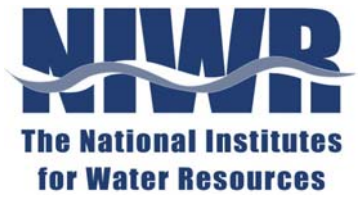
California
Water Resources Center



Annual Report
2003 – 2004

July 1, 2003 – June 30, 2004

Dr. John Letey, Director
Dr. Andrew Chang, Associate Director

UC Center for Water Resources

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:

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Copies of Center publications may be examined at:

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FROM THE DIRECTOR

Dr. John Letey

The University of California Center for Water Resources (CWR) is composed of various programs which were initially established as separate programs. Each was established on a different date for different purposes.

The Water Resources Center (WRC) is a multicampus research unit in the University's Division of Agriculture and Natural Resources and is charged with stimulating and coordinating research and information dissemination on water. The Center was first funded in 1957 by the California legislature as a University-wide organized research unit. Over the years, its mission has expanded from an early focus on the State Water Project to one that encompasses virtually all water and water-related issues.

The Federal Water Resources Research Act of 1964 specified that each state have a water resources institute as part of the network of National Institutes of Water Resources (NIWR).

The University of California WRC was selected to be California's Institute. As a member of NIWR, the Center receives a base budget ($92,524 during 2003-2004) and the opportunity to submit proposals to the National Competitive Grants Program and also receive USGS funding for specific research projects. The University of California received one of the eight projects funded nationally from the Competitive Grants Program. The award was "Institutional Re-arrangements: forging "smart use" water policy coalitions at the intersection of geo-geotechnical engineering with urban open space" with Dr. Helen Ingram from the University of California, Irvine, as principal investigator ($70,767).

Through the Center, $807,936 was awarded to Dr. Joel Michaelsen at UC Santa Barbara for the project "Spatially Explicit Modeling and Monitoring of Hydroclimatic Extremes: Reducing the Threat to Food Security n the Developing World". That contract has been extended to September 2007 for an additional $3,042,444.

The Coordinating Board, comprised of academic senate members from the U.C. campuses, serves as the governing body of the WRC. The Advisory Council participates with the Coordinating Board members in reviewing research proposals to be funded from WRC and NIWR moneys and discussing business matters at joint meetings.

The largest proportion of the WRC budget goes to supporting research projects on a broad range of water-related issues. The annual progress reports on these projects are included within this publication. The projects serve the dual role of developing knowledge and training students. On average, more than

80% of the budget is used to support students involved in the research.

The WRC provides the major support budget for the Water Resources Center Archives, located on the Berkeley campus. However, the financial and other support services by various donors and the Advisory Board to the Water Resources Center Archives are acknowledged and greatly appreciated. A more detailed report on the Archives is presented on page 9 of this annual report.

Salinity/Drainage Program

The Salinity/Drainage Program (S/D) was developed in 1985 to promote research in the area of critical agricultural and environmental problems on the west side of the San Joaquin Valley. The program was established after the discovery of selenium toxicosis of waterfowl at the Kesterson Reservoir, which then served as a collection site for farm subsurface drainage water.

The Prosser Trust Fund is administered through the Salinity/Drainage Program. Joseph G. Prosser and his son developed the tensiometer as a soil water-sensing device. Subsequent relationships he developed with scientists at the Citrus Experiment Station in Riverside, led to his providing the University of California an endowment to support the development of efficient irrigation activities. The annual income from this trust fund is distributed for research and extension activities pursuant to the terms of the trust.

The Salinity/Drainage and Prosser Trust funds were designated for mission oriented research and, therefore, the call and review of proposals for these programs is separate from the WRC and NIWR funded projects. The annual research progress reports from these projects are published separately.

Budget

The University of California received a large budget reduction for 2003-2004 as a result of the state fiscal crisis. As a result, the Water Resources Center was assessed a 17.5% budget reduction ($200,000). The uncertainty in the budget for a period well beyond July 1 necessitated awards to the research projects approved for initiation in 2003 to be delayed until October 1. The Salinity/Drainage Program received a 45% budget cut ($250,000). Although administrative budget cuts were imposed, the major part of the budget reduction had to come at the cost of supporting research projects.

Personal Note

On a personal note, I retired July 1, 2003; however, I have maintained a part-time appointment as Interim Director to the Center. The appointment was initially through December 31, 2003, later extended through June 30, 2004, and, finally, through September 2004, which will complete my slightly more than 11 years of administrative responsibility to the UC Center for Water Resources. Just prior to publication of this report my appointment has been extended to December 31, 2004.

My tenure with the Center has been a very rewarding and enjoyable experience. At the top of my positive list are the numerous individuals with whom I have become acquainted and interacted with in the quest to address the present and future issues associated with water resources management in California. I particularly acknowledge and thank the numerous individuals who have served on technical and advisory committees serving the Center for Water Resources. Their service and contributions have been extremely valuable and made my assignment much easier.

