnitude of sediment delivery to downstream reaches. This equation has been modified based on field and flume tests and it is now ready to be used in drainage network-scale sediment routing models. The improved accuracy provided by this equation is important for understanding the effect of changes in management practices on downstream aquatic habitats, for instance during the augmentation of spawning gravel available to salmon.

Steep streams (gradients of 3-20%) comprise a large portion of mountainous drainage networks. However, flow and sediment transport in these channels are highly variable processes that are poorly understood. Large, relatively immobile grains cause spatial fluctuations in flow and the transport of finer, more mobile sediment. In addition, the local availability of more mobile grains may be limited due to a stochastic sediment supply. Most transport equations do not account for such spatial and temporal variability and therefore over-predict flux in steep streams by several orders of magnitude. As a consequence, these fundamental questions can not be answered: 1) how does a change in sediment supply (due to land management practices) affect channel morphology, bed texture, and therefore aquatic habitat throughout the river network, 2) what is the time frame for sediment movement over a given distance downstream and 3) what controls bedrock erosion rates in steep channels?

During the first year of UC Water Resources Center funding, we developed a transport equation to account for the stress borne by large, relatively immobile grains and the limited availability of the smaller, more mobile sediment. We tested this equation using a small, steep flume in which we fed fine gravel through fields of regularly-spaced immobile spheres. In these experiments, our transport equation generally predicted flux to within an order of magnitude. To further test and refine our equation, we measured flow (depth and velocity), sediment transport rates, and bed properties in a small steep tributary of the South Fork Eel River.

We conducted another set of flume experiments (in collaboration with Mark Schmeckle) to understand, in detail, flow and sediment transport around large, immobile grains. The immobile grains caused an order of magnitude variation in the sediment transport rate

across the flume. Furthermore, these large grains increased near-bed downstream velocities and therefore caused sediment transport that would otherwise not occur.

During the second year of funding, we further tested and modified our model, and completed a manuscript for submission to a peer-reviewed journal. Our work has provided a modified transport equation available to be incorporated into network-scale sediment routing models to predict the timing and magnitude of sediment delivery to downstream reaches. Since large roughness elements are often used to enhance freshwater salmon habitat, our model should be useful for determining the impact of large, immobile grains on the deposition and retention of spawning gravel in sediment-starved stream reaches.

Collaborative Efforts

Dr. Mark Schmeckle (Arizona State University).

Professional Presentations

Yager, E., M. Schmeckle, W.E. Dietrich, and J.W. Kirchner, The Effect of Large Roughness Elements on Local Flow and Bedload Transport, American Geophysical Union, San Francisco, Fall Meeting 2004, Abstract H41G-05. *Eos, Transactions, American Geophysical Union*, 85(47).

For further information, please contact:

• Dr. William E. Dietrich
e-mail: bill@eps.berkeley.edu
Phone: 510-642-2633

Webpage:

<http://socrates.berkeley.edu/~geomorph>



Estimating the Water Stored as Snowpack Using Remote Sensing and Advanced Data Assimilation Techniques

Steven A. Margulis and Michael Durand
Department of Civil and Environmental Engineering
UC Los Angeles

Snowmelt represents a significant contribution to California's annual water budget. Remote sensing represents the most efficient method for estimating the snow water equivalent (SWE) of snowpack in mountainous regions. However, its usefulness has been compromised by difficulties in discerning deep and/or wet snow as well as excluding vegetative cover when using traditional snow retrieval algorithms. We have designed and field-tested an assimilation approach which is capable of providing estimated SWE in cases of deep snow, wet snow, and light to moderate vegetative cover.

Like many semi-arid regions of the world, California depends on annual snowmelt for the majority of its water supply. However the primary method for estimating the amount of water stored in snow pack (snow water equivalent, SWE) still relies on field snow surveys. This approach is extremely limited since survey data are sparse point estimates which rely upon regression and comparison to historical measurements.

For the past several decades, researchers have been developing computer models which utilize remotely sensed snowpack data to estimate SWE. However these estimates can contain large uncertainty. For data 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 has motivated the development of the data assimilation approach used in this project.

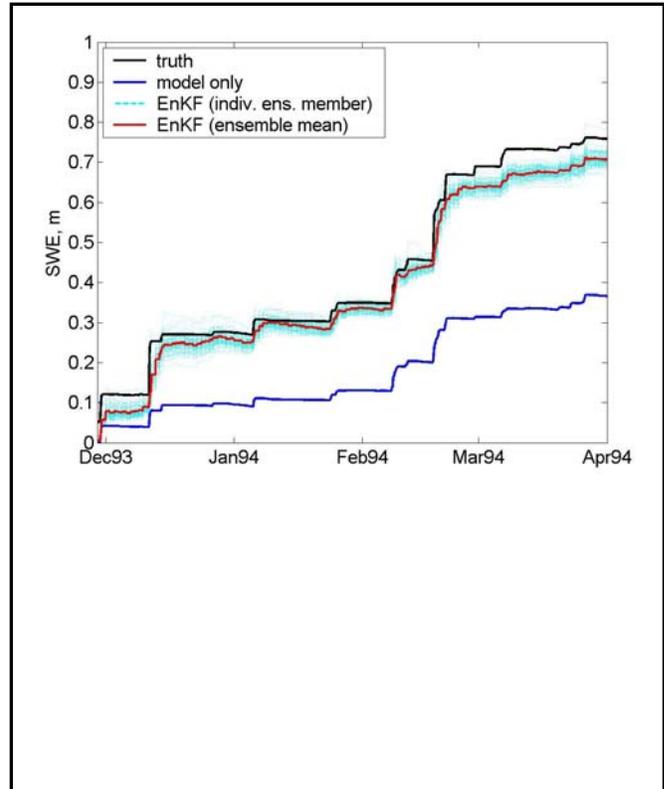
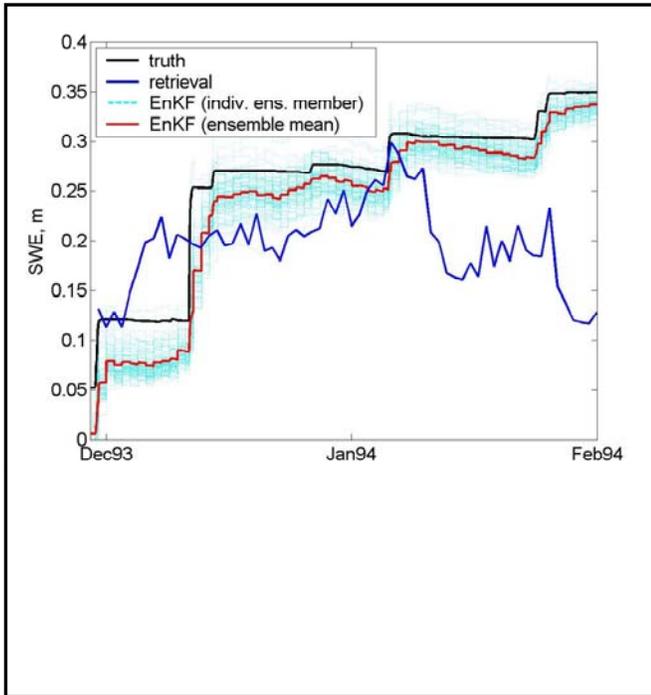
Data assimilation methods, such as the Ensemble Kalman Filter (EnKF) are used to merge remote sensing observations into a hydrologic model to produce estimates of SWE over the entire basin. The EnKF weighs the relative uncertainty of the model and of the observations and provides an estimate of the state variable as well as an estimate of its uncertainty. For this project, we have undertaken a feasibility study to estimate 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.

First, snow and remote sensing models were selected and developed that are appropriate for 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) which were found to be extremely important parameters in the radiative transfer (remote sensing) model. These model refinements should significantly improve SWE estimates. We have applied the model to data in the Mammoth Mountain region in the Sierra Nevada. These models have been embedded in a data assimilation framework (EnKF) to test their ability to estimate SWE from remotely sensed microwave radio-brightness observations.

Then, experiments at the point-scale were performed 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.

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 which are subject to large input errors due to sparsely collected data in remote mountainous regions. Our future work will extend the method to a spatially distributed basin-scale application.



Professional Presentations

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

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

Publications

Durand, M. and S.A. Margulis, Feasibility test of multi-frequency radiometric data assimilation to estimate snow water equivalent, *Journal of Hydrometeorology*, *accepted*.

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

For further information, please contact:

• **Dr. Steven A. Margulis**

e-mail: margulis@seas.ucla.edu

Phone: 310-267-5490

Webpage:

http://cee.ucla.edu/cgi-bin/peop_faculty.php?fpg=0&uid=20



Estuarine Landscape Modeling of Suisun Bay

David H. Schoellhamer and Neil G. Ganju
Department of Civil & Environmental Engineering
UC Davis

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 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. Once we have validated the model with short-term (<1 year) measurements of water depth, salinity, and sediment flux, we 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 then validate the long-term simulations using historical measurements of bathymetric change, which span from 1850 to 1990.

We have successfully configured a public-domain hydrodynamic model (Regional Oceanic Modeling System, ROMS; <http://marine.rutgers.edu/po/>) for Suisun Bay, and we are currently validating the model with tidal-timescale data in Suisun Bay. 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. We are in the process of validating the sediment flux calculations of the model with measurements made in 2004.

Once we have completed our validation tasks, we can simulate multiple scenarios of change. These will include changes in rainfall and snowpack, sediment supply, and water resource management. This provides a planning tool for assessing the response of estuarine habitats to changes in climatic and anthropogenic forcings. The restoration of marshes, mudflats, and estuarine communities will benefit from this predictive tool, thereby increasing the biological value of California.

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

Collaborative Efforts

The validation data from 2004 was collected by the U.S. 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.

For further information, please contact:

- Dr. David H. Schoellhamer
e-mail: dschoell@ucdavis.edu
Phone: 916-278-3126

Webpage:

<http://cee.engr.ucdavis.edu/faculty/schoellhamer/default.htm>



Future Regional Climate Change in the Ten Hydrologic Regions of California: A Climate Modeling Investigation

Lisa C. Sloan
Department of Earth Sciences
UC Santa Cruz

A regional climate model suggests that California's water reserves will be strongly impacted as atmospheric CO₂ emissions double pre-industrial levels within the next five decades. The model indicates annual mean temperatures increasing by at least 2° C, and both total precipitation and precipitation stored as snowpack decreasing. These effects will vary in amplitude across the ten hydrologic regions of California. For example, the greatest temperature increase will occur in the Sacramento River region, and the greatest decrease in precipitation will occur in the southernmost regions. Adapting to these changes will require significant changes in current water management practices, which will need to be specific to the changes occurring at the regional scale.

This study focuses on two questions: (1) how will anthropogenically driven climate change affect California's resources, especially the hydrologic resources, in the coming decades; and (2) what water resources will be available in the future, and at what times during the year (e.g., seasonality and amounts of rain and snow)?

To answer these questions, we apply a regional climate model (RCM) to a domain centered upon California. We specify atmospheric greenhouse gas concentrations as predicted by the Intergovernmental Panel on Climate Change (IPCC) for the next several decades, and calculate the climate that would likely occur under these conditions, as compared to modeled scenarios of present day climate.

Key findings include that a doubling of atmospheric CO₂ concentrations above pre-industrial values will lead to increased temperatures, decreased precipitation, and decreased snow accumulation across California. Model predictions show that for all ten of California's hydrologic regions, the median annual temperature increases from 2 to 4 °C in the future, with the greatest temperature increase occurring in the Sacramento River region. Median annual precipitation in the future will be reduced for the six southernmost regions of the state by up to 17%. Future annual snow accumulation decreases for all hydrologic regions. Decreases in snow accumulation, by volume, are greatest in the Sacramento River, the North Coast, and the San Joaquin River regions.

Our model results suggest that California will be strongly impacted by climate change. Increased temperatures may affect agricultural production, energy consumption, water consumption, human health, and ecosystems. Changes in precipitation and decreased snow accumulation may affect water storage and delivery, causing greater stress on a system already under significant pressure. Adaptation to these changes will likely necessitate significant changes in current water management practices.

Publications

Snyder, M.A., L.C. Sloan, and J.L. Bell, 2004. Journal American Water Resources Association, 40(3):591-601.

For further information, please contact:

• **Dr. Lisa C. Sloan**

e-mail: lcsloan@pmc.ucsc.edu

Phone: 831-459-3693

Webpage: <http://es.ucsc.edu/~lcsloan/>



Mount Shasta's Glaciers: An Endangered Resource?

Slawek Tulaczyk and Ian Howat
Department of Earth Sciences
UC Santa Cruz

We have documented a 30% elongation over the last five decades of one of Mt. Shasta's glaciers, the Whitney Glacier. This trend represents a scenario in which increased precipitation due to a warming Pacific Ocean can increase the spring snow accumulation at high elevations and, consequently, foster glacier growth. As lower elevation snow packs thin, higher elevation glaciers grow. Such a scenario would have far reaching impacts on the accurate assessment of California's snow reservoir during a warming climate.

Seasonal melt of Mt. Shasta's glaciers represents a significant dry season and drought period water source to north central California. Deterioration of these glaciers during a warming climate would have a significant impact on the water supply for the region. The latest climate models predict that northern California will warm by several degrees Celsius over the next century. If this prediction holds true, it is feasible that we may see a significant shrinkage or even a complete extinction of this glacier system in the next several decades. In this study we are assessing the stability of Mt. Shasta's glacier system through temporal analysis of ice volume and modeling of its possible response to climate warming.

First, photogrammetric analysis revealed that glaciers on Mt. Shasta have increased in areal extent nearly continuously from the 1940's through the present day. The Whitney glacier, North America's most southerly valley glacier, advanced 850m, or approximately 30% of its length, since 1951 and continues to expand. Comparison with available meteorological data over the past century suggests that this expansion is linked to an increase in winter precipitation accompanied by a decrease in summer temperatures, resulting in a positive annual snow balance. While there has also been an increase in winter temperature, resulting in a thinner spring snow pack at lower elevation, the high elevations of the glaciers are insensitive to this warming, remaining below the freezing level for most of the winter.

Second, field measurements of mass balance, ice thickness and velocity provide parameters for numerical models. Several methods were employed for field data collection, including high-precision GPS, ground penetrating radar, and sonic distance metering.



Fieldwork on the Hotlum Glacier.

Based on these field parameters, we constructed a numerical model of glacier flow, calibrated using the 100 year record of glacier length and concurrent meteorological data. This model was used to examine glacier sensitivity to potential warming scenarios. At current temperature trends, it is likely that high elevation glaciers will continue to increase in size due to increasing precipitation. However, these results stand in contrast to predictions of a regional climate model that suggest disappearance of the glaciers in the next 50-100 years as temperatures increase.

The trend we have observed is significant because it presents a scenario in which climate warming may result in increased spring snow accumulation at high elevations and glacier growth. This would have far reaching implications for assessments of the impact of climate change on California's snow reservoir.

Professional Presentations

Howat, I.M., S. Tulaczyk, M. Snyder, L.C. Sloan, California's Snow Gun, AGU Fall Meeting, San Francisco, CA., December 9, 2003.

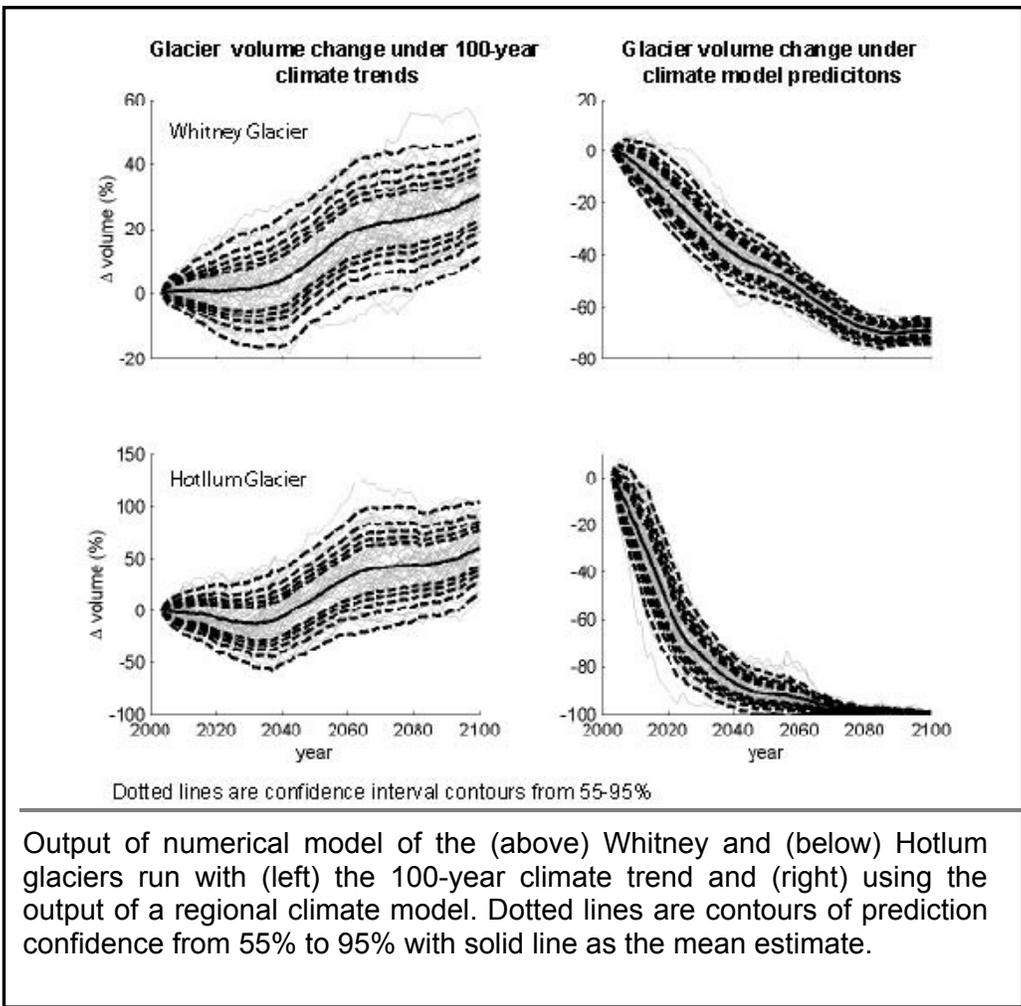
Howat, I.M., S. Tulaczyk, Trends in California's snowpack under warming. California Energy Commission Conference on Climate Change, Sacramento, CA., May 28th, 2004

Publications

Howat, I. M., and S. M. Tulaczyk (in press), Trends in California's snow water volume over a half century of climate warming, Ann. Glaciol., 40.

For further information, please contact:

- Dr. Slawek Tulaczyk
e-mail: tulaczyk@pmc.ucsc.edu
Phone: 831-459-5207
Webpage: www.es.ucsc.edu/~tulaczyk
- or
- Ian Howat
e-mail: ihowat@pmc.ucsc.edu





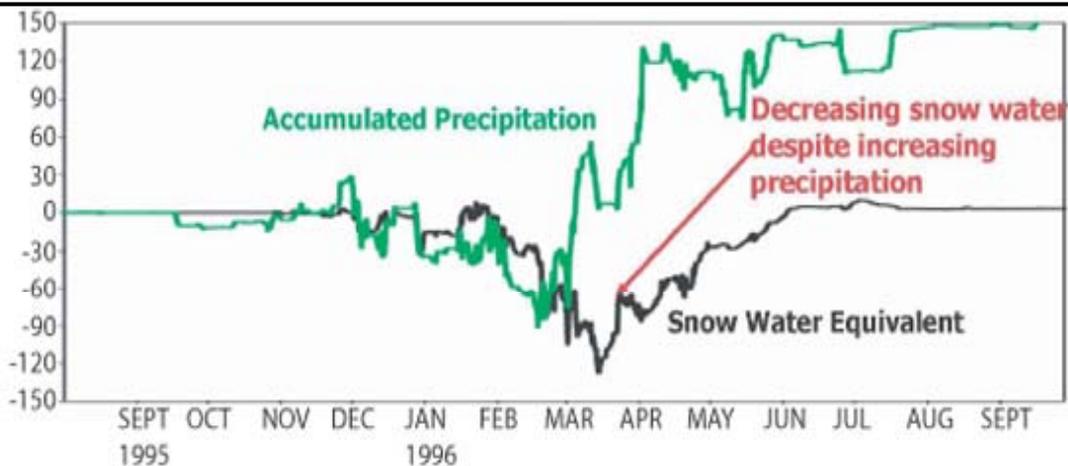
California-2100: Assessing California's Future Water Resources

Bryan C. Weare and Hui Du
Department of Land, Air and Water Resources
UC Davis

As a preliminary step in providing high resolution estimates of California's water budget out to the year 2100 (Cal21), several different climate change scenarios were analyzed based on results obtained with the widely used regional model MM5. The results of the primary experiment, in which all present day irrigated and urban areas are replaced by scrub land, indicate that the surface temperatures in the Central Valley would be lower while those of the higher elevation foothills would be higher. As a result, a smaller fraction of incoming precipitation would be stored as snow above the 1000 m elevation level than is currently stored.

This study initiated a long-term modeling project, 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 on estimating the effects of increased irrigation in California over the past century on regional climate, especially snow accumulation.

The utilized regional model is the widely used MM5 running at 30km grid spacing and having 45 levels. The outer boundaries, which are placed in the central Pacific Ocean and the Midwestern United States, are from the ERA-40 reanalysis. Currently, we have made seven runs for the period 1 August, 1995- 30 September, 1996. The outputs are stored in netcdf format for easy storage and comparisons.



Results of primary experiment modeling California's snowpack above 1000m based on parameters of the presence of shrub land in place of irrigated agriculture and urban areas (minus control).

Initial statistical comparisons of the output of these model runs have been made with the NCEP North American Regional Reanalysis (NNRR) and other observations for the California region. Six present-day MM5 runs with slightly different parameterizations of rainfall and the planetary boundary layer have been run. In general, these runs simulate well the observed patterns of variation of precipitation and surface temperature. However, the simulated surface temperatures are approximately two degrees Centigrade colder than the NNRR nearly everywhere.

Then, in the primary experiment, all of the present day irrigated and urban areas are replaced by scrub land. Our preliminary results indicate that the climate of an un-irrigated California would have lower Central Valley and higher foothill temperatures (see Figure above). Associated with the greater high altitude temperatures is a smaller fraction of precipitation remaining as snow.

Professional Presentations

Weare, B. C., Global Climate Change in the Past Century: Focus on California Climate Change: Challenges and Solutions for California Agricultural Landscapes, UC Davis, May 12, 2005.

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

Collaborative Efforts

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

For further information, please contact:

- **Dr. Bryan C. Weare**

e-mail: [bcweare at ucdavis dot edu](mailto:bcweare@ucdavis.edu)

Phone: 530-752-3445

Webpage:

http://lawr.ucdavis.edu/directory_facultypages.php?id=32

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 work on the classification, transport and impact of contaminants and pollutants. Also included in this category are studies of the use of artificial ecosystems for water reclamation, fundamental investigations related to wetland management, studies of the impact of land use practices on aquatic habitats and reconstruction ecology.





Nutrient Loading and the Invasion of Giant Reed (*Arundo donax*) into California's Riparian Ecosystems

Richard Ambrose

Department of Environmental Health Sciences
UC Los Angeles

Giant reed (*Arundo donax*) is an invasive alien species that has dramatically altered the physical and ecological setting of many southern Californian riparian zones. The distribution of giant reed has been strongly affected by anthropogenic impacts on the fluvial landscape such as nutrient loading of stream water. In addition, we recently documented stimulation of the growth of *A. donax* due to fire in riparian ecosystems of the Santa Clara River. Within a few months of a very extensive wildfire during October, 2003, giant reed quickly re-grew in comparison to native vegetation and became dominant across the

Giant reed (*Arundo donax*) is rapidly invading riparian ecosystems along rivers in Mediterranean-type climates, including California. Its aggressive invasion into southern California's riparian ecosystems has resulted in extensive stands or monocultures in some places, causing serious physical and biological problems. Giant reed increases risks of flooding, creates a fire hazard, out-competes native species for scarce water resources, and reduces the value of riparian habitat for wildlife.

Natural and human disturbance have played a large role in its successful invasion. However, natural disturbance along streams in California is not a new phenomenon, with most anthropogenic disturbance dating back much earlier than the onset of giant reed invasion in California. Thus, other factors must contribute to the success of this plant's invasion. One of the main human impacts on California's watersheds is the increased delivery of nutrients from anthropogenic sources. Since soils of mediterranean-type climates generally have much lower nutrient concentrations than other regions of the world, recent nutrient loading of freshwater systems is hypothesized to be one of the main factors contributing to giant reed's invasion in California.

We investigated the influence of increased anthropogenic nutrient loading on the invasion of *A. donax* throughout several rivers of coastal southern California. At a watershed-scale, we evaluated nutrient levels in shallow groundwater, soil and plants located within patches of either *A. donax* or native riparian vegetation. Sampling design was stratified by watershed and land use type to understand the relationship between *A. donax* abundance and land use. Effect of location with respect to geomorphic landform was also analyzed. Nutrient levels in shallow

groundwater and plant tissue were highest in the more developed watersheds, adjacent to agricultural land. After extensive wildfires swept through southern California in October 2003, we extended our work to study feedbacks between *A. donax* and wildfire. Besides native shrubs, over 600 acres of riparian vegetation on fluvial terraces and floodplains were also burned along the Santa Clara River and its tributaries. Although fire is a natural component of the native shrubland ecosystems, riparian ecosystems are thought to be barriers to fire. We used this natural disaster as an opportunity to study the role of *A. donax* in the spread of wildfire across southern California watersheds and the contribution of fire to invasion of *A. donax* into watersheds.

Results of the fire study indicate that *A. donax* has changed fire behavior in the Santa Clara River watershed and that fire is an important factor contribut-



Sampling groundwater along Santa Clara River, near *Arundo donax* stand.

ing to *A. donax* invasion on riparian terraces. This was the largest recorded aerial extent of fire in riparian ecosystems of the Santa Clara River in history. New fire behavior was documented, both bridge and highway effects, in the Santa Clara River watershed. In addition, fire stimulated growth of *A. donax* in riparian ecosystems of the Santa Clara River. Due to its quick regrowth after the fire compared to native vegetation, *A. donax* was able to dominate these burned riparian ecosystems within a few months after the fire.

Results of these analyses provide: (1) critical information on the main sources (land use types) of nutrients contributing to *A. donax* invasion, (2) locations of problematic *A. donax* populations in these watersheds, (3) descriptions of fire behavior in watersheds with *A. donax* infestations, and (4) data useful for the long-term control of *A. donax* in river systems.



Gretchen Coffman standing in burned riparian habitat with *Arundo donax* regrowth

Publications

Coffman, G.C., R.F. Ambrose, and P.W. Rundel. 2004. Invasion of *Arundo donax* in river systems of Mediterranean climates: causes, impacts and management strategies. Proceedings 10th MEDECOS Conference. Arianoutsou & Papanastasis (eds) Millpress, Rotterdam.

Professional Presentations

Coffman, G.C., R.F. Ambrose, and P.W. Rundel. Invasion of *Arundo donax* in river ecosystems of Mediterranean climates: causes, impacts and management strategies. 10th MEDECOS Conference Rhodes, Greece, April 25-May1, 2004.

Coffman, G.C., T. Dudley, P.W. Rundel and R.F. Ambrose. Are we creating the ideal conditions for

Arundo donax invasion in California? Cal-IPC, Chico, California, 2005.

Collaborative Efforts

Thomas Dudley, UC Santa Barbara. Additionally, support was provided by the California State Coastal Conservancy, the Fruitgrowers Laboratory (Santa Paula, CA), and the DANR Laboratory at UC Davis.

For further information, please contact:

- Dr. Richard Ambrose
e-mail: rambrose@ucla.edu

Phone: 310-825-6144

Webpage:

<http://www.ph.ucla.edu/ehs/ambrose.htm>

or

- Dr. Gretchen Coffman
e-mail: gcoffman@ucla.edu



Hydrological Regimes, Pond Morphology, and Habitat Use: Predicting the Impact of an Emerging Aquatic Pathogen

Cheryl Briggs
Department of Integrative Biology
UC Berkeley

Chytridiomycosis, a newly-identified fungal disease of amphibians, is leading to rapid die-offs of mountain yellow-legged frog populations in some parts of the Sierra Nevada, but not in other sites where frogs persist with only mild fungal infections. Our data indicate that this spatial difference in disease outcome is not due to differences in fungal virulence or frog susceptibility, and now we are exploring other potential causative factors including characteristics of the physical environment such as pond morphology and hydrologic regime.

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.

We are exploring a number of factors, including: (a) differences in pond morphology or topography of the landscape in different areas that result in the frogs using the habitat differently at the different sites, altering their risk of acquiring and succumbing to the disease; (b) differences in the transmission, infectivity, and/or virulence of the fungal strains at the different sites; or (c) differences in susceptibility of the frog genotypes at the different types of sites which could lead to the observed differences in the impact of the fungal pathogen. As part of (c) we are investigating the effects of antimicrobial peptides, which are released from the frog skin, which may determine the frogs' susceptibility to disease.

During the summers of 2004 and 2005 we conducted detailed surveys 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

used a newly-developed, non-destructive, quantitative PCR protocol 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 found 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. Interestingly, at the persistent infected sites, some adult *R. muscosa* were found to lose the infection through time, and some infected individuals survived over the long overwintering period. Data are still being gathered on hydrological regime, pond morphology, and habitat use.

Prior laboratory experiments found no evidence that differences in fungal strains are responsible for the different population-level impacts of the disease at the different sites.

In recent experiments we investigated variability the susceptibility of *R. muscosa* to *B. dendrobatidis*, concentrating on the impacts of antimicrobial peptides in the frogs' defense against disease. We exposed subadult *R. muscosa* to different quantified doses of *B. dendrobatidis*. In some treatments we removed the antimicrobial peptides from the frogs prior to exposure to *B. dendrobatidis*, and in other treatments the peptides were not removed. It was predicted that if antimicrobial peptides served to defend the frogs against the disease, then individuals from which peptides had been removed prior to exposure would be more likely to become infected. However, we found absolutely no difference between the fractions of individuals that became infected after peptide removal versus those that were exposed to the same dose without prior peptide removal. This suggested that the

antimicrobial peptides are not sufficient to protect *R. muscosa* from chytridiomycosis in even a simple experimental situation, and therefore that differences in antimicrobial peptide production between sites is unlikely to be responsible for the observed differences in the population-level impacts of this disease.

Publications

Briggs, C.J., V.T. Vredenburg, R.A. Knapp, and L. J. Rachowicz., Investigating the population-level effects of chytridiomycosis, an emerging infectious disease of amphibians, Ecology, in press.

Rachowicz, L. J., Transmission of an emerging infectious disease in a declining amphibian species: *Batrachochytrium dendrobatidis* in the mountain yellow-legged frog (*Rana muscosa*), Ph.D. Dissertation, University of California, Berkeley, 2005.

Professional Presentations

Briggs, C. J., Investigating the population-level effects of chytridiomycosis, a fungal disease of amphibians, Invited Seminar, Oregon State University, Zoology Department, Corvallis, OR, October 17, 2004

Briggs, C. J., Investigating the population-level effects of chytridiomycosis, a fungal disease of amphibians, Invited Seminar, Arizona State University, Department of Mathematical Biology, Tempe, AZ, November 10, 2004

Briggs, C. J., Host-pathogen population dynamics, of chytridiomycosis and mountain yellow-legged frogs in the Sierra Nevada Mountains, California, Integrative Research Challenges in Environmental Biology grant meeting, Tempe, AZ, November 11, 2004

Briggs, C.J., Host-pathogen population dynamics, of chytridiomycosis and mountain yellow-legged frogs in the Sierra Nevada Mountains, California, California/Nevada Declining Amphibian Population Task Force Meeting, Berkeley, CA, January 14, 2005

Briggs, C. J., Investigating the population-level effects of chytridiomycosis, a fungal disease of amphibians, Invited Seminar, San Francisco State University, Biology Department, San Francisco, CA, May 3, 2005

Briggs, C. J., Investigating persistence of a chytrid fungal disease of amphibians, Invited Seminar, Ecology and Evolution of Infectious Diseases Meeting, Fort Collins, CO, May 19, 2005

Briggs, C. J., "Investigating the population-level effects of chytridiomycosis in mountain yellow-legged frogs", Invited Symposium Presentation International Union of Microbiological Societies, San Francisco, CA, July 25, 2005

For further information, please contact:

- **Dr. Cheryl J. Briggs**

e-mail: cbriggs@berkeley.edu

Phone: 510-643-3889

Webpage:

<http://socrates.berkeley.edu/~cbriggs/>



Structure and Seasonal Changes of Nematode Communities from Vernal Pools of The Santa Rosa Plateau

Paul De Ley
Department of Nematology
UC Riverside

Vernal pools typically contain endemic, often endangered, flora and fauna. During this first study of nematode communities in these ephemeral wetlands, we found a diverse nematode fauna reflecting healthy soil and aquatic ecosystems. During the hot and dry summer months, when the vernal pools within southern California's Santa Rosa Plateau evaporate, plant remains serve as important refugia for nematodes. While it was initially feared that some nematode populations might pose a significant risk to endangered species of plants and fairy shrimp within the vernal pools, we found no evidence of predation of fairy shrimp cysts by the few parasitic nematode species identified.