THE COORDINATING BOARD

The Coordinating Board establishes policy for the Center and makes final decisions regarding the allocation of available funds. It is chaired by the Vice President of Agriculture and Natural Resources, through whom it reports directly to the President of the University. The Board, appointed by the President of the University, is composed of at least 13 faculty members from diverse disciplines and various administrative, teaching and research responsibilities. All members have a strong interest in water-related research. Eight of the nine campuses of the University are represented on the Board. The Board normally meets twice yearly (either in person or via phone conferencing), although special committees of the Board may meet from time to time throughout the year and individual members attend Center-sponsored meetings and conferences. Members serve as liaisons or as contacts on their own campuses, as well as to agencies, citizens, faculty, and students in water-related research. These liaison interactions contribute valuable insights in establishing policy for the Water Resources Center. Members of the Coordinating Board during 2003-2004 were:

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THE ADVISORY COUNCIL

The Advisory Council shall include representatives from the State Water Resources Control Board, Department of Water Resources, California Department of Fish and Game, and the U.S. Geological Survey who are selected by the appropriate administrator for each agency. Additionally, experts from a broad spectrum of water interests are appointed to the Advisory Council.

The Council members serve a very effective liasion function between the Water Resources Center and the public and private organizations that are involved in the management, development, control and use of water resources.

The Advisory Council meets jointly with the Coordinating Board to evaluate and rank research proposals based on scientific merit and relevancy.

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RESEARCH ACTIVITY BY CAMPUS

	2003 - 2004		
LOCATION	PROJECTS FUNDED	GRADUATE STUDENTS SUPPORTED	UNDERGRADUATE STUDENTS SUPPORTED
UC Berkeley	6	7	4
UC Davis	7	9	6
UC Irvine	0	0	0
UC Los Angeles	3	3	0
UC Riverside	8	11	8
UC San Diego	0	0	0
UC Santa Barbara	1	2	0
UC Santa Cruz	2	3	5
TOTAL	27	35	23

INFORMATION PROGRAM ACTIVITIES

THE WATER RESOURCES CENTER ARCHIVES

Mission

The mission of the Water Resources Center Archives (WRCA) is to develop and maintain a collection of water-related materials to meet the research needs of the University of California's systemwide instructional, research, and service programs. Established in 1957, the collection is relied upon by the University community as well as government agencies, corporate professionals, and the public.

Collection

WRCA is a research library with more than 150,000 cataloged items. The scope of the collection includes freshwater supply and quality, groundwater, municipal and industrial water uses, flood control, water reuse, wastewater treatment, river mechanics, coastal engineering, estuaries, water pollution, and water law. WRCA collects a variety of types of materials including printed reports, government documents, books, manuscripts, maps, videos, photographs, and electronic resources. The collection concentrates on materials about California and the West, but also includes materials about national and international water resources.

WRCA added 1,010 new titles to its collection in 2003-2004. Use of the collection in 2003-2004 consisted of 7,810 transactions, including both items used on the premises and items borrowed. Users were approximately as follows: graduate students: 28%, undergraduate students: 16%, faculty and staff: 8%, general public 39%, interlibrary loans: 10%.

Outreach

California Colloquium on Water

The California Colloquium on Water is an interdisciplinary lecture series that aims to increase understanding and appreciation of water resources and contribute to informed decision-making about water in California. Each semester four distinguished scholars in the fields of humanities, natural sciences, engineering, social sciences, law, and environmental design present lectures to students, faculty, and the general public. VHS tapes of the lectures are available for loan at WRCA.

In 2003-2004, financial support totaling $12,000 was provided by deans of five UC Berkeley colleges (Engineering, Environmental Design, Letters & Science, Natural Resources, Boalt Hall School of Law) as well as the UC Berkeley Executive Vice-Chancellor & Provost and the Groundwater Resources Association of California.

Publicity was increased to a wide variety of print and online media, both on campus and off, as well as extensive email communication. Attendance increased

again, reaching an average of 65-75 people per lecture in the spring, with over 100 audience members each at several of the lectures. The program is listed below.

September
"Four Decades of Saving the Bay"
Sylvia McLaughlin, Co-founder of Save The Bay

October
"A Paranoid's View of the Colorado River"
Thomas Levy, Consultant

November
"Channel Change of the Colorado River: A Mandate for Restoration?"
John C. Schmidt, Associate Professor of Aquatic, Watershed & Earth Resources, Utah State University

December
"The Geysers: The Nature, Development & Preservation of a Unique Resource"
W. T. (Tom) Box, Jr., Vice President, Geothermal Resource Management, Calpine Corporation

February
"Frontiers of Hydrologic Research in the 21st Century"
Ignacio Rodriguez-Iturbe, Professor of Environmental Studies and Civil & Environmental Engineering, Princeton University

March
"Rotten Foundations: The Reclamation Act & Urbanization of the West"
Gray Brechin, Research Fellow, Department of Geography, UC Berkeley

April
"Desalination Issues in the United States"
Kevin Price, Manager, Water Treatment Engineering Research & Development Group, U.S. Bureau of Reclamation

May
"The Evolution of California Water Policy"
David Kennedy, Former Director, California Department of Water Resources

Publications

Newsletter & Selected Recent Accessions

WRCA continued to produce *Selected Recent Accessions* and *WRCA News*. *Selected Recent Accessions* is a bi-monthly list of publications added to the collection. *WRCA News* is now published only twice a year. Both publications are available in PDF format only, and their completion is published via an email list (currently over 250 subscribers). Current and past issues are available on the WRCA Web site (http://www.lib.berkeley.edu/WRCA/).