Vernal pools are ephemeral wetlands, typically with a diverse and highly adapted flora and fauna. We are conducting the first nematode survey on record for this ecologically important habitat. After two years of sampling the soils in and around each of two vernal pool basins in the Santa Rosa Plateau Ecological Reserve, our results show that their nematode fauna is healthy and diverse, and that adjacent ephemeral pools can have unique microscopic soil communities. These findings suggest that nematode communities can be used to monitor the ecosystem health of these pools over time.

During this study we isolated an estimated 51 nematode genera, including at least 62 species. Detailed statistical analysis of the 2003-04 sample series confirms that the two sampled pools differ substantially in the composition and dynamics of their nematode communities. Significant differences were observed between and among the four sample locations, three sample dates and two extracted sample fractions (soil fraction versus root and plant debris fraction). This includes two sample series collected during the rare full inundation of the pools.

Differences in spatial and temporal abundance patterns were significant across nematode genera. During the dry summer phase, roots and dry plant debris on the soil surface of the pool beds play an important role as refugia for omnivorous, bacterivorous and phytoparasitic nematodes. Adults of large nematodes in genera such as *Dorylaimus* and *Labronemella* congregate preferentially in dead plant material, perhaps not only in response to drought but also because of the fine texture of the underlying soil. Surprisingly, "aquatic" genera such as *Tobrilus* persist throughout the dry phase, especially in plant debris.



Live nematode adults (*Dorylaimus*) extracted from the soil of a vernal pool, Santa Rosa Ecological Reserve, Spring 2005.

Additionally, our research showed no indication that nematode parasitism or predation poses a threat to the endangered plants and fairy shrimp in either of the pools we studied. Our work provides the first data on such possible predation or parasitism of the endemic vernal pool flora and fauna by nematodes. We have also conducted laboratory experiments using predatory nematodes from the vernal pools to test whether they feed on cysts of cultured fairy shrimp. No predation was observed in the lab setting, although it is possible our experiments need to be modified to more closely reflect natural conditions.

Professional Presentations

De Ley, P., I. Tandingan De Ley, S. Esfahani and J. Abolafia. Nematode communities from two vernal pools in the Santa Rosa Plateau Ecological Reserve,

California. Rhizosphere 2004, Munich, Germany September 12-17th 2004.

De Ley, P., I. Tandingan De Ley, M. Yoder, S. Esfahani, K. Carter and J. Abolafia. Nematode communities from two vernal pools in Santa Rosa Plateau Ecological Reserve, California. 45th Annual Meeting of the Society of Nematologists. Fort Lauderdale, FL July 9-13th 2005.

Collaborative Efforts

Frozen nematode intestines will be analyzed in collaboration with Dr. Marie Simovich (University of San Diego) to check for the possible presence of fairy shrimp DNA. As part of updated permit requirements,

all fairy shrimp cysts collected this past year were deposited with Dr. Simovich.

For further information, please contact:
• **Dr. Paul De Ley**
e-mail: paul.deley@ucr.edu
Phone: 951-827-2280
Webpage:
<http://faculty.ucr.edu/~pdeley/lab/labhome.html>



Soil samples being collected from the edge of a large, fully-inundated vernal pool, March 2005.



Pyrethroid Insecticides in Nursery Runoff: Transport and Impact on Aquatic Invertebrates

Jay Gan
Department of Environmental Sciences
UC Riverside

Synthetic pyrethroids, used by agriculture as insecticides, are toxic to aquatic organisms, especially invertebrates. We have found that the actual toxicity of pyrethroids within irrigation run-off is reduced in the presence of suspended solids and dissolved organic matter (DOC). This inhibition of pyrethroid toxicity results from its ready absorption onto suspended solids and DOC. This suggests that any water quality criteria developed to delimit the amount of pyrethroids acceptable within freshwater systems should be based on monitoring its concentration dissolved in the liquid phase, since the bioavailability of pyrethroids absorbed on solids and DOC is greatly reduced.

The research focus of this project is to evaluate the behavior and ecotoxicological effects of synthetic pyrethroids in runoff on aquatic organisms. Synthetic pyrethroids are widely used insecticides in both urban and agricultural environments. The use of pyrethroids is likely to increase further as the use of some popular organophosphates is restricted.

Pyrethroids display high toxicity to a wide range of aquatic organisms including invertebrates. However, due to their strong affinity to absorb to sediment and soil particles, pyrethroids are expected to partition between the solid and the dissolved phase in runoff or stream effluents. Because only the dissolved chemical concentration is considered bioavailable, the actual toxicity of pyrethroids may be regulated by the level and properties of the suspended solids and dissolved organic matter (DOM) present in runoff. However, current water quality programs require that the whole effluent is extracted and the total chemical concentration of the pyrethroids is determined. Such practices will likely result in erroneously high estimates of toxicity.

With the support of this grant, we developed a solid phase microextraction (SPME) method that offers selective detection of the dissolved concentration. We further evaluated the application of this method for biomimetic sampling. This method has been used to study the phase distribution of a number of pyrethroids in water systems containing suspended solids. We have demonstrated that in runoff effluents containing suspended solids at 100 mg/L, a significant fraction of pyrethroids was associated with the solid phase and (DOM). The freely dissolved concentration was

inversely proportional to the content of suspended particulates and DOM. Using ¹⁴C-labelled compounds, we further found that bioaccumulation of pyrethroids decreased with increasing levels of suspended solids. Using EPA protocols, we showed that the acute toxicity of pyrethroids in sediment suspensions decreased with increasing levels of suspended particulates and DOM. It appears that both the amount and properties of suspended solids and DOM affect the bioavailability and toxicity of pyrethroids. The inhibitory effect of suspended solids and DOM on bioavailability and toxicity should be considered in monitoring efforts as well as in establishing water quality standards for pyrethroid compounds.

Collaborative Efforts

We have closely collaborated with a range of stakeholders in carrying out this project. Our collaborators include nursery growers in Orange and Ventura Counties, farm advisors, and regulatory agencies (e.g., SWRCB, Santa Ana RWQCB, CDP). We have collaborated extensively with the following individuals/entities:

John Kabashima, UCCE Orange County; Darren Haver, UCCE Orange County; Julie Newman, UCCE Ventura County; Dr. Inge Werner, Aquatic Toxicology Laboratory, UC Davis; Dr. Daniel Schlenk, Department of Environmental Sciences, UC Riverside; Doug Shibberu, Santa Ana RWQCB; Frank Spurlock, CDP, (Sacramento); Kean Goh, CDP, (Sacramento); FMC Incorporation, Specialty Product Group, Princeton, NJ; and the Pyrethroid Workgroup (PWG)

Publications

Lee, S.J., J. Gan, W.P. Liu, and M.A. Anderson, Evaluation of K_d underestimation using solid phase microextraction, *Environmental Science & Technology* 37: 5597-5602, 2003

Lee, S.J., J. Gan, J.S. Kim, J.N. Kabashima, and D. Crowley, Microbial transformation of pyrethroid insecticides in aqueous and sediment phases. *Environmental Toxicology and Chemistry* 23: 1-6, 2004

Liu, W.P., J. Gan, S.J. Lee, and J.N. Kabashima, Phase fractionation of pyrethroids in runoff and stream water, *Environmental Toxicology and Chemistry* 23: 7-11, 2004

Kabashima, J.N., S.J. Lee, D.L. Haver, L. Wu, K. Goh, and J. Gan, Pesticide runoff and mitigation at a commercial nursery site, In Gan, J., P. Zhu, S.A. Aust, and A.T. Lemley (eds). *Deactivation and Detoxification of Biocides and Pesticides*. ACS Symposium Series, ACS: Washington, DC, pp. 213-230, 2004

Gan, J., S.J. Lee, W.P. Liu, D. Haver, and J.N. Kabashima, Distribution and persistence of synthetic pyrethroids in runoff sediments, *Journal of Environmental Quality* 34: 836-841, 2005

Professional Presentations

Gan, J. Underestimation of K_d measurement for hydrophobic chemicals, Annual American Society of Agronomy Meetings, November 2-6, 2003. Denver, Colorado (talk).

Gan, J., S.J. Lee, D.L. Haver, J.N. Kabashima, and L. Wu, Pesticides in nursery runoff: assessment and mitigation, Annual American Society of Agronomy Meetings, November 2-6, 2003. Denver, Colorado (poster).

Gan, J., and S.J. Lee, How persistent are those pyrethroids? SETAC 24th Annual Meeting in North America, November 9-13, 2003. Austin, TX (poster).

Gan, J., W. Yang, M.A. Irwin, and W.P. Liu, Synthetic pyrethroids: bioavailability in surface water, ACS 227th National Meeting. March 28-April 1, 2004, Anaheim, CA (talk)

Gan, J., J.N. Kabashima, D. Haver, and L. Wu, Management practices for mitigating pesticide runoff from nurseries, ACS 227th National Meeting. March 28-April 1, 2004, Anaheim, CA (invited talk)

Gan, J., Bioavailability of synthetic pyrethroids in surface water system, Chemical Society of Canada Annual Meetings, June 1, 2004, London, Canada (Invited talk).

Gan, J., and W. Yang, Bioavailability of synthetic pyrethroid insecticides in surface water, The 1st International Internal Exposure Workshop, August 21-26, 2004, Ascona, Zurich. (Poster, won best poster award).

Gan, J., Bioavailability of synthetic pyrethroids in surface streams, September 14, 2004, Mid-Atlantic Pesticide Metabolism Discussion Group Annual Dinner Meeting, Fort Washington, PA (invited feature presentation).

Gan, J., W. Yang, and W. Hunter, Chemical methods for measuring bioavailability, Southern California SETAC Annual Conference, Loyola Marymount University, Los Angeles, CA, May 20-21, 2005.

Gan, J., W. Yang, and W. Hunter, Polymer fibers to measure bioavailable concentrations, 88th Canadian Chemistry Conference and Exhibition. Saskatoon, CA, May 28-June 1, 2005.

Hunter, W., W. Yang, and J. Gan, Bioavailability of permethrin in sediments estimated with solid phase micro-extraction (SPME), Southern California SETAC Annual Conference, Loyola Marymount University, Los Angeles, CA, May 20-21, 2005. (Student poster award)

Yang, W., W. Hunter, and J. Gan, Bioavailability of synthetic pyrethroids in surface water, Southern California SETAC Annual Conference, Loyola Marymount University, Los Angeles, CA, May 20-21, 2005. (Poster)

For further information, please contact:

• **Dr. Jay Gan**

e-mail: jgan@ucr.edu

Phone: 951-827-2712

Webpage:

<http://www.envisci.ucr.edu/index.php?file=faculty/gan/gan.html>



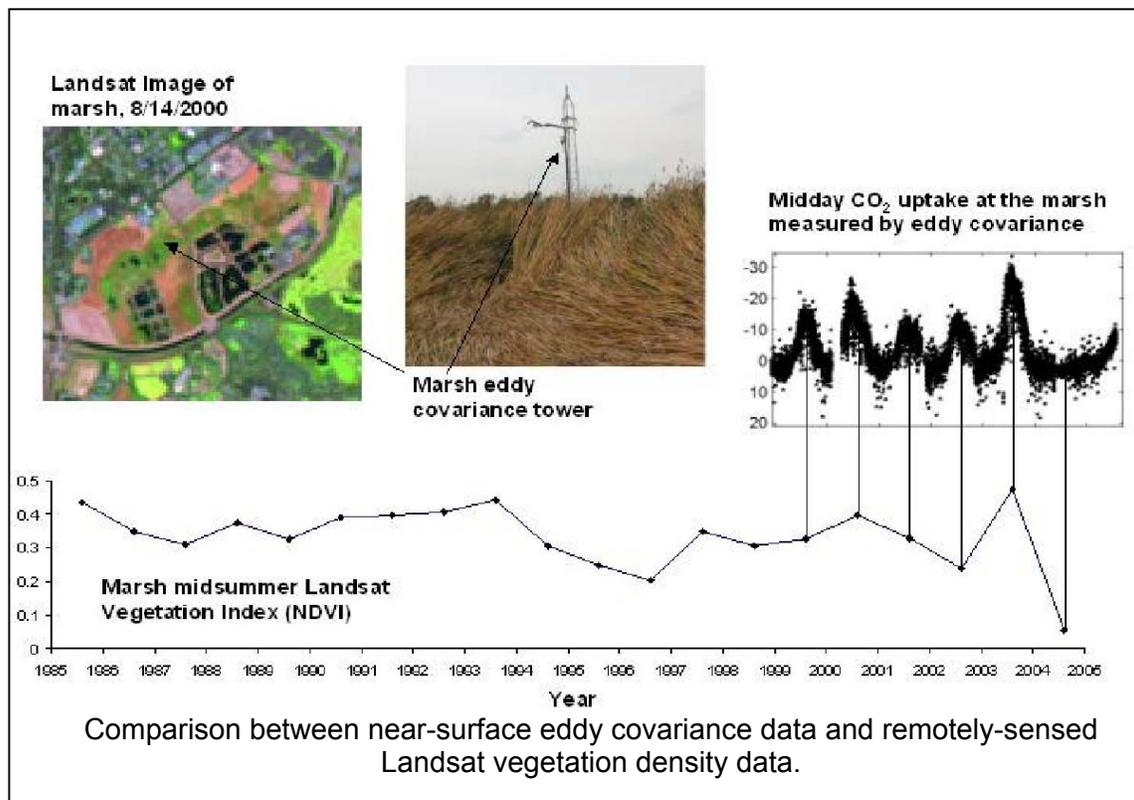
Spatial and Temporal Patterns of Wetland Evapotranspiration, Primary Production, and Nutrient Cycling

Michael Goulden and Adrian V. Rocha
Department of Earth System Science
UC Irvine

Use of the eddy covariance technique showed that the primary productivity of a small southern California marsh's vegetation changed dramatically from one year to the next over a six-year period. In order to understand the causes and consequences of these interannual shifts, a 20-year record of Landsat images of the marsh were compiled. The corresponding six year period of Landsat data, which provides a measurement of the actual vegetation areal extent, agreed with measurements of primary productivity made on-site. This strong correlation allowed us to determine that large annual fluctuations of marsh productivity were not atypical at a decadal time scale.

The biological, chemical and physical processes that control the carbon, nutrient and water cycles of California's wetlands remain poorly understood. We are working at southern California'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 UCI's campus, allowing easy access for research and facilitating student training.

Our research uses the eddy covariance technique to measure the exchanges of CO_2 (F_{CO_2}) and water vapor (evapotranspiration, E) between the atmosphere and a few hectare patch of marsh. Measurements at the marsh since 1999 indicate the marsh's CO_2 exchange fluctuates dramatically from one year to the next, with high photosynthetic uptake in summer 2000 and 2003, moderate uptake in 1999, low uptake in 2001, 2002, and 2005, and extremely low uptake in 2004. The midsummer rate of evapotranspiration also fluctuates dramatically, with high E in 2000 and 2003, moderate E



in 1999, low E in 2001, 2002, and 2005, and negligible E in 2004. The interannual shifts in F_{CO_2} and E are only partially a result of variation in flooding. While the extremely low rates of CO_2 uptake and evaporation observed in 2004 were a result of drainage to reduce mosquito habitat, the low rates observed in 2001, 2002, and 2005 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.

The primary goal of our UC WRC grant is to understand the causes and consequences of these interannual shifts. Much of our work during the last year has focused on using remotely-sensed data to place these oscillations into a larger context. Photosynthesis and evaporation are positively coupled through the density of green vegetation – years with high F_{CO_2} and E also have dense vegetation. The density of vegetation can be estimated from measurements made by the Landsat satellite. Recently, a continuous 20-year record of Landsat images for the marsh was assembled and calibrated. These 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.