Calendar

WRCA collaborated again this year with the Harmer E. Davis Transportation Library to produce a wall calendar. Entitled *Building Our Bridges: Then and Now*, the 2004 calendar featured historical and current photographs of construction of the San Francisco-Oakland Bay Bridge and the Carquinez Bridge. Many of the photographs are from WRCA's manuscript collections. The calendar was financially supported by four corporate sponsors: HBG Flatiron, Inc., T.Y. Lin International, Moffatt & Nichol Engineers, and ROMA Design Group. 1300 calendars were distributed to friends and donors of the two libraries and sold in local bookstores and via mail order. The two libraries are currently working on the 2005 calendar, which will also feature historical and contemporary images of those two bridges.

Beach Sand Exhibit

Linda Vida, WRCA Director, prepared an exhibit about beach sand in collaboration with Robert L. Wiegel, Professor Emeritus of Civil & Environmental Engineering. The exhibit paired Prof. Wiegel's sand

collection with materials from WRCA, including books, journals, and photos from the Wiegel Coastal Slides Collection. Berkeley Library staff performed graphic design and installation of the exhibit in UC Berkeley's undergraduate library (Moffitt).

Conferences
WRCA staff exhibited at four conferences in 2003-2004:

- Water Environment Federation's Technical Exhibition and Conference (WEFTEC); Los Angeles, CA; October 11-15, 2003
- State of the Estuary Conference; Oakland, CA; October 21-23, 2003
- 24th Biennial Groundwater Conference; Ontario, CA; October 28-29, 2003
- Water Conservation Showcase and Product Expo; San Francisco, CA; May 25, 2004 (Sponsors: Pacific Energy Center, U.S. Green Building Council, Northern California Chapter)

Online Resources

San Francisco Bay Fund Inventory of Projects
In October 2003, WRCA completed the San Francisco Bay Fund Inventory of Projects (*http://lib.berkeley.edu/WRCA/bayfund*), the culmination of an $8,000 grant from the San Francisco Foundation. This online inventory is a central clearinghouse of information about the projects funded by The San Francisco Bay Fund Initiative.

Over the course of three years, The San Francisco Bay Fund, an initiative of The San Francisco Foundation, has provided funding to over 30 locally based environmental projects that work to improve water quality or reduce pollution through research or restoration in San Francisco Bay or its watershed. These projects focus on public health, fisheries, and wildlife.

WRCA partnered with the UC Davis Information Center for the Environment (ICE) to create this inventory as part of a larger goal of facilitating access to information about the wide variety of restoration projects in the Bay Area. WRCA staff members Terry Richards and Xiaojun Peng compiled a wealth of information and designed a user-friendly Web interface, complete with photographs, volunteer information, and more for each of the 2001 grantees. Each project is also registered with the Natural Resource Projects Inventory database.

Robert L. Wiegel Coastal Slides Catalog
WRCA completed a searchable online catalog: the *Robert L. Wiegel Coastal Slides Catalog*. This recent addition to the WRCA Web site indexes Professor Emeritus Wiegel's collection of almost 12,000 slides and photographs, which he recently donated to WRCA.

The subjects of the slides and photos include beaches, waves, breakers, rip currents, river mouths, erosion, structures, and beach nourishment, as well as some dams and inland waters. In addition to his own images, Prof. Wiegel has collected some by Joe W. Johnson, William J. Herron, Jr., Orville T. Magoon, the U.S. Army Corps of Engineers, and others.

While the images themselves are not online, the catalog greatly facilitates access to this unique collection. Prof. Wiegel originally created a catalog of these slides and photos using the Papyrus Bibliography System. Former WRCA staff member Marisa Escobar imported these records into a more current format. Paul Atwood, WRCA's Technical Services Librarian, has worked with UC Berkeley Library's Digital Publishing Group to make this information available on the WRCA Web site. The online catalog is searchable by country, state, and county (U.S. locations), as well as by date and other keywords.

The catalog is now available online at *http://www.lib.berkeley.edu/WRCA/wiegel_intro.html*. The collection is housed at WRCA and is available for viewing.

eScholarship
The Archives has recently become a partner in eScholarship, a program designed to improve cooperation and communication between research and education by providing full-text online access to academic literature (www.cdlib.org/programs/escholarship.html) Through the use of innovative technology, the program seeks to develop a financially sustainable model and improve all areas of scholarly communication, including its creation, peer review, management, dissemination, and preservation. The Archives is in the process of adding the last several years of WRC Technical Completion Reports to the eScholarship Web site as well as recent river restoration and hydrology course term papers. The papers will also be cataloged in Melvyl with a link to the full-text resource.