Using this technique, we observed excellent agreement since 1999 between the NDVI and the simultaneous measurements of F_{CO_2} and E at the marsh – years with high F_{CO_2} and E also have a high NDVI. The longer

twenty-year record of NDVI recorded by the Landsat imagers was then analyzed to document oscillations in marsh activity. This analysis provided evidence that the patterns observed since 1999 are not atypical for the San Joaquin Marsh. Moreover, a tool developed from this methodology is being used to determine whether other wetlands also show large year-to-year oscillations. 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

Collaborative Efforts

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

For further information, please contact:

• **Dr. Michael Goulden**

e-mail: mgoulden@uci.edu

Phone: 949-824-1983

Webpage:

www.ess.uci.edu/~goulden/Marshproductivity.html

or

• **Adrian V. Rocha**

email: arocha@uci.edu

Webpage:

<http://essgrad.ps.uci.edu/~arocha/>



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

Michael Johnson
John Muir Institute of the Environment
UC Davis

Based on the annual growth rate and stable nitrogen isotope composition of trees growing adjacent to salmon streams, we have developed a model which has reliably reconstructed historic salmon abundances and returns to a Northern California stream over a 20-year period. We are currently expanding the geographic extent of our investigations. Additionally, we are refining our nitrogen extraction technique to improve our model's accuracy.

Although it is generally accepted that anadromous Pacific salmon and trout populations have declined throughout California, trends for individual watersheds are largely based on anecdotal information and provide little basis for estimating the true extent of the decline. This is especially true in small coastal watersheds where continuous records of salmon escapement (i.e., the number of fish that return to freshwater to spawn) seldom 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 fortunate result of feeding in the marine environment is that the bodies of adult anadromous salmon are uniquely enriched with 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 salmon return to their natal streams and die after spawning, these heavy isotopes are liberated during carcass decomposition and incorporated into aquatic and terrestrial food web.

Our results to date indicate that trees growing adjacent to spawning streams readily sequester and incorporate marine-derived nitrogen ($\delta^{15}\text{N}$) when available. In fact, annual tree growth, $\delta^{15}\text{N}$, and percent nitrogen content have all been found to positively correlate with the number of salmon returning to spawn in a given year. By determining the stable nitrogen isotope composition ($\delta^{15}\text{N}$) of annual growth rings from extant riparian trees, we are able to infer changes in salmon abundance over time and model historic salmon returns for periods where no such information exists.

Over the past year we have expanded our project to field sites in the Salmon River (Siskiyou County) and

Waddell Creek (Santa Cruz County) watersheds. In addition to supporting important salmon runs, these California basins contain the requisite combination of mature trees and periods of known salmon escapement that permit us to validate our tree ring reconstructions.

In the laboratory, we continue to improve our ability to extract and quantify nitrogen isotopes from wood samples. Research has demonstrated that nitrogen



Salmon carcasses contain nearly all the nutrients essential for plant growth and often provide a large fraction of the nitrogen sequestered by riparian trees.

molecules can be highly mobile in the xylem of some tree species and such mobility can potentially cloud interpretation of nitrogen availability at the time of ring formation. To that end, we are investigating methods to remove soluble forms of nitrogen (primarily sap residues) prior to stable isotope analysis.

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 would 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.

Collaborative Efforts

Dr. Mike Bradford, Fisheries and Oceans, Canada, and Simon Fraser University



Collecting an increment core (tree ring) sample from a riparian coast redwood tree

For further information, please contact:

- **Dr. Michael Johnson**
e-mail: mbjohnson@ucdavis.edu
Phone: 530-752-8837
Webpage:
<http://johnmuir.ucdavis.edu/aeal/index.html>



Temporal and Spatial Linkages Between Watershed Land Use and Wetland Vegetation Response, Elkhorn Slough, Monterey County, CA

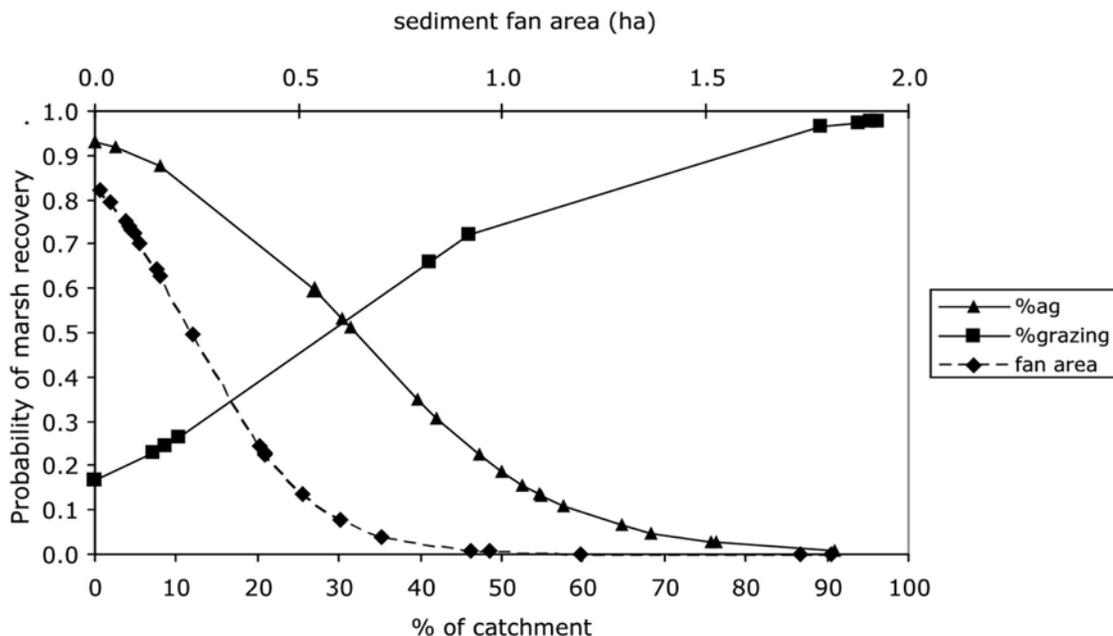
Maggi Kelly
Department of Environmental Science, Policy and Management
UC Berkeley

Elkhorn Slough supports one of California's largest coastal marshes, which is protected as an ecological reserve. More than three decades of upstream farming in a watershed characterized by steep topography and sandy soils have produced significant sedimentation, which has formed sandy fans in the salt marsh. As these fans have grown, salt marsh vegetation has converted to riparian willows. Salt marsh recovery depended on the type of land use in individual catchments, with more grazing and less farmland leading to better chances of recovery.

Elkhorn Slough supports one of the largest coastal marshes in California and contains a NOAA estuarine research reserve and other protected lands. Agriculture, specifically strawberry farming, has increased dramatically in the watershed since 1970. This land use change has led to sedimentation in the slough and the growth of sediment fans in the salt marsh over several decades. The goal of this project was to determine how watershed land use change over

30 years influenced changes in salt marsh soil physical/chemical properties, and in turn, plant composition through the use of remote sensing, GIS and field methods.

Historical aerial photo change detection revealed a shift in wetland species in response to sedimentation. Sedimentation caused arroyo willow (*Salix lasiolepis*) encroachment into pickleweed-dominated (*Salicornia*



Probability of salt marsh recovery from sedimentation according to 1980 land use and sediment fan size, based on fitted logistic regression models. Sediment fan area is on the top X-axis and percent land cover in on the bottom X-axis.

virginica) salt marsh on 11 sediment fans, with willow gain of 4.75 ha and salt marsh loss of 2.34 ha. A multiple-decadal analysis provided information about transitional stages of plant community succession

Changes in salt marsh properties were investigated in the field to explain vegetation zonation patterns of arroyo willow, cattail (*Typha* spp.), and pickleweed on sediment fans. Fan development increased elevation at least 2/3 meter above the marsh plain and increased topographic variability. Deposition of sandy sediment led to higher elevation, higher soil bulk density, lower salinity, lower soil moisture, and lower soil nitrogen, compared to reference sites.

The high sand content of the transported sediment likely influenced changes in these soil properties. Willow expansion was limited by environmental thresholds, which included elevation of at least 1.8 meters NAVD88 where tidal influence existed, spring soil moisture less than 20% and salinity less than 3 dS/m year-round. Overall, increased sedimentation within a watershed defined by highly erodible sandy soils and steep topography led to a shift in the type of wetland that could be supported downhill of agriculture.

Present-day sediment fan size was explained by historical catchment landscape and land cover characteristics in multiple regression models, with large catchment characteristics (>10 ha) being stronger predictors of fan size ($R^2 = 0.96$). Salt marsh recovery potential increased with more grazing and less farmland. Results indicate a time-lag between land use change, sedimentation and wetland vegetation response. Results indicate a time-lag between land use.

Considerable efforts have been made by the Elkhorn Slough Foundation, the Natural Resources Conservation Service, the Monterey County Resource Conservation District, and other organizations to reduce soil erosion in the Elkhorn Slough watershed and improve wetland habitat. Findings from this study emphasize the importance of continuing efforts by these groups to estuarine conservation in central California.

Publications

Byrd, Kristin B., N. Maggi Kelly, and Eric Van Dyke, Decadal changes in a Pacific estuary: a multi-source remote sensing approach for historical ecology, *GIScience and Remote Sensing* 41(4):347-370, 2004.

Byrd, Kristin B., Temporal and Spatial Linkages between Watershed Land Use and Wetland Vegetation Response in the Elkhorn Slough Watershed, Monterey, County, California. Ph.D. Dissertation, 173 pp, 2005.

Professional Presentation

Byrd, K.B. and N.M. Kelly, The relationship between watershed land use change, wetland soil physical properties and plant succession in a California coastal estuary, Proceedings of the 89th Annual Ecological Society of America Meeting, Portland, OR, August 1 – 6, 2004.

Collaborative Efforts

We would like to acknowledge Eric Van Dyke, Geographical Ecologist and Kerstin Wasson, Research Coordinator from the Elkhorn Slough National Estuarine Research Reserve and Adina Merenlender, UC Berkeley, for their contributions to this project. We would also like to thank Bryan Largay, hydrologist with the Monterey County Resource Conservation District for his input on watershed hydrology and Rikk Kvitek, CSU Monterey Bay for his assistance with elevation surveys.

For further information, please contact:

• **Dr. Maggi Kelly**

e-mail: mkelly@nature.berkeley.edu

Phone: 510-642-7272

Webpage:

<http://kellylab.berkeley.edu/>



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

Sharon P. Lawler
Department of Entomology
UC Davis

Water resources help support both native fauna and introduced fish in high mountain lakes. This study shows that a threatened native amphibian has better breeding success in lakes with fewer introduced fish, and that fish removals lead to more 'export' of aquatic insects to terrestrial food webs. Continuing work will address the effects of introduced fish on upland species that consume aquatic insects and amphibians.

Historically, a significant proportion of California's high elevation wilderness lakes were fishless, providing habitat for native fauna that are predatory on insects, including amphibians, reptiles, birds, and bats. Now, trout have been introduced into the vast majority of mountain lakes for sport fishing, and studies have shown declines in the native fauna, especially amphibians and some reptiles, including the Cascades frog (*Rana cascadae*), a state and federal species of special concern.

In order to assess the effects of fisheries management techniques on the distribution and abundance of fish, amphibians, emerging aquatic insects, birds, reptiles and bats, we have undertaken a multi-year study. Our experimental design compares 12 wilderness lakes subject to three different fisheries management techniques (continued fish stocking, cessation of stocking, and fish removal) to four historically fishless reference lakes. Our 16 study lakes are between 1920 to 2210 m in elevation, with depths ranging from 2.7 - 11.2 m. The lakes are grouped in four geographical blocks within which sites were randomly assigned for stocking suspension, fish removal, or continued stocking. There is one historically fishless basin in each block.

We collected pre-treatment data in 2003, then removed trout or suspended stocking in eight basins. In 2004 we quantified post-treatment populations of fish, Cascades frogs and other amphibians, aquatic insects, birds, reptiles and bats. We sampled lakes six times per summer. Amphibians and snakes were monitored via mark-recapture and visual surveys. Aquatic insects were sampled using benthic sweeps, insect emergence traps and sticky traps. Bats were monitored via acoustic bat detectors, and bird abundances were quantified using point-count surveys.

At the beginning of our study in 2003, large-bodied insects, frogs, and garter snakes (*Thamnophis sirtalis*) were all less abundant in stocked sites compared with historically fishless 'control' basins. Our surveys in 2004 showed a higher abundance of Cascades frog tadpoles and metamorphs in fish removal lakes and in lakes where stocking was suspended compared to stocked lakes (Figure 1). Aquatic invertebrates also showed signs of recovery in basins with fewer fish. We expect that frogs and aquatic insects will continue to recover in our 2005 field season. Such recovery will allow us to more conclusively assess the indirect impacts of fish on snakes, birds and bats.

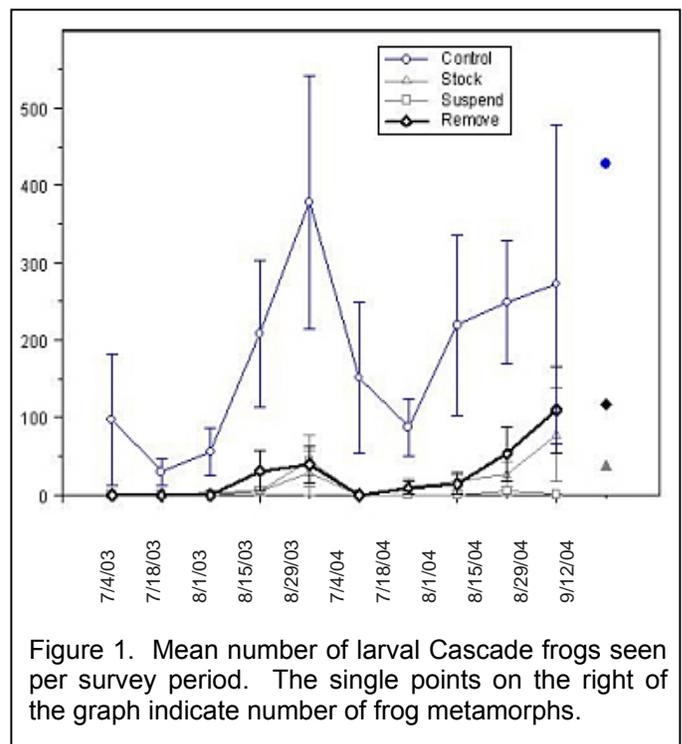


Figure 1. Mean number of larval Cascade frogs seen per survey period. The single points on the right of the graph indicate number of frog metamorphs.

Our work will be significant for the management of wilderness lakes in the Trinity Alps and elsewhere in California because it documents the responses of a wide variety of taxa to the introduction of fish via stocking. This information is vital to policy development for protecting and managing biodiversity in the extensive montane wilderness areas in the western United States. Information provided by this project will show whether adjustment of fish stocking practices could create landscapes where fish and frogs can coexist at broad scales.

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.

Professional Presentations

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

Collaborative Efforts

Karen Pope, M.S., is the project leader. She is a graduate student in Ecology at U.C. Davis and an ecologist with the USDA Forest Service's Redwood Science Laboratory. This large-scale project was made possible by assistance from our granting agencies and the following people who contributed expertise, time and equipment to the project: Hartwell Welsh and the U.S. Forest Service Redwood Sciences Laboratory; Bernie Aguilar, Betsy Bolster and the California Department of Fish and Game.

For further information, please contact:

- **Dr. Sharon Lawler**

e-mail: splawler@ucdavis.edu

Phone: 530-754-8341

Webpage:

<http://entomology.ucdavis.edu/faculty/facpage.cfm?id=lawler>



Anthropogenic Nutrient Deposition and Alteration of the Food Web Structure in Alpine Lakes: Response by Microbial Communities

John M. Melack and Craig Nelson

Department of Ecology, Evolution and Marine Biology, and
The Bren School of Environmental Science and Management
UC Santa Barbara

The ecosystems of remote, high-elevation lakes within the Sierra Nevada mountain range are increasingly being impacted by anthropogenic pressures, including atmospheric nitrogen deposition and stocking with non-native trout. Our initial research indicates a remarkably active and diverse natural bacterial community throughout the Sierra Nevada high alpine lakes. Our results suggest that the metabolism and population dynamics of these microbes are important year-round to high-elevation lake nutrient cycling and food-web processes.

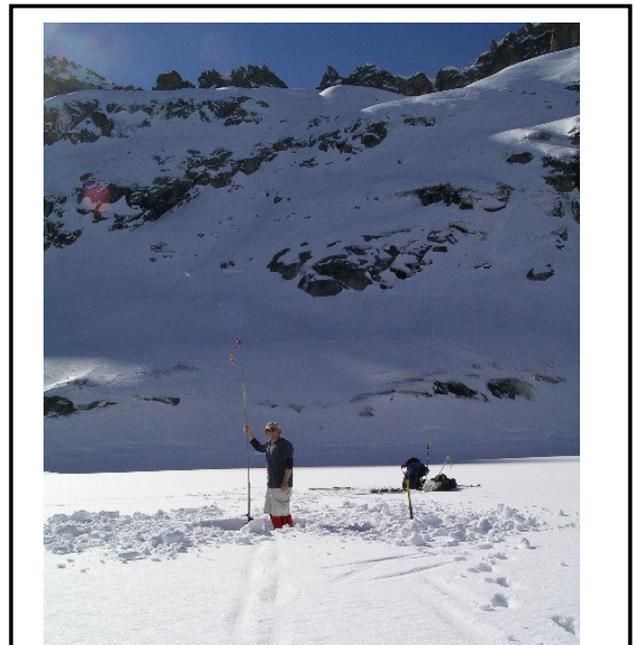
High-elevation alpine lakes of California's Sierra Nevada mountain range, once considered isolated from human impacts, are increasingly experiencing the effects of population expansion. Nutrient loading, the result of increasing atmospheric deposition, and the stocking of non-native trout, halted in 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. Significant and lasting impacts at a regional scale, including the eradication of endangered species, alterations to algal productivity, and changes in zooplankton population dynamics, have occurred. Connecting these shifts to ecosystem function and biogeochemical cycling is necessary for understanding and predicting ecological impacts in these lakes. However, such research has not yet been a focus, despite the documented sensitivity of alpine lake ecosystems to even minor changes in water chemistry or nutrient availability.

This research investigates the potential regional ecosystem impacts of eutrophication and non-native trout introductions by examining the role of microbes in the structure and function of Sierran lakes. In oligotrophic 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.

During 2004-2005, year-round sampling of the microbial and biogeochemical variables in Emerald

Lake (2,800 meters elevation, Sequoia National Park) established a baseline understanding of bacterioplankton communities and insight into links between bacterioplankton dynamics and seasonal physical and chemical parameters. In addition, a snapshot survey of six fishless and trout-stocked lakes in Humphrey's Basin (Inyo National Forest) was conducted in mid-July of 2004 to evaluate differences in bacterioplankton and organic matter stocks attributable to the presence or absence of introduced trout.



Ph.D. student Craig Nelson cores through two meters of ice and snow covering Emerald Lake in January, 2004. Sampled water will be analyzed for bacterial community composition, metabolic activity, and physical and chemical parameters.

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

- 1) Marked seasonal variability in the community composition and metabolic activities of bacterioplankton in Emerald Lake.
- 2) Significant diversity and abundance of previously unknown bacterioplankton across the Sierra Nevada.
- 3) Evidence for interaction between bacterioplankton communities and catchment export of both nitrate and dissolved organic carbon.
- 4) A baseline dataset for continued evaluation of interannual variability in Sierran lake chemical and microbial dynamics.

The seasonal and spatial dataset established in this first year will support experiments and surveys in 2005-2006 aimed at directly evaluating responses of microbial populations and organic matter metabolism to the dual impacts of nutrient enrichment and fisheries management. Continuing inter-annual monitoring for eutrophication will be well-informed by the results of this research, as will efforts to determine the ecosystem-scale impacts of introduced trout stocking and/or removal in high-elevation lakes throughout the Western United States. In addition, regional surveys of organic matter dynamics, nutrient stocks and microbial communities in Sierran lakes

will inform land managers seeking to integrate biogeochemical and ecosystem-scale data into existing management frameworks.

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.

For further information, please contact:

- **Dr. John M. Melack**

e-mail: melack@lifesci.ucsb.edu

Phone: 805-893-3879

Webpage:

<http://www.lifesci.ucsb.edu/eemb/faculty/melack/index.html>

Research Category III

Water Quality

Research in this category encompasses all factors and processes affecting the quality of the sources of surface and groundwater regardless of the use, and the quality and treatment of water in the transportation and distribution systems. Topics that fall within this category include studies of the sources and the nature of contaminants including those emanating from agricultural and industrial processes, 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 and for preventing water quality degradation.





Cryptosporidium in Bivalves as Indicators of Fecal Pollution in the California Coastal Ecosystem

Patricia Conrad, Woutrina Miller, Rob Atwill, and Ian Gardner
School of Veterinary Medicine
UC Davis

Fecal pollution flowing from land to sea poses major health risks. New methods using bivalves (such as clams and mussels) as bio-indicators of fecal contamination were designed and evaluated in our lab. We then successfully applied these methods to monitor fresh and marine water quality in coastal California ecosystems. Our results suggest that humans and animals ingesting fecal-contaminated water and shellfish may be exposed to both host-specific and anthrozoonotic *Cryptosporidium* genotypes of public health significance.

Fecal pathogen pollution at the terrestrial-aquatic interface poses health risks to both humans and animals. Sensitive and specific detection of zoonotic fecal protozoa, such as *Cryptosporidium* spp., is needed to investigate fecal pathogen pollution from land to sea. Environmental monitoring for fecal protozoa can be problematic, partly because of the dilution effect that occurs as oocysts are disseminated from the feces of animals and humans to terrestrial and aquatic ecosystems, and also because particulate matter can inhibit or interfere with detection methods. Bivalve molluscs can concentrate protozoal oocysts from fecal-contaminated aquatic environments, and may therefore be useful for monitoring water quality.

The objective of Dr. Woutrina Miller's PhD research was to obtain data on the epidemiology of the fecal pathogen *Cryptosporidium* in freshwater, estuarine, and nearshore marine ecosystems in California. Goals were to evaluate innovative *Cryptosporidium* detection techniques, to assess the genotypes of *Cryptosporidium* flowing from land to sea, and to identify risk factors for fecal contamination in coastal ecosystems.

First, a real-time TaqMan polymerase chain reaction (PCR) system that allows large scale, semi-quantitative detection of *Cryptosporidium* spp. was compared to more conventional detection methods in mussels (*Mytilus californianus*) using tissue spiking experiments. Next, tank exposure experiments and then sentinel bivalve studies in the field were conducted to evaluate clams (*Corbicula* spp.) and mussels (*Mytilus* spp.) as bioindicators of fecal contamination in freshwater and marine ecosystems, respectively, in California.

Our results indicate that TaqMan PCR, conventional PCR, and fluorescent antibody techniques can all be used to detect *Cryptosporidium* in bivalves. The most

sensitive method was immunomagnetic concentration of bivalve digestive gland followed by fluorescent antibody detection. Applying these methods in controlled tank exposure experiments confirmed that mussels and clams can concentrate *Cryptosporidium* oocysts from inoculated waters, and that oocysts are detectable for days to weeks post-exposure.

Our use of sentinel clams in the field was the first report worldwide utilizing *Corbicula* clams to detect *Cryptosporidium* and *Giardia* in natural riverine ecosystems in California. *Cryptosporidium* oocysts and *Giardia* cysts were both detected significantly more often in the wet season than in the dry season.

Additionally, our use of sentinel clams in the field was the first multi-year project using bivalves to detect *Cryptosporidium* on the Pacific coast. We successfully detected zoonotic as well as host-specific genotypes of



Dr. Woutrina Miller's PhD project involved collecting mussels near Bodega Bay.

Cryptosporidium. Exposure to freshwater outflow and recent precipitation preceding bivalve collection were identified as risk factors associated with protozoal detection in mussels.

These findings indicate that, in California, fecal contamination is flowing from land to sea and clams and mussels can be used to monitor water quality. Humans and animals ingesting fecal-contaminated water and shellfish may be exposed to both host-specific and anthrozoonotic *Cryptosporidium* genotypes of public health significance. Continued investigation is needed to better understand the dynamics of fecal pathogen pollution and how to manage it in order to minimize health risks.

Professional Presentations

Smith, W.A., E.R. Atwill, H.M. Fritz, R.P. Hedrick, A.C. Melli, K.D. Arkush, and P.A. Conrad, Detecting environmental levels of *Cryptosporidium* in clams (*Corbicula fluminea*), International Association for Aquatic Animal Medicine, Kona, Hawaii, May, 2003.

Miller, W.A., M.A. Miller, I.A. Gardner, E.R. Atwill, M. Harris, J. Ames, D.A. Jessup, K. Worcester, D. Paradies, A.C. Melli, N.M. Barnes, P. Olin, and P.A. Conrad, *Cryptosporidium* epidemiology in fecal impacted coastal California ecosystems, using mussels (*Mytilus* spp.) as bioindicators. International *Giardia* and *Cryptosporidium* Congress, Amsterdam, Netherlands, September, 2004.

Miller, W.A., E.R. Atwill, I.A. Gardner, M. Miller, M. Harris, J. Ames, D. Jessup, S. Jang, B. Byrne, A. Melli, D. Paradies, K. Worcester, P. Olin, and P. Conrad, Habitat quality in California: risk factors for detecting fecal pathogens in coastal ecosystems. International Association for Aquatic Animal Medicine Conference, Seward, Alaska, May, 2005.

Miller, W.A., P. Conrad, M. Miller, I.A. Gardner, E.R. Atwill, M. Harris, J. Ames, D. Jessup, D. Paradies, K. Worcester, A. Melli, N. Barnes, P. Olin, and P.A. Conrad, Detection of pathogenic protozoa in marine ecosystems using mussels as bioindicators. International Wildlife Disease Association, Cairns, Queensland, Australia, June, 2005.

Miller, W.A., E.R. Atwill, I.A. Gardner, M. Miller, B. Byrne, M. Harris, J. Ames, D. Jessup, S. Jang, A. Melli, D. Paradies, K. Worcester, and P.A. Conrad. Risk factors for detecting protozoal and bacterial fecal pathogens in coastal California ecosystems, World Assoc. for the Advancement of Veterinary Parasitology, Christchurch, New Zealand, October, 2005.

Publications

Miller, W.A., E.R. Atwill, I. Gardner, M. Miller, H. Fritz, R. Hedrick, A. Melli, N. Barnes, and P.A. Conrad, Clams (*Corbicula fluminea*) as bioindicators of fecal contamination with *Cryptosporidium* and *Giardia* in freshwater ecosystems of California, *International Journal for Parasitology*, 2005, 35(6):673-684.

Miller, W.A., M.A. Miller, I.A. Gardner, E.R. Atwill, A.C. Melli, M. Harris, J. Ames, K. Worcester, N. Barnes, D. Jessup, and P.A. Conrad, New genotypes and factors associated with *Cryptosporidium* detection in mussels (*Mytilus* spp.) along the California coast, *International Journal for Parasitology*, 2005, June 30 [Epub].

Miller, W.A., I.A. Gardner, C.M. Leutenegger, M. Miller, E.R. Atwill, R. Hedrick, A.C. Melli, N. Barnes, and P.A. Conrad, Evaluation of methods for improved detection of *Cryptosporidium* spp. in mussels, *Journal of Microbiological Methods*, 65(3):367-379, 2005.



Sentinel freshwater clams just before placement in the San Lorenzo River.

Collaborative Efforts

Melissa Miller and Dave Jessup, CA Department of Fish and Game; Kristen Arkush, Bodega Marine Lab; Christian Leutenegger, UC Davis; Gary Ichikawa, CA Mussel Watch Program; Karen Worcester, CCRWCB; Dave Paradies, Bay Foundation for Morro Bay; Bryn Phillips, Granite Canyon Marine Lab; Paul Olin, CA Sea Grant Program; and David Lewis, UC Extension Office.

For further information, please contact:

- Dr. Patricia Conrad
e-mail: paconrad@ucdavis.edu

Phone: 530-752-7210

Webpage:

<http://faculty.vetmed.ucdavis.edu/faculty/paconrad/>

or

- Dr. Woutrina Miller
e-mail: wasmith@ucdavis.edu



Development of Biosensors for Real Time Analysis of Perchlorate in Water

William T. Frankenberger
Department of Environmental Sciences
UC Riverside

Perchlorate (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 ClO_4^- detection in water.

Perchlorate (ClO_4^-) contamination of ground water is a widespread problem in the United States, which can adversely affect human health and wildlife. Current methods for detecting and quantifying 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 ClO_4^- in the field.

In the first year of this study (July 2004 to June 2005) we constructed and characterized a biosensor for the rapid determination of ClO_4^- in water by employing a ClO_4^- reductase from a novel perchlorate-reducing bacterium (*Dechloromonas* sp. perc1ace). Using a 3 mm GCE (glass carbon electrode), we successfully constructed a ClO_4^- sensing bio-electrode by coating an aliquot of the enzyme on a 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 ClO_4^- concentration. The biosensor responded strongly to ClO_4^- at concentrations as low as 1 $\mu\text{g/L}$ and the sensor displayed a linear response to ClO_4^- concentrations in the range 25 to 100 $\mu\text{g/L}$. Response time to ClO_4^- at 100 $\mu\text{g/L}$ was approximately 111 ± 28 seconds. Kinetic evaluation of the sensor response to 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 (μS) in the 25 to 100 $\mu\text{g/L}$ linear domain of the biosensor. Biosensor response to ClO_4^-

was maximal at an applied potential range of -0.6 to -1.0V . ClO_4^- reduction current increased with increase in pH and was maximal in the range of 7.6 to 8.0.

The ClO_4^- biosensor displayed excellent stability after repeated use (24 analyses conducted on a single day over a 10-h period at room temperature). Nitrate concentrations below the drinking water regulatory limit ($<45 \text{ mg/L NO}_3^-$) did not interfere with ClO_4^- biosensor performance. Analysis of a natural ground water sample collected from the field with the ClO_4^- biosensor and ion-chromatography revealed comparable readings of $418 \pm 24 \mu\text{g/L}$ and $367 \pm 9 \mu\text{g/L}$, respectively. This study indicates great potential for the development of a potable and field deployable biosensor for real time analysis of ClO_4^- in water.

Publications

Frankenberger, W.T., Development of a Perchlorate Reductase-Based Biosensor for Real Time Analysis of Perchlorate in Water. *Biosensors and Bioelectronics* (submitted).

Collaborative Efforts

Quan Jason Cheng, Department of Chemistry, UC Riverside

For further information, please contact:

• Dr. William Frankenberger
e-mail: william.frankenberger@ucr.edu
Phone: 951-827-3405

Webpage:
<http://envisci.ucr.edu/index.php?file=faculty/frankenberger/frankenberger.html>



Kinetics of Inorganic Arsenic Contamination

Michael McKibben
Department of Earth Sciences
UC Riverside

The rate of release of aqueous arsenic from common primary source minerals in rocks and soils has been quantified experimentally, yielding rate equations that can be used in computer modeling of arsenic contamination in surface and subsurface waters. Arsenopyrite, rather than pyrite, has been found to release aqueous arsenic the most rapidly.

Pyrite and arsenopyrite are the most abundant arsenic (As)-bearing minerals in the crust, making them important natural primary sources of As release to waters and soils. Although the kinetics of aqueous pyrite oxidation are well known, those of arsenopyrite are not. Determining the kinetic rate laws for arsenopyrite will allow their use in computer models to predict the release rates of As from rocks and soils, and to model the downstream migration of As in surface and subsurface waters, particularly those waters impacted by mine tailings.

A high flow-rate batch reactor was used to measure rates of inorganic arsenopyrite oxidation in 0.01 M NaCl aqueous solutions as a function of pH, oxidant concentration and temperature. Natural arsenopyrite crystals were ground, sieved, and cleaned ultrasonically and chemically to produce fresh, bulk grain surfaces free of fine mineral powder for the rate measurements. The initial rate method was used to determine reaction rate order dependencies on pH (from 2-5) and oxidant concentrations ($O_{2(aq)}$, Fe^{3+}). B.E.T surface area measurements of the grains were used to calculate specific rate constants, and temperature dependence of the rates were measured over the range 10-40°C.

For systems in which ferric ion is initially absent, the specific rate law at 25°C is: $R_{sp} = -k (O_2)^{0.33} (H^+)^{0.27}$ where dissolved oxygen and proton concentrations are expressed in molar units, the specific rate in units of moles arsenopyrite $m^{-2} s^{-1}$, and the rate constant is $10^{6.11} \text{ moles}^{0.5} L^{0.5} m^{-2} s^{-1}$.