Digitization of Lippincott Photos of L.A. Aqueduct
Funding for $19,000 was received from the State Library to digitize approximately 680 photographs in the Joseph B. Lippincott Collection that document the construction of the Los Angeles Aqueduct. The grant funds also cover making the images available on the Web, linked from the existing Lippincott Collection finding aid through the Online Archive of California (OAC). WRCA is working with a freelance archivist, Dayna Holz, to create and implement the required metadata for this project. Technical Services Librarian Paul Atwood is the Project Manager for this grant. The digitized images are expected to be available online in August. Check here for updated information: *http://www.lib.berkeley.edu/WRCA/aqueduct.html* Upon completion, the Los Angeles Aqueduct Photograph Digitization Project will greatly improve access to these historical materials while helping to preserve them into perpetuity.

Advisory Board to Archives (2003-2004)
WRCA continued its fundraising activities during the fiscal year. The Advisory Board to the Archives continued to meet semi-annually to assist with formulating out-reach and fundraising strategies. Board members for the 2003-2004 year are as follows:

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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 Methods

William E. Dietrich
Earth and Planetary Science
UC Berkeley

Project Summary

The majority of the total channel length in mountainous watersheds occurs in steep (gradients greater than 3%), rough channels. Sediment mobilized on hillslopes must first pass through these channels before entering lower-gradient reaches. However, conventional transport equations, developed for lower-gradient reaches, typically over-predict sediment flux in steep streams by several orders of magnitude. This limits our ability to model bedrock incision, route sediment through watersheds, and determine the downstream effects of land use practices on hillslopes.

Steep rough streams have complex hydraulics and a wide range of grain sizes that move over a range of timescales. Sediment transport in these streams is often supply limited due to low grain mobility and episodic sediment supplies from landslides, bank failures and debris flows. We have developed a transport equation to account for the drag on large, relatively immobile grains and the limited supply of relatively mobile sediment. Our goal is to use known bed grain size distributions, the spacing and size of immobile elements, and a river discharge to predict the stress borne by and transport rate of the finer, mobile fraction.

We previously conducted experiments in a small, steep (slope of 10%) in which we fed fine gravel at a constant rate through fields of immobile spheres. We have predicted the flow and sediment transport with our model and five published resistance, and five commonly used sediment transport equations. Our model had the lowest error in prediction of both flow and sediment transport out of all tested equations.

We have also analyzed measurements of flow and sediment transport in a small, steep tributary of the South Fork Eel River. We found that drag borne by the large grains significantly varied with the stage and that the bed was not well represented by isolated roughness elements. We are now using these data to include the effect of boulder clusters and steps in our model instead of our current isolated boulder bed. We are also making similar

When complete, our model could be incorporated into a basin-scale transport calculation to propagate sediment through a channel network.

measurements in another steep channel to further develop and calibrate our model to field conditions.

In addition to boulder clustering, we are modifying our model to include spatial variations in stress and their effects on sediment transport. We conducted experiments in a low gradient flume with Mark Schmeeckle at Arizona State University. Here we measured the local flow and sediment transport (in two dimensions) on beds with and without roughness elements. Preliminary analyses suggest beds with roughness elements have greater spatial distributions in shear stress. Furthermore, the stresses created by the boulders causes transport that would otherwise not occur. Thus, although large boulders often slow the flow and trap gravel (that may be used for spawning) in steeper channels, these grains may induce gravel erosion in lower gradient streams. This may have implications for stream restoration projects in which boulder placement is supposed to augment spawning gravel recruitment.

Our experiments suggest that bed coverage by mobile sediment is an adequate proxy for sediment supply. Inclusion of the mobile stress (predicted through stress-partitioning) and the bed covered by mobile sediment in most transport equations will significantly improve the predicted flux. However, the effects of spatial variations in stress and the presence of boulder clusters are important for field application of our model. When complete, our model could be incorporated into a basin-scale transport calculation to propagate sediment through a channel network. This result could help determine the impacts of land-management practices on downstream sediment supply and therefore on aquatic habitat.

Professional Presentations

Yager, E., J.W. Kirchner, W.E. Dietrich, and D.J. Furbish, Prediction of sediment transport in steep boulder-bed channels, Eos, Transactions, American Geophysical Union, Fall Meeting Supplement, San Francisco, CA, December 10, 2002.

Student Training

Elowyn Yager, graduate, Ph.D.; Earth and Planetary Science, UC Berkeley

Additional Funding

Horton Research Grant for graduate studies, $10,000.

Collaborative Efforts

Collaboration with Mark Schmeeckle on detailed flume measurements of flow and sediment transport around large spherical elements.

Feasibility of Snowpack Characterization Using Remote Sensing and Advanced Data Assimilation Technique

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

Project Summary

Many semi-arid regions of the world, including California, depend on annual snowmelt for the majority of their water supply. According to the Los Angeles Department of Water and Power (DWP), half of the water for the city of Los Angeles over the last ten years has come from Eastern Sierra surface water runoff. However the primary method for estimating the amount of water stored in the snow pack (snow water equivalent, SWE) is done by field snow surveys. This approach is extremely limited because the survey data are sparse point estimates and because they rely upon regression and comparison to historical measurements.