Arsenopyrite oxidation by aqueous O_2 and Fe^{3+} under these conditions is nearly three orders of magnitude faster than pyrite oxidation, indicating that arsenopyrite will release As even faster in rocks with high pyrite/arsenopyrite ratios.

In the absence of initial ferric iron, the release of As into solution is non-stoichiometric, with about half of it apparently remaining behind with sulfur on mineral surfaces. The presence of initial ferric iron or pH values above 4.5 cause As release to become stoichiometric. This behavior suggests that ferric iron either inhibits As retention on arsenopyrite surfaces or rapidly oxidizes As to a more mobile aqueous species.

Publications

McKibben, M.A., B.A. Tallant, and Jozi K. Del Angel, Kinetics of aqueous arsenic release from sulfide minerals, Geological Society of America Abstracts with Programs, Vol. 37, No. 7, Oct. 2005, 1 (abstract)

Tallant, B.A. and M.A. McKibben, Arsenic Mineral Kinetics: Arsenopyrite Oxidation, *Geochimica et Cosmochimica Acta*, Volume 69, Issue 10, Supplement 1, p. 820., May 2005, 1 (abstract)

Tallant, B.A., Kinetic Rate of Arsenopyrite Dissolution by Oxygen in Low Temperature, Low pH Solutions, M.Sc Thesis, June 2005, UC Riverside, 204 pp.

Professional Presentations

McKibben, Michael A., Bryan A. Tallant, and Jozi K. Del Angel, Kinetics of aqueous arsenic release from sulfide minerals, Geological Society of America Annual Meeting, Salt Lake City, UT, Oct. 2005

Tallant, B.A. and M.A. McKibben, Arsenic Mineral Kinetics: Arsenopyrite Oxidation, Goldschmidt Geochemistry Conference, Moscow, ID, May 2005

For further information, please contact:

• **Dr. Michael McKibben**

e-mail: michael.mckibben@ucr.edu

Phone: 951-827-3444

Webpage: <http://mckibben.ucr.edu>



Detection of the Herbicide Atrazine in Freshwater Using DNA Aptamers

Ashok Mulchandani
Department of Chemical & Environmental Engineering
UC Riverside

Agricultural producers across the country rely on atrazine as the foundation of their weed control programs. Widespread pollution of the environment by atrazine is a major concern as an increasing number of rivers and aquifers have been observed to be contaminated by these herbicides. Understanding the spatial extent of such contamination would be improved if a cost-effective methodology for the detection of atrazine were available. We have developed DNA aptamers which offer a reasonably-priced methodology for not only the sensitive detection, but also the bioremediation, of atrazine in California's freshwater systems.

Many crops, commodities and services in the U.S. could not be supplied in an economic fashion without the use of the herbicide atrazine in weed control programs. However, because of the extreme toxicity of atrazine, its maximum contaminant level (MCL) has been set at 3 parts per billion (ppb) by the EPA. A survey by the Cal/EPA's Department of Pesticide Regulation (DPR) of freshwater samples taken from 3,564 wells in 48 of California's 58 counties revealed the presence of atrazine above regulatory limits in many areas, especially where soil characteristics favor the movement of pesticides to groundwater.

The objective of the proposed research was to develop novel single-stranded deoxyribonucleic acid (ssDNA) aptamers for the selective and cost-effective detection and bioremediation of atrazine in drinking water supplies. ssDNA aptamers are a new class of bioreceptors that have affinity characteristics for ligands similar to those of antibodies, but that do not require either the immunization of animal hosts or mammalian cell culture. ssDNA aptamers can be selected using combinatorial selection approaches and subsequently should be able to be economically mass produced to provide a cost-effective method for large scale water treatment application.

We used Systematic Evolution of Ligands by Exponential Enrichment (SELEX), a combinatorial selection technique to select ssDNA aptamers with affinity for atrazine. A 66 bases DNA library with 30-mer random DNA flanked with priming sites and

labeled with radioactive P^{32} was incubated with magnetic polystyrene beads modified with atrazine. Then, recovery/elution was accomplished using a high concentration of atrazine solution and amplification of the recovered ssDNA by polymerase chain reaction. Eleven rounds of SELEX were performed and a decreasing diversity of the ssDNA library (higher percentage of atrazine binder in the library) with each passing round was observed (0.4% to 40%).

The binding affinity constant, K_d , of the ssDNA library was determined to be $7 \mu M$. The cloning of the library in a bacterium host followed by screening of a single ssDNA sequence is expected to provide a receptor with improved K_d suitable for atrazine monitoring and remediation applications in freshwater systems.

Collaborative Efforts

A DNA aptamer-based fluorescence polarization bioassay is being developed in conjunction with Intelligent Optical Systems, Inc., of Torrance, CA.

For further information, please contact:

• **Dr. Ashok Mulchandani**

e-mail: adani@enr.ucr.edu

Phone: 951-827-6419

Webpage:

<http://www.enr.ucr.edu/~adani>



Development of a Real-Time Method for Enumeration of Host-Specific Fecal Bacteria Based on Quantitative Polymerase Chain Reaction

Kara Nelson
Department of Civil and Environmental Engineering
UC Berkeley

To effectively manage watershed quality requires identifying the dominant sources of fecal contaminants, both spatially and temporally, such that the effectiveness of mitigation strategies can be assessed. Toward this end, we are developing a quantitative method for determining the relative contribution to fecal pollution concentrations from different animals. Our technique relies on using real-time quantitative polymerase chain reaction methods developed to identify several host-specific bacteria at the low concentrations typically encountered in the field. These lab developed methods are then being applied in the field to allow comparison to traditional water quality measurements.

Fecal pollution continues to be among the leading contaminants of our nation's waters. The goal of the proposed research is to develop and evaluate a quantitative method for calculating the fractional contribution of fecal pollution from human and animal sources by measuring host-specific fecal indicator bacteria using real-time, quantitative polymerase chain reaction (QPCR).

The experimental methods include both laboratory and field research. In the laboratory, we are developing QPCR methods for total *E. coli* as well as several host-specific target sequences in fecal indicator bacteria (other than *E. coli*). In the field, we are characterizing the sources of fecal pollution in a watershed by combining our QPCR methods with traditional water quality measurements, such as culturable *E. coli*, nutrients, and BOD.

First we focused on developing a QPCR method for total *E. coli*. The main challenge was the elimination of trace levels of contamination in commercial preparations of the polymerase enzyme, which interfere with detection of low levels of *E. coli*. A novel DNase treatment step was developed that may have widespread relevance for many QPCR-based applications. Next we developed QPCR methods for several host-specific targets that we have identified from the literature and discussions with colleagues.

This research will provide improved tools for managing fecal pollution, ultimately increasing our ability to identify and target the dominant sources of pollution, to monitor changes in the concentration of fecal pollution and its sources over time, to assess the effectiveness of specific mitigation strategies, and to provide more information for evaluating the true public health risks.

For further information, please contact:

• Dr. Kara Nelson

e-mail: nelson@ce.berkeley.edu

Phone: 510-643-5023

Webpage: <http://www.ce.berkeley.edu/~nelson/>



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

Anthony T. O'Geen
Department of Land, Air and Water Resources
UC Davis

In the California's Central Valley, constructed wetlands can improve the water quality of irrigation return flows by intercepting particulate organic carbon, nitrogen, phosphorous, and sediment before it reaches the San Joaquin River. The longer a constructed wetland has been established, the more efficient it becomes at these removals.

Two constructed wetlands (CW) in California's Central Valley were monitored to evaluate their impact on irrigation water quality prior to its return to the San Joaquin River during the 2004 irrigation season (April-September). The initial stage of this project encompassed baseline sampling of seasonally submerged soils and identification of appropriate strategies for water quality and flow monitoring in a new CW (W-1) and 10-year-old CW (W-2).

Our results demonstrate that CWs are effective traps for sediment, particulate organic carbon, nitrogen and phosphorus removed from irrigated farmland. Soil samples were analyzed for C, N, P and their particle size distribution was determined. Intricate input/output flow monitoring systems were designed and tested, in order to calculate constituent loads in subsequent years. Input/output waters from CWs were collected on a weekly basis and analyzed for the following constituents: 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). Carbon, nutrient and sediment retention efficiency was evaluated from input/output concentration data.

First year results indicate that the older W-2 was more efficient at removing POC and contaminants. Average POC retention was 75% in W-2 and 66% in W-1. Chlorophyll-a tended to be higher at W-1 compared to W-2, especially in the inputs. Initially, output concentration of chlorophyll-a increased 15 fold in W-2, however over time, as emergent vegetation became established, chlorophyll-a decreased to 35% of input levels. While W-1 was generally a sink for DOC, W-2 was often a source of DOC possibly due to leaching of DOC from vegetation and litter.

Average TN removal efficiency was 44% for W-2 compared to 15.5% in W-1. After an initial release of P due to establishment of reducing conditions in the wetland sediments, average P removal efficiency was 71% at W-2 compared to 19% at W-1. CWs were most effective at removing TSS with average removal efficiency of 84 and 97% for W-1 and W-2, respectively.



Jon Maynard collects samples from constructed wetlands that intercept irrigation run-off prior to its return to the San Joaquin River. Water and soil samples are analyzed to determine how efficient these ecosystems are at improving water quality.

Collaborative Efforts

Mike McElhiney, USDA-NRCS District Conservationist for Stanislaus County; Erwin Van Nieuwenhuyse, U.S. Bureau of Reclamation

Professional Presentations

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

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, 2005.

Maynard, J.J., A.T. O'Geen and R.A. Dahlgren, Monitoring Carbon and Nutrient Dynamics of Constructed Wetlands in the San Joaquin Valley, California. Soil Science Soc. Am., Seattle WA. 2004.

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



For further information, please contact:

• **Dr. Anthony T. O'Geen**

e-mail: atogeen@ucdavis.edu

Phone: 530-752-2155

Webpage:

http://lawr.ucdavis.edu/directory_facultypages.php?id=46



Development of a Microarray to Simultaneously Detect Fecal Waste Sources and a Major Pathogen, *E. coli* O157:H7, in Stormwater Runoff

Betty Olson

Department of Environmental Health, Science & Policy
UC Irvine

Stormwater runoff often contains fecal contamination that is discharged directly into freshwater systems. To aid regulatory agencies in identifying pathogens of concern in these waters, we have developed a prototype low-density oligonucleotide diagnostic microarray. This tool is designed to be a quick and inexpensive method to detect *E. coli* O157:H7 (an important human pathogen) as well as fecal waste from four sources (human, cow, pig and bird) in environmental water samples. Testing of our microarray indicates that further refinements are needed prior to its use to consistently detect contaminants at the low concentrations found in stormwater runoff.

To aid water managers in quickly and inexpensively identifying fecal waste carried by runoff through storm drains and other sources discharging directly into environmental waters, we have worked to develop an oligonucleotide microarray capable of identifying four fecal waste sources (human, cow, pig and bird) and a major bacterial pathogen, *Escherichia coli* O157:H7. This low-density array is designed to obtain results for all five items simultaneously within 48 hours.

Our overall approach has been to design a system with maximum flexibility requiring the minimum number of manipulations. Our design combines magnetic bead assemblages to create assays capable of capturing multiple genetic markers specific for target pathogens from a complex matrix. For example, we coupled magnetic capture hybridization (binding together of matching nucleic acid strands) with quantitative PCR (MCH-qPCR) to identify the presence of *E. coli* O157:H7 through the detection of three specific genes - the flagellar antigen gene, *fliC*, and the two toxin genes, *stx1* and *stx2* -- in one sample.

The use of MCH-qPCR incorporates magnetic bead probes designed to separate inhibitors and target DNA, therefore simultaneously concentrating and purifying DNA extracts in preparation for qPCR. These steps are necessary because inhibition is a major problem preventing genetic identification in environmental samples using a DNA microarray. Primers, dual-labeled probes, and magnetic bead probes were designed for *fliC*, *stx1*, and the *stx2* genes to discriminate between *E. coli* O157:H7 and other non-pathogenic serotypes. Each assay was screened using *E. coli* O157:H7 ATCC strain #43895 as the positive control. The total genomic DNA was extracted from cow feces and waste lagoon waters, aliquots of which

were hybridized to magnetic probes specific for our target genes and quantified using qPCR.

We tested our design using cow feces and cow waste lagoon samples across a range of dilutions. Screening samples for the LTIIa toxin gene (10-50 copies per water sample volume 10 – 100 ml) using this procedure was successful. However, we found the MCH-qPCR assay using *fliC* and *stx1* probes yielded a minimum detection of 1×10^6 per ml and 1×10^5 per ml, respectively. Thus, while such high values might be found in food, the technique is not sensitive enough for environmental samples.

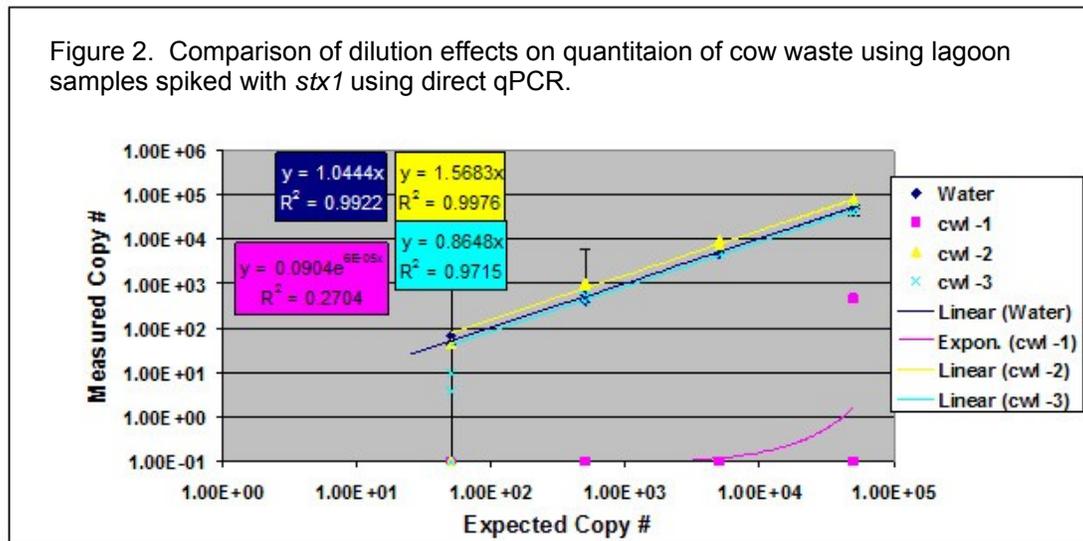
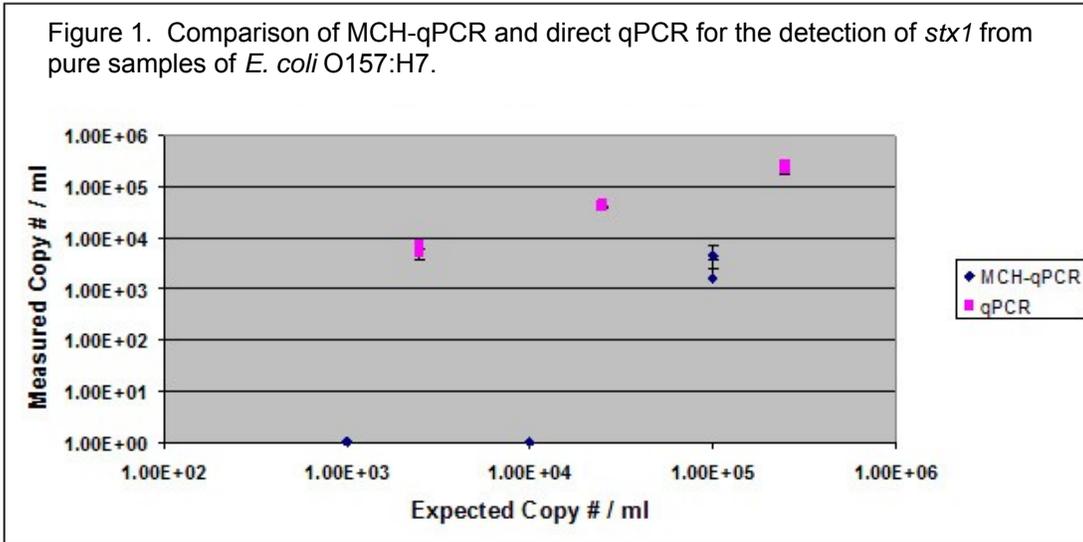
qPCR was more sensitive on DNA extracted from environmental samples than MCH-qPCR in the detection of *fliC* or *stx1* (Figure 1). A 2-tailed T-test showed a significant difference ($p < 0.05$) in method sensitivity for both genes. Undiluted DNA extracts of cow fecal material and cow waste lagoon samples caused inhibition of both methods. By diluting samples, we were able to detect *stx1* (Figure 2) and *fliC* (data not shown) in spiked cow waste lagoon waters using qPCR. Additionally, by surveying cow waste lagoons, we learned the frequency of the *fliC* gene was greater than we had seen in a previous study where 25% of farms had a frequency of 3-10% for the *E. coli* O157 genotype. We are now determining if we had cross reactivity with unidentified H antigens (53 H-antigens used to develop our primer/probe set) or simply if the H7 antigen was more prevalent in our samples.