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

Data assimilation methods, such as the Ensemble Kalman Filter (EnKF) are used to merge remote sensing observations into a hydrologic model to produce spatially distributed estimates of SWE over the entire basin. The EnKF weighs the relative uncertainty of the model and of the observations and provides an estimate of the state variable as well as an estimate of its uncertainty. This project constitutes a feasibility study for estimating SWE through the incorporation of remote sensing observations in the microwave, visible, and thermal infrared parts of the spectrum into a physically-based snow model.

More realistic models for snow grain diameter evolution and snow albedo (reflectivity) have been incorporated in the radiative transfer models which should significantly improve the estimates of the amount of water stored in snow pack.

Our work has focused on the selection and development of the required snow and remote sensing models needed in the data assimilation approach. We selected the Snow and Radiative Transfer models which are widely accepted as the foundation of the data assimilation framework. More realistic models for the snow grain diameter evolution and snow albedo (reflectivity) have been incorporated in the radiative transfer model which should significantly improve the SWE estimates. We have applied the model to data in the Mammoth Mountain region in the Sierra Nevada. The preliminary results from the snow model show realistic prediction of snowpack characteristics (depth, density, grain diameter, and temperature) over the course of a month-long simulation. These snow states provide input to the radiative transfer model which predicts the brightness temperature emitted from the snowpack. Brightness temperatures at different frequencies are related to different snow states at different depths. These predictions will be used with observations in the data assimilation scheme to estimate the true snow states.

The major goal of this project is to see if this methodology is feasible in characterizing the snowpack. After verifying that the methodology can be used to recover the true state in synthetic tests, we plan to extend our work to an entire watershed near Mammoth Mountain. We will also include a comparison of our methodology with other existing methods of SWE estimation in the literature. We hypothesize that our novel methodology will yield superior estimates of basin-wide SWE over traditional field sampling or retrieval algorithms, which provide significant benefits for water resource management and planning for the state of California.

Student Training

Michael Durand, graduate, Ph.D.; Civil and Environmental Engineering, UC Los Angeles

Additional Funding

The preliminary work started in this project was helpful in obtaining a NASA New Investigator Program (NIP) award, which is a three year project (total budget $250,000).

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

Project Summary

Using a regional climate model (RegCM2.5), we explored the potential impacts of increasing atmospheric CO_2 concentrations on the climate of California, in hydrologic regions initially defined by California's Department of Water Resources; as South Coast, Colorado River, South Lahontan, Tulare Lake, Central Coast, San Joaquin, San Francisco Bay, North Lahontan, Sacramento River, and North Coast. This study has focused on two questions: (1) how will anthropogenically driven climate change affect California's climate, 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)? We carried out two regional climate modeling experiments, one containing preindustrial CO_2 levels (280 ppm), and one containing doubled preindustrial CO_2 levels (560 ppm). The latter condition has been projected to occur by approximately 2050. CO_2 concentrations increased temperatures up to 4.0 °C on an annual average basis and up to 5.0 °C on a monthly basis.

Our findings suggest that the doubling of CO_2 concentration would result in a decrease in total amount of water, an increase in water needs, and a perturbation of the timing of water availability in California.

Temperature increases were greatest in the central and northern hydrologic regions of the state. On a monthly basis, the temperature response was greatest in February, March and May for nearly all regions. Snow accumulation was significantly decreased in all months and regions, with the greatest reduction occurring in the Sacramento River region (see accompanying figure). Precipitation results indicate drier winters for all ten hydrologic regions, with a large reduction in precipitation in the period of December to April, and a lesser decrease in the period of May to November. The result is a wet season that is slightly reduced in length. Our findings suggest that the doubling of CO_2 concentration would result in a decrease in total amount of water, an increase in water needs, and a perturbation of the timing of water availability in California.

Publications

Snyder, M.A., Sloan, L.C., and Bell, J.L., Modeled Regional Climate Change in the Hydrologic Regions of California: A CO_2 Sensitivity Study, J*ournal of the American Water Resources Association*, 2004, in press (June)

Professional Presentations

Sloan, Lisa C., Regional climate modeling studies for California: Future scenarios and impacts, California Energy Commission's First Annual Climate Change Conference, Sacramento, CA, June 10, 2004.

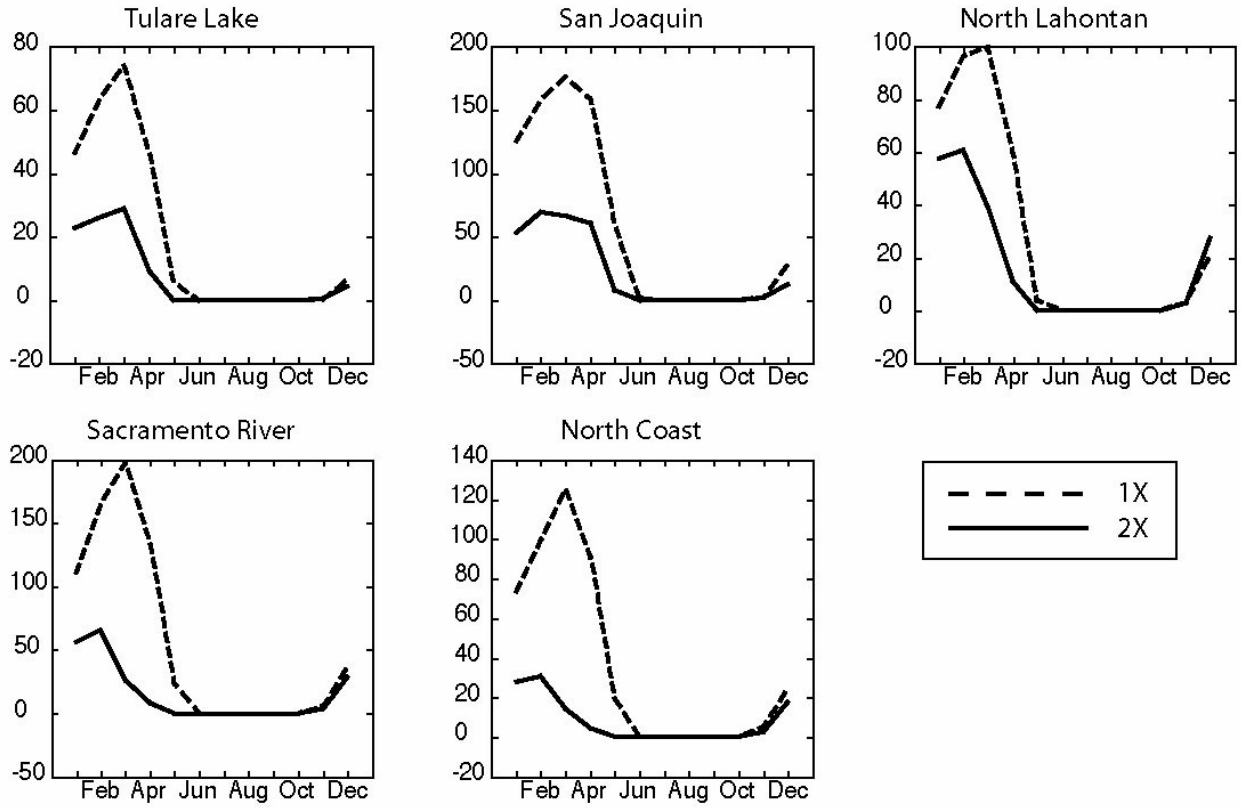
Student Training

Mark Snyder, graduate, Ph.D.; Earth Sciences, UC Santa Cruz

Sarah Bryant, graduate, Ph.D.; Earth Sciences, UC Santa Cruz

Additional Funding

$15,000, from UC Santa Cruz STEPS Institute, 2004.



B. Median monthly snow accumulation from the 1X and 2X cases. Units are mm snow water equivalent.

Mount Shasta's Glaciers: An Endangered Resource?

Slawek T. Tulaczyk
Department of Earth Sciences
UC Santa Cruz

Project Summary

The objective of this study is to assess the stability of Mt. Shasta's glacier system through temporal analysis of ice volume and modeling of the possible response to climate warming. Seasonal melt of Mt. Shasta's glaciers represents a significant dry season and drought period water source to California and deterioration of those glaciers could have a significant practical impact on the water supply for the region. The health of the Mt. Shasta glacier system could be endangered when faced with decadal scale climate warming trends. The latest climate models predict that northern California will warm by several of 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.

The first year of this two year investigation focused on, firstly, examining the photogrammetric record of fluctuations in the size of Mount Shasta's glaciers and, secondly, field observations of glacier mass balance aimed at supporting energy balance parameterizations in future modeling. Our photogrammetric analysis of 5 glaciers since 1951 revealed that each of the glaciers increased in area throughout the time period, excluding a brief contraction in the late 1980's. The Whitney glacier, North America's most southerly valley glacier advance 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 an increased annual snow balance. While there has also been an increase in winter temperature, resulting in a thinner spring snow pack at low elevations, the high elevations of the glaciers are insensitive to this warming, remaining below the freezing level for most of the winter. Such trend 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 the assessment of the impact of climate change on California's snow reservoir.

Our data present a scenario in which climate warming may result in increased spring snow accumulation at high elevations and glacier growth.

During the summer of 2002, a series of ablation stakes and temperature sensors were deployed on the Hotlum and the Whitney glaciers, including a logging echo sounder system, to provide time series of surface melt and temperatures. Correlation of these time series will help constrain model parameterizations of the glacier surface energy balance. For 2002, both of the monitored glaciers lost mass. However, total loss was, small considering that the winter of 2002 produced 54% of normal snowfall and was one of the warmest summers on record. This suggests that Mt. Shasta's glaciers may be relatively insensitive to climate change.

The second year of this study supplemented the energy balance information with observations of glacier velocity and ice thickness using differential global positioning system and ice penetrating radar. This information will be used to construct a numerical model of Mt Shasta's glaciers and their response to both observed and predicted climate forcing.