To date this approach allows the simultaneous detection of various waste sources and an important pathogen. By examining cow waste lagoons, infected herds can be isolated and treated prior to processing, reducing loss of beef products and limiting risk of

exposure. Contamination from a variety of sources can be identified using this platform. Furthermore, our design will be inclusive of recently recognized *stx2* variants believed to influence the pathogenicity of *E. coli* O157:H7 that can be overlooked in most PCR based methods. Using low-density microarray analysis, we hope to improve water quality testing through the rapid assessment of the relative risk potential of waters, and aiding policy makers in decreasing exposure to human pathogens.

Collaborative Efforts

Dr. Donna Williams-Hill
 Dr. Chong Cheng
 United States Food and Drug Administration
 Pacific Regional Laboratories Southwest
 Irvine, CA 92612



For further information, please contact:

- Dr. Betty Olson

e-mail: bholson@uci.edu
 Phone: 949-824-5281
 Webpage:
<http://www.seweb.uci.edu/faculty/olson/>



Use of Bioassays to Assess the Water Quality of Wastewater Treatment Plants for the Occurrence of Estrogens and Anti-estrogens

Daniel Schlenk
Department of Environmental Sciences
UC Riverside

Using an *in vivo* whole animal bioassay, effluents from a major water reclamation producer were evaluated for the occurrence of estrogenic and anti-estrogenic compounds. The efficiency of water treatment processes in removing these compounds varied. No activity was seen in reclaimed water that had been treated by reverse osmosis or groundwater filtration, whereas that which had been treated by filtration/chlorination or by wetland reclamation still contained measurable estrogens and anti-estrogens.

Endocrine disrupting agents encompass a vast array of compounds that have multiple biological targets and degrade water quality, especially if this water is to be re-used for groundwater recharge or irrigation. Antiestrogenic and estrogenic activities and chemicals have been observed in wastewater effluents even though they have received full secondary treatment. Assuming that estrogens and antiestrogens are present in wastewater effluent, the overall aim of this study is to assess the efficiency of several treatment processes for the removal of these compounds in one of the major water reclamation producers in the western United States: the Orange County Water District.

Utilizing an *in vivo* whole animal (fish) bioassay, water treatment effluents were evaluated for the occurrence of estrogenic and antiestrogenic compounds. Four water treatment processes were evaluated, including reverse osmosis, filtration/chlorination of secondary effluent, ground water filtration, and wetland treatment. Our data indicated the occurrence of antiestrogenic and estrogenic compounds in water following two of the treatment processes: filtration/chlorination and passage through constructed wetlands.

In vivo estrogenic activity was observed in fish exposed to effluent treated with filtration/ chlorination (which can be subsequently used for non-potable purposes) and in water after passage through a constructed wetlands. No activity was observed in reconstituted water that had been treated with reverse osmosis or ground water. Our results also suggest that *in vitro* assays based solely on estrogen receptor ligand activity (YES) may underestimate estrogenic activity of sampled water.

In vivo antiestrogenic activity was observed in fish exposed to wastewater samples treated with

filtration/chlorination and passed through constructed wetlands. Although not as robust a measurement as estrogenic activity, the *in vivo* bioassay for antiestrogenic activity indicated that wastewater after the wetlands treatment seemed to have more antiestrogenic activity than before the treatment.

Based on our research, we recommend that future studies be undertaken utilizing chromatographic fractionation methods to allow source identification that will provide a better understanding of the potential risks associated with these compounds in reclaimed water.

Publications

Xie, L., Y. Sapozhnikova, O. Bawardi, and D. Schlenk, Evaluation of wetland and tertiary wastewater treatments for estrogenicity using *in vivo* and *in vitro* assays, Archives of Environmental Contamination and Toxicology 48:82-87, 2005.

Professional Presentations

Xie, L., D. Hinton, and D. Schlenk, Evaluation of shallow groundwater from California for estrogenic activity using Japanese medaka (*Oryzias latipes*), Abstracts of the 25th Annual Meeting of the Society of Environmental Toxicology and Chemistry. Portland, OR, 2004.

Shi, D., L. Xie, and D. Schlenk, Inhibition of Vitellogenin Expression in 17 β -Estradiol Treated Male Japanese Medaka by Subsequent Dihydrotestosterone Exposure, Abstracts of the 25th Annual Meeting of the Society of Environmental Toxicology and Chemistry. Portland, OR, 2004

Xie, L., Sapozhnikova, Y., Bawardi, O., Woodside, G. and D. Schlenk, Evaluation of Estrogenicity in Tertiary Treated Wastewater Effluent from Orange County Water District, California, USA, Abstracts of the 24th Annual Meeting of the Society of Environmental Toxicology and Chemistry. Austin, TX, 2003

Collaborative Efforts

Greg Woodside, Stephen Lyon, Orange County Water District

David Hinton, Duke University

For further information, please contact:

- **Dr. Daniel Schlenk**

e-mail: daniel.schlenk@ucr.edu

Phone: 951-827-2018

Webpage:

<http://www.envisci.ucr.edu/index.php?file=faculty/schlenk/schlenk.html>

Research Category IV

Water Development and Management Alternatives

This category encompasses methods and techniques for formulating and evaluating water resources planning, development and management alternatives. Topics that logically fall in this category include policies and planning and operating water supply systems, conjunctive use of surface and subsurface storage, alternative uses for reclaimed and low quality water markets and water pricing and development and improved criteria for water project planning.





Imperial Valley Agriculture and Water: A Regional Economic Analysis

Kurt Schwabe
Department of Environmental Sciences
UC Riverside

Reductions in Colorado River allotments to California's productive Imperial Valley, as well as potential restrictions on effluent discharges into the Salton Sea, will necessitate greater water use efficiency from agricultural systems. We have developed and calibrated a mathematical programming model of Imperial Valley production that is designed to evaluate the ability of growers to meet these new demands. Inputs into the model include costs associated with modifying major irrigation systems and changing crop types, savings associated with water reduction strategies, and yield response to altered biophysical parameters. This model has been calibrated and can now be used to evaluate various biophysical and economic questions. Additional components to be evaluated include the impacts of these regulations on changes in labor and income as they will affect the regional economy by linking the results of our model to a well-accepted economic multiplier software program (IMPLAN).

During our first year of this project we have developed the mathematical programming model and explored possibilities to link its results to a regional economic multiplier model. The agricultural production model is now developed. Cost and price parameters, as described below, as well as the response functions, have been entered and initial model runs have been successful. With calibration completed, the model can now be used to evaluate various biophysical and economic issues, including the potential impact of the Quantification Settlement Agreement on agricultural profitability.

Price and Production Cost Data. In developing this model, we have estimated and calculated representative price and production cost data for the major irrigation systems (furrow, sprinkler, and drip) and cropping categories (represented by wheat, lettuce, alfalfa, sugar beets, and carrots). These have all been entered into the programming model.

Water Reduction Strategies. In addition to changing crop type, irrigation system, and applied water rates, we have estimated costs and water savings associated with tail-water recovery, reduced frequency of irrigation events, and early cutoff techniques. These have all been entered into the programming model.

Biophysical Response Functions. To develop the seasonal response functions that relate evapotranspiration (ET) to applied water (AW), and yield (Y) to ET , we begin with a plant level model that consists of the following two equations:

$$1 - Y_{at} / Y_m = k_y (1 - ET_t / ET_m) \quad (1)$$

$$ET_t = ET_m \frac{1}{1 + \left(\frac{1 + AW_t}{AW_{50}} \right)^{-\phi}} \quad (2)$$

Y_m and ET_m in equation (1) are parameters representing maximum yield (under non-stressed conditions) and maximum ET , k_y is a factor relating deficits in ET to deficits in yield, and Y_{at} and ET_t are the actual yield and ET variables at time t during the season. Equation (2) is the specific functional form used to capture the daily relationship between applied water and ET , where AW_{50} represents the allocation of water that corresponds to a decrease in ET by 50%. $t \in \{1, T\}$, where T is the number of days within the growing season for any particular crop, and ϕ is a coefficient to be estimated.

Through simulations that generate seasonal data on ET , AW , and Y by varying both the critical moisture level which triggers an irrigation event and the magnitude of the irrigation response relative to the moisture deficit when such an event occurs, response functions that represent seasonal ET - AW and seasonal Y - ET can be estimated.

The seasonal ET - AW specification is presented in Figure 1 using the example of carrots and three different irrigation systems.

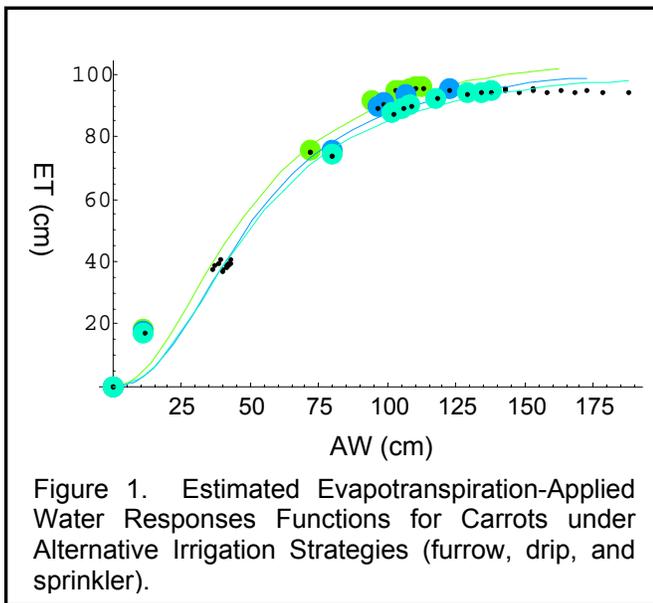


Figure 1. Estimated Evapotranspiration-Applied Water Responses Functions for Carrots under Alternative Irrigation Strategies (furrow, drip, and sprinkler).

Response functions for $Y-ET$ have been estimated under a variety of well-known functional specifications, including a linear, quadratic, and root function as listed in Table 1. Here the results compare the different specifications using a well-accepted goodness of fit measure - minimizing the sum of squares residuals (SSR). In most cases, the $Y-ET$ specification that minimizes the SSR is the root function. These functions and their estimated coefficients have been entered into the programming model.

ET, AW, and Runoff. Application of water to meet the needs of crops will result in some runoff. Soils in Imperial Valley are prone to swelling shut during irrigation. This suggests that there will be tail-water runoff generated in the irrigation process if water is applied after the soils have sealed. Equation (3) captures this relationship and can be used to investigate the effects of water applications from Imperial Valley agriculture production on deep percolation and tail-water runoff.

$$ET + R = AW \quad (3)$$

Runoff (R) is the sum of deep percolation flows and tail-water runoff. The relationship among R, drainwater effluent, and inflows into the Salton Sea are being investigated currently.

Regional Economic Multiplier Analysis. To evaluate how changes in agricultural activities influence the regional economy, we have acquired a well-accepted economic multiplier software program, IMPLAN. We are currently investigating how our choice of link

between the agricultural production model and the regional economic multiplier, either through changes in labor or changes in income, influences the output from IMPLAN.

Professional Presentations

Schwabe, K., and N. Nergis, Fundamentals of Estimating the Net Benefits of Ecosystem Preservation: The Case of the Salton Sea, Salton Sea Centennial Symposium: A Salton Sea for the 21st Century: Science, Rehabilitation, and Management, San Diego, California, April 1st, 2005

Table 1. Sum of square residuals under alternative functional form by crop and irrigation Type (best fit in bold).

	<u>Linear</u> ¹	<u>Root</u> ²	<u>Quadratic</u> ³
Wheat			
Furrow	7.68x10 ⁻⁵	3.62x10⁻⁷	3.76x10 ⁻⁶
Sprinkler	9.66x10 ⁻⁵	8.4x10⁻⁵	8.55x10 ⁻⁵
Drip	1.16x10 ⁻⁴	8.9x10 ⁻⁵	8.56x10⁵
Alfalfa			
Furrow	0.314	0.295	0.303
Sprinkler	0.201	0.187	0.192
Drip	0.104	0.004	0.006
Sugar beets			
Furrow	0.008	0.004	0.001
Sprinkler	0.003	0.002	0.003
Drip	0.007	0.0006	0.002
Carrots			
Furrow	64.76	59.58	64.76
Sprinkler	26.40	10.90	20.22
Drip	0.496	0.183	0.174
Lettuce			
Furrow	11.47	0.436	0.151
Sprinkler	13.92	3.015	1.809
Drip	14.60	6.182	9.708

Footnotes:

1. Dinar and Letey (1996) [Modeling Economic Management and Policy Issues of Water in Irrigated Agriculture](#), Greenwood Publishing Group.
2. Hexem and Heady (1978) [Water Production Second Functions for Irrigated Agriculture](#), Iowa State University Press.
3. Kan et al. (2002).

For further information, please contact:

- **Dr. Kurt Schwabe**
e-mail: kurt.schwabe@ucr.edu
Phone: 951-827-2361
Webpage:
<http://www.envisci.ucr.edu/index.php?file=faculty/schwabe/schwabe.html>



Futures Markets for Water in California: Effective Management of Supply-Side Risk

Jeffrey Williams
Department of Agricultural/Resource Economics
UC Davis

Would a state-sponsored, long-term water options market in California provide positive net benefits to the state by allocating water among competing uses more efficiently over time? Efforts thus far suggest yes; work progresses on determining the optimal structure of the institution and the magnitude of the benefits.

In the early 1990s, the California Department of Water Resources established several temporary water banks to ensure that all urban, agricultural and environmental critical needs were met during drought conditions. As demands on the water supply intensify, policymakers will be asking whether California should consider sponsoring a formal market mechanism to facilitate forward trades in water during all years, not just during critically dry years. A well functioning futures market would improve the allocation of water over time and space. It would help make better use of existing storage, provide an alternative to additional storage construction, and reduce the supply-side risks inherent in the California water system.

Option agreements, whereby a water agency purchases the right to buy water at a predetermined price should the water year turn out to be dry, already exist in California on a bilateral basis. The value of an option represents the value of transferring the risk of supply uncertainty from the buyer to the seller. The question is whether such option agreements will continue to emerge naturally through bilateral negotiation, or whether the negotiation and enforcement costs of undertaking such agreements make them prohibitive in the absence of state involvement.

Our mathematical programming model is designed to analyze whether allowing water agencies to trade water across time as well as space would result in significant benefits for California, in the form of lower price variation and lower supply uncertainty from year to year.

Before our model can perform final policy simulations, several project tasks must fall into place. First, we have begun modifications to CALVIN, the economic-engineering optimization model of the California state water system, which are necessary in order to deter-

mine option value at multiple locations within California. These locational option values will indicate to us whether water agencies in the state would be willing to buy and sell options in the first place.

Second, we are identifying possible institutional structures for the option market which would be feasible for and attractive to water traders. Our initial research has given us insights into the use of option agreements in California, as well as the use of other contractual risk management tools available to water agencies, such as temporary leasing of water rights rather than outright purchase, and participation in water banks. In addition, an econometric analysis has demonstrated that the predominance of water rights sales versus leases within each of 12 western states depends on hydrological and economic conditions, as well as the existence or absence of laws to protect the environment and third parties from harm resulting from water transfers.

Publications

Howitt, Richard and Kristiana Hansen, Trading a Quasi-Public Resource: Evolving Western Water Markets. *Choices*, 27(2), 2005.

Professional Presentations

Hansen, Kristiana, Richard Howitt and Jeffrey Williams, Water Markets in the Western United States: An Econometric Test of the Endogeneity of Institutions, Western Agricultural Economics Association, San Francisco, CA, July 2005; and American Agricultural Economics Association, Providence, RI, July, 2005.