Field work on the Hotlum Glacier, showing echo sounder equipment and GPS position recording.

Professional Presentations

Howat, I.M., S. T. Tulaczyk, M. Snyder, L.C. Sloan, California's Snow Gun, AGU Fall Meeting, San Francisco, CA, 2003.

Howat, I.M., The impact of climate warming on California's seasonal snow mass balance, Northwest Glacological Society, Vancouver, B.C., Canada, October 18-19, 2003.

Howat, I.M., Mount Shasta's Glacier System. Northwest Glacological Society, Vancouver, B.C., Canada, October 18-19, 2003.

Student Training

Ian Howat, graduate, Ph.D.; Earth Sciences, UC Santa Cruz
Mike Ward, undergraduate; Earth Sciences, UC Santa Cruz
Nate Casebeer, undergraduate; Earth Sciences, UC Santa Cruz
Brian Spear, undergraduate; Earth Sciences, UC Santa Cruz
Evan Lindenbaugh, undergraduate; Earth Sciences, UC Santa Cruz
Kevin Israel, undergraduate; Earth Sciences, UC Santa Cruz

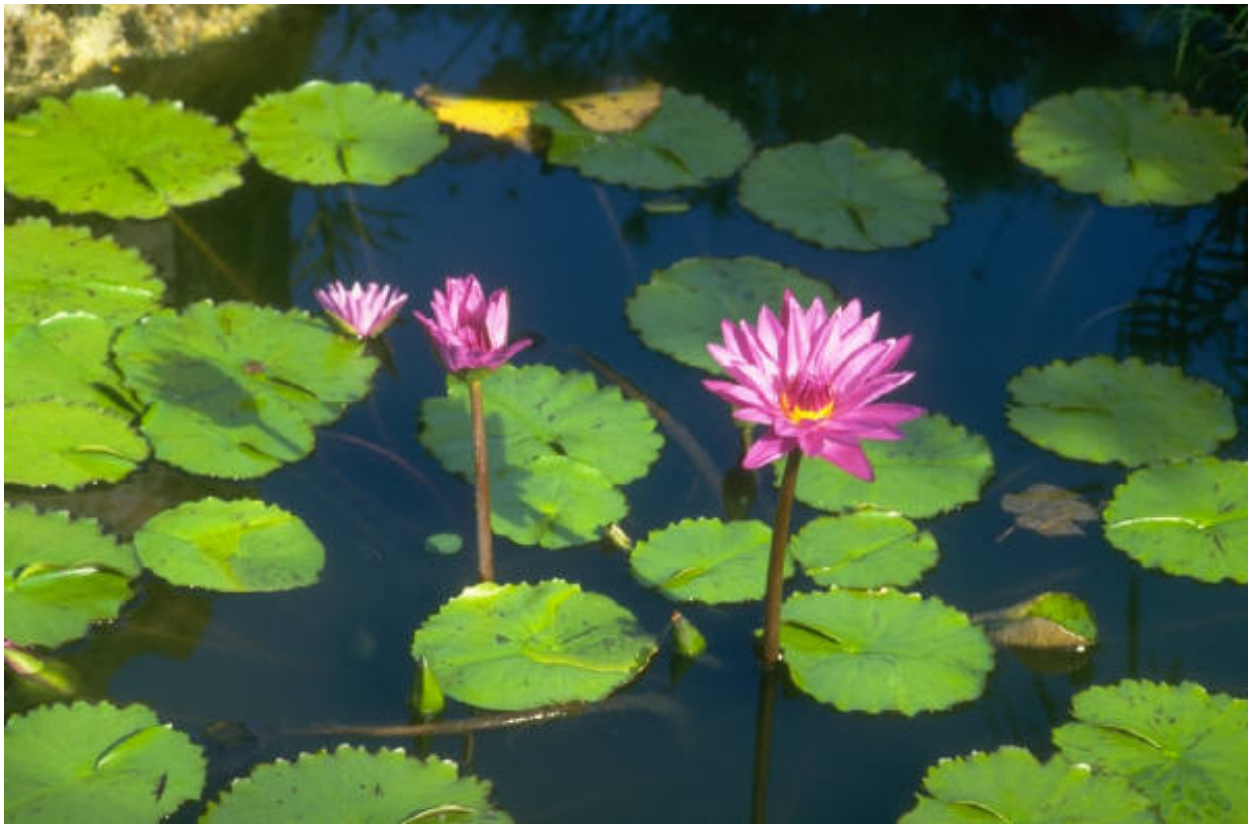
Additional Funding

American Alpine Club, Alpine Sciences Grant - $500.

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.