For further information, please contact:

• **Dr. Jeffrey Williams**

e-mail: williams@primal.ucdavis.edu

Phone: 530-754-7625

Webpage: <http://www.agecon.ucdavis.edu/>



Modeling and Optimization of Seawater Intrusion Barriers in Southern California Coastal Plain

William W-G. Yeh and Ben Bray
Department of Civil & Environmental Engineering
UC Los Angeles

Saltwater intrusion is a problem that threatens the water quality of many coastal aquifers around the world. An effective way to mitigate seawater intrusion is to form subsurface hydraulic barriers by injecting freshwater into an array of wells aligned parallel to the coastline. We have successfully simulated the complexity of barrier operations with a state-of-the-art groundwater flow and transport model. This model is being applied to develop management strategies to improve the operation and efficiency of the three major coastline barriers of Los Angeles County. It will also allow the investigation of alternative and competing strategies and their cost-effectiveness for future operation.

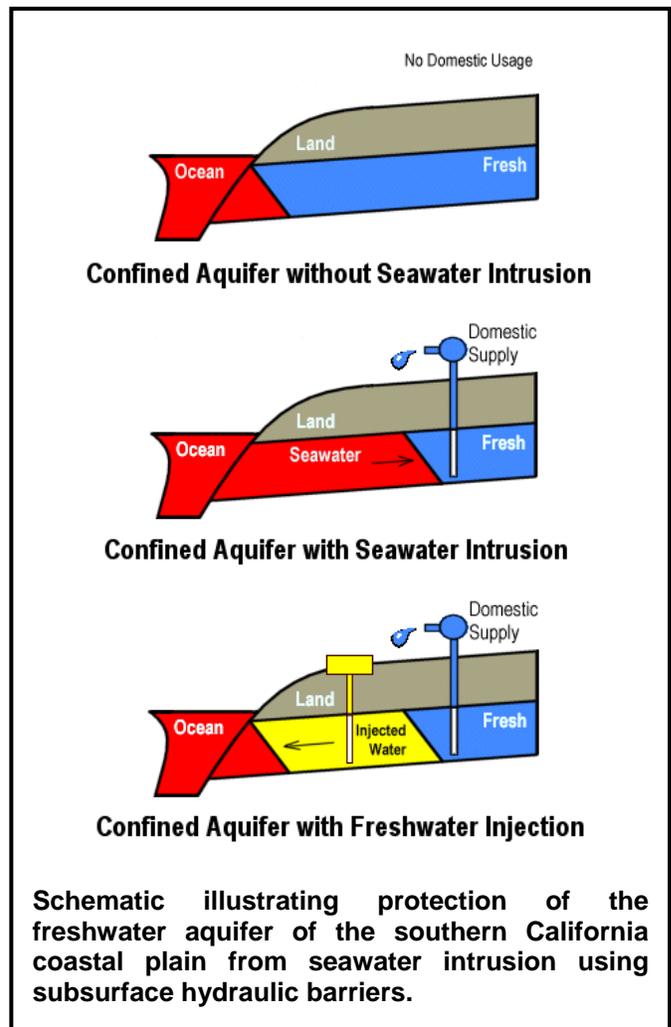
Today, there are three major hydraulic barriers in operation along the coastline of Los Angeles County. Here reclaimed water is injected into the subsurface in order to protect freshwater pumping wells in the coastal plain. This process raises the water level to prevent seawater intrusion into the freshwater aquifer, and protects the 20,300,000 acre-foot groundwater reservoir used to meet approximately 35% of the potable water supply for 3.2 million residents.

The goal of this research project is to use state-of-the-art groundwater modeling and optimization techniques to develop management strategies that will improve the operation and efficiency of one of the three Los Angeles County barriers, the Los Alamitos Gap Barrier. Specifically, the objectives are to: (1) calibrate and validate a flow and transport computer model to simulate the complex barrier operations, (2) determine the optimal management strategy of the existing barrier facilities, (3) identify the optimal candidate sites for additional injection wells, and (4) investigate alternative and competing management strategies that may be cost effective in addressing the seawater intrusion problem.

Currently the first phase of the study, the model development and calibration, has been completed. Documentation of the model has been ongoing during transition to its use to determine management strategies. The random hydraulic conductivity field has been estimated using natural-neighbor-kriging (NNK). For each aquifer considered, the NNK results are consistent with prior maps of hydraulic conductivity trends based on physical characteristics.

Transport calibration requires significantly longer computer simulation runs to maintain accuracy. An optimal lumped transport parameter setting is identified, and the model error could not be reduced further by

increasing the transport parameter complexity. A draft manuscript has been completed describing the model development and calibration phase and has been



formally submitted for journal publication. Completion of the second management phase and documentation is slated for November 2005.

Collaborative Efforts

Youn Sim, Ph.D., P.E., Water Resources Division, County of Los Angeles, Department of Public Works.

Professional Presentations

Bray, B.S., Y. Sim, , W.W-G Yeh, "Calibration of a Complex Three-Dimensional Coastal Aquifer with Density-Dependent Flow", American Geophysical Union 2004 Fall Meeting, San Francisco, Dec. 13-17, 2004.

Acknowledgements

Thanks to the Water Resources Division, County of Los Angeles, Department of Public Works for illustrations.

For further information, please contact:

- **Dr. William W-G. Yeh**
e-mail: williamy@seas.ucla.edu
Phone: 310-825-2300
Webpage:
http://cee.ucla.edu/cgi-bin/peop_faculty.php?fpg=0&uid=4

Research Category V

Water Law, Institutions and Policy

This category encompasses all institutional arrangements (including laws and regulations) that are available or potentially available for developing and managing water resources. Topics which logically fall in this category include institutional arrangements for managing water scarcity, institutional arrangements for managing groundwater (both quantitatively and qualitatively), potential institutional conflicts associated with specific water development and management alternatives and the evolution of water management institutions in California. There is an especially compelling need for policy studies which involve analytical investigations of alternative polities for dealing with all aspects of California's water situation.





An Economic Analysis of Groundwater Nitrate Pollution Control in Dairy-Intensive Watersheds

Kenneth A. Baerenklau
Department of Environmental Sciences
UC Riverside

Non-trivial time lags are inherent in the process of lessening groundwater nitrate pollution due to dairy farms. We are developing a mathematical model that incorporates these time lags, allowing us to explore the environmental and economic effects of different regulatory alternatives. Preliminary results indicate that altering herd dynamics alone can take on the order of five to ten years. The ability to assess such delays will help state policy-makers balance the health of the dairy industry with that of the environment.

A mathematical model is being developed to assess the costs of the various alternatives available to control groundwater nitrate pollution in dairy-intensive watersheds. The results of the analysis will be applied to designing policies capable of achieving nitrate standards cost-effectively.

Our modeling approach builds upon previous agricultural economics literature that recognizes the importance of accounting for delayed effects of pollution control policies when assessing the economic efficiency of policy alternatives. Simply put, a longer time lag between the initiation of a source control policy and the realization of reduced damages at a receptor point tends to favor less stringent source control efforts.

In the case of dairy farms, there are three main sources of delay. First, the dynamic nature of managing a dairy herd implies a farmer's optimal response to changing operating conditions will not be instantaneous. Rather, there will be a gradual transition from one herd profile to another. Second, the organic nitrogen resulting from dairy operations must be mineralized before it can be leached, and this process takes time. And third, nitrogen leachate must be transported from source to receptor before it causes damage.

Determining the optimal balance between source control and receptor treatment efforts requires accounting for these dynamic processes. Therefore we are modeling each process in a single mathematical framework to allow the simulation of the economic and environmental effects of different nitrate pollution control alternatives. Our model includes: farm-level decision-making, herd and crop production, waste generation and reuse, and fate and transport mechanisms.

Preliminary results from the model indicate that the delay caused by herd dynamics alone can be on the order of five to ten years. Then, a similar amount of time may be required for soil nitrogen concentrations to reach a new steady state level. These non-trivial time lags must be included in any analysis of the cost-effectiveness of dairy farm regulations; otherwise the derived policies will most likely be economically inefficient.

Collaborative Efforts

Dr. Thomas Harter, Associate Groundwater Quality Hydrologist, UC Davis.

For further information, please contact:

• **Dr. Kenneth Baerenklau**

e-mail: ken.baerenklau@ucr.edu

Phone: 951-827-2628

Webpage:

<http://www.envisci.ucr.edu/index.php?file=faculty/baerenklau/baerenklau.html>



Principal Investigator Index

Richard Ambrose

Environmental Science & Engineering Program
Dept. of Environmental Health Science
University of California
Los Angeles, CA 90095-1772
Phone: 310-825-6144
Fax: 310-206-3358
Email: rambrose@ucla.edu
Website: <http://www.ph.ucla.edu/ese/faculty/ambrose.html>

Kenneth A. Baerenklau

Dept. of Environmental Sciences
University of California
Riverside, CA 92521
Phone: 951-827-2628
Fax: 951-827-3993
Email: ken.baerenklau@ucr.edu
Website: <http://www.envisci.ucr.edu/index.php?file=faculty/baerenklau/baerenklau.html>

Cheryl Briggs

Dept. of Integrative Biology
3060 Valley Life Sciences Bldg.
University of California
Berkeley, CA 94720-3140
Phone: 510-643-3889
Fax: 510-643-6264
Email: cbriggs@berkeley.edu
Website: <http://socrates.berkeley.edu/~cbriggs/>

Patricia A. Conrad

Dept. of Pathology, Microbiology, and Immunology
1126 Haring Hall
One Shields Avenue
University of California
Davis, CA 95616
Phone: 530-752-7210
Fax: 530-752-3349
Email: paconrad@ucdavis.edu
Website: <http://faculty.vetmed.ucdavis.edu/faculty/paconrad/>

Paul De Ley

Dept. of Nematology
University of California
Riverside, CA 92521
Phone: 951-827-2280
Fax: 951-827-3719
Email: paul.deley@ucr.edu
Website: <http://faculty.ucr.edu/~pdeley/lab/labhome.html>

William E. Dietrich

Earth and Planetary Sciences
307 McCone Hall
University of California
Berkeley, CA 94720
Phone: 510-642-2633
Fax: 510-643-9980
Email: bill@eps.berkeley.edu
Website: <http://socrates.berkeley.edu/~geomorph>

William T. Frankenberg Jr.

Dept. of Environmental Sciences
University of California
Riverside, CA 92521
Phone: 951-827-3405
Fax: 951-827-2954
Email: william.frankenberg@ucr.edu
Website: <http://envisci.ucr.edu/index.php?file=faculty/frankenberg/frankenberg.html>

Jay Gan

Dept. of Environmental Sciences
University of California
Riverside, CA 92521
Phone: 951-827-2712
Fax: 951-827-3993
Email: jgan@ucr.edu
Website: <http://envisci.ucr.edu/index.php?file=faculty/gan/gan.html>

Michael Goulden

Dept. of Earth System Science
3319 Croul Hall
University of California
Irvine, CA 92697
Phone: 949-824-1983
Fax: 949-824-3256
Email: mgoulden@uci.edu
Website: <http://www.ess.uci.edu/~goulden/>
<http://www.ess.uci.edu/~goulden/Marshproductivity.html>

Michael Johnson

John Muir Institute of the Environment
One Shields Avenue
University of California
Davis, CA 95616
Phone: 530-752-8837
Fax: 530-754-9141
Email: mbjohnson@ucdavis.edu
Website: <http://johnmuir.ucdavis.edu/aeal>

Maggi Kelly

Dept. of Environmental Science, Policy and Management
137 Mulford Hall #3110
University of California
Berkeley, CA 94720-3114
Phone: 510-642-7272
Fax: 510-642-1477
Email: mkelly@nature.berkeley.edu
Website: <http://kellylab.berkeley.edu>

Sharon P. Lawler

Entomology
One Shields Avenue
University of California
Davis, CA 95616
Phone: 530-754-8341
Fax: 530-752-1537
Email: splawler@ucdavis.edu
Website: <http://entomology.ucdavis.edu/faculty/facpage.cfm?id=lawler>

Steven A. Margulis

Dept. of Civil and Environmental Engineering
5732D Boelter Hall
University of California
Los Angeles, CA 90095
Phone: 310-267-5490
Fax: 310-206-2222
Email: margulis@seas.ucla.edu
Website: <http://www.seas.ucla.edu/~margulis/>

Michael McKibben

Dept. of Earth Sciences
University of California
Riverside, CA 92521
Phone: 951-827-3444
Fax: 951-827-4324
Email: michael.mckibben@ucr.edu
Website: <http://mckibben.ucr.edu>

John M. Melack

Dept. of Ecology, Evolution and Marine Biology, and
The Bren School of Environmental Science and Management
University of California
Santa Barbara, CA 93106
Phone: 805-893-3879
Fax: 805-893-4724
Email: melack@lifesci.ucsb.edu
Website: <http://www.lifesci.ucsb.edu/eemb/faculty/melack/>

Ashok Mulchandani

Chemical and Environmental Engineering
Bourns College of Engineering
University of California
Riverside, CA 92521
Phone: 951-827-6419
Fax: 951-827-5696
Email: adani@engr.ucr.edu
Website: www.engr.ucr.edu/~adani

Kara Nelson

Civil and Environmental Engineering
University of California
Berkeley, CA 94720-1710
Phone: 510-643-5023
Fax: 510-642-7483
Email: nelson@ce.berkeley.edu
Website: <http://www.ce.berkeley.edu/~nelson/>

Anthony T. O'Geen

Dept. of Land, Air and Water Resources,
One Shields Avenue
University of California
Davis, CA 95616
Phone: 530-752-2155
Fax: 530-752-1552
Email: atogeen@ucdavis.edu
Website: http://lawr.ucdavis.edu/directory_facultypages.php?id=46

Betty H. Olson

Environmental Health, Science & Policy
1368 Social Ecology II
University of California
Irvine, CA 92697
Phone: 949-824-5281
Fax: 949-824-2056
Email: bholson@uci.edu
Website: <http://www.seweb.uci.edu/faculty/olson/>

Daniel Schlenk

Dept. of Environmental Sciences
University of California
Riverside, CA 92521
Phone: 951-827-2018
Fax: 951-827-3993
Email: daniel.schlenk@ucr.edu
Website: <http://envisci.ucr.edu/index.php?file=faculty/schlenk/schlenk.html>

David H. Schoellhamer

Dept. of Civil and Environmental Engineering
One Shields Avenue
2001 Engineering III
University of California
Davis, CA 95616
Phone: 916-278-3126
Fax: 916-278-3013
Email: dschoell@ucdavis.edu
Website: <http://cee.engr.ucdavis.edu/faculty/schoellhamer/>

Kurt A. Schwabe

Dept. of Environmental Sciences
University of California
Riverside, CA 92521
Phone: 951-827-2361
Fax: 951-827-3993
Email: kurt.schwabe@ucr.edu
Website: <http://envisci.ucr.edu/index.php?file=faculty/schwabe/schwabe.html>

Lisa C. Sloan

Dept. of Earth Sciences
1156 High St
University of California
Santa Cruz, CA 95064
Phone: 831-459-3693
Fax: 831-459-3074
Email: lcsloan@pmc.ucsc.edu
Website: www.es.ucsc.edu/~lcsloan/

Slawek Tulaczyk

Dept. of Earth Sciences
1156 High St.
University of California
Santa Cruz, CA 95060
Phone: 831-459-5207
Fax: 831-459-3074
Email: tulaczyk@pmc.ucsc.edu
Website: www.es.ucsc.edu/~tulaczyk

Bryan C. Weare

Dept. of Land, Air and Water Resources
One Shields Avenue
University of California
Davis, CA 95616
Phone: 530-752-3445
Fax: 530-752-1552
Email: bcweare@ucdavis.edu
Website: http://lawr.ucdavis.edu/directory_facultypages.php?id=32

Jeffrey Williams

Dept. of Agricultural/Resource Economics
University of California
One Shields Avenue
Davis, CA 95616
Phone: 530-754-7625
Fax: 530-752-5614
Email: williams@primal.ucdavis.edu
Website: http://www.agecon.ucdavis.edu/aredepart/faculty_info.php?id=37

William Yeh

Dept. of Civil and Environmental Engineering
5732B Boelter Hall
University of California
Los Angeles, CA 90095-1593
Phone: 310-825-2300
Fax: 310-825-7581
Email: williamy@seas.ucla.edu
Website: www.cee.ucla.edu/faculty/yeh.htm