Influence of Nutrient Loading in the Invasion of an Alien Plant Species, Giant Reed (Arundo donax), in Southern California Riparian Ecosystems (Extended project - "Effects of Fire on Giant Reed (Arundo donax) Invasion in Riparian Ecosystems")

Richard F. Ambrose
Environmental Science & Engineering Program
UC Los Angeles

Project Summary

The unique biodiversity of Mediterranean-type climate regions is under threat by the introduced plant, giant reed (*Arundo donax*), which is rapidly invading river systems in California. 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. Excess water and nutrients from expanding urbanization and agricultural development adjacent to riparian ecosystems in these regions are thought to contribute to this invasion problem. Currently, community-based watershed management planning efforts around California have focused on removal of giant reed from rivers. Federal and state regulatory agencies require giant reed removal as part of their permit programs. However, to completely eradicate giant reed and restore biological diversity to riparian ecosystems, ecological research is needed to understand the invasion process. The main objective of this study is to determine the contribution of nutrients delivered to coastal river systems of mediterranean Southern California to invasion of giant reed.

This study indicates an important relationship between elevated nutrient levels and giant reed infestations in riparian floodplain and terraces of coastal streams of Southern California

Natural and human disturbances have played a large role in successful invasion of giant reed. However, natural disturbance along rivers in California is not a new phenomenon and most physical human disturbance dates back much earlier than the onset of the massive giant reed invasion. Thus, other factors must contribute to the success of this plant's invasion. One of the main human alterations along rivers in California is the delivery of nutrients from adjacent land uses to river systems within a watershed. Since soils of mediterranean-type climates have relatively low soil nutrient concentrations, recent nutrient loading of rivers is hypothesized to be one of the

main factors contributing to giant reed's invasion in California.
This study addresses three critical water resource problems in California:
(1) threats to river ecosystems by one of the most invasive alien plant species,
(2) the impacts of various land use types on river systems, and
(3) the impact of increased nutrient loading in rivers on natural riparian ecosystem functioning.

This research employs a watershed-scale approach to these critical water problems, with study sites located along three streams of Southern California (various sizes and nutrient sources). Field sampling is stratified by land use types: agricultural, residential and natural/open space. The quantity of nutrients in soil and shallow groundwater surrounding giant reed infestations and native riparian vegetation were sampled throughout three watersheds of Southern California, Santa Clara River, Calleguas Creek and Topanga Canyon. In addition, plant material from each sampling site was collected and analyzed for nutrient concentrations.

Preliminary data analyses indicate that giant reed infestations occur in river floodplains where groundwater nutrient levels were elevated in all study watersheds. Large patches of giant reed occur on river terraces where nitrogen is higher. Groundwater nutrient levels are highest in areas infested with giant reed adjacent to agricultural land uses. Calleguas Creek, the most highly modified stream system studied, was found to have the highest groundwater and leaf tissue nutrient levels whereas the reference sites without Giant Reed contained the lowest levels (Calleguas Creek>Santa Clara River>Topanga Canyon>Reference sites). This study indicates an important relationship between elevated nutrient levels and giant reed infestations in riparian floodplain and terraces of coastal streams of Southern California.

A unique opportunity to study post-fire vegetation dynamics presented itself after the October 2003 wildfires in Southern California. More than a dozen study sites containing giant reed burned along the Santa Clara River. A study was immediately initiated after the fires to determine the contribution of giant reed to the spread of wildfire as well as to document growth rates of giant reed compared to native riparian plants after fire. Preliminary data show that giant reed grows up to four times faster than native plants after fire and is well-adapted to fire due to its underground structure.

Publications

G.C. Coffman, R.F. Ambrose, and P.W. Rundel, Invasion of *Arundo donax* in river systems of Mediterranean climates: causes, impacts and management strategies. *Proceedings 10th MEDECOS Conference*, April 25-May 1, 2004, Rhodes, Greece, Arianoutsou & Papanoutsou (eds), 2004 Millpress, Rotterdam, p. 138, 2004.

Professional Presentations

Gretchen C. Coffman, R.F. Ambrose, and P.W. Runde, Factors influencing invasion of giant reed (*Arundo donax*) in riparian ecosystems of mediterranean-type climates, 5th APRU Doctoral Students Conference, The University of Sydney, Australia, August 9-13, 2004.

Gretchen C. Coffman, R.F. Ambrose, and P.W. Rundel, Invasion of *Arundo donax* in river systems of Mediterranean-type climates: causes, impacts and management strategies, Cal-IPC Symposium 2004 (California Invasive Plant Council), Ventura, CA, October 7-9 , 2004.

Gretchen C. Coffman, R.F. Ambrose, and P.W. Rundel, Invasion of *Arundo donax* in river systems of Mediterranean climates: causes, impacts and management strategies, 10th MEDECOS Conference, Rhodes, Greece, April 25-May 1, 2004.

Gretchen C. Coffman, R.F. Ambrose, and P.W. Rundel, Invasion of *Arundo donax* in river systems of Mediterranean-type climates: causes, impacts and management strategies. 89th Annual Ecological Society of America Meeting, Portland, OR, August 1-6, 2004.

Student Training

Gretchen C. Coffman, graduate, Ph.D.; Environmental Health Sciences, UC Los Angeles

Additional Funding

CA State Coastal Conservancy (SCC)/Friends of the Santa Clara River (FSCR) $ 14,000

Santa Clara River Trustee Council Restoration Grant Program $ 24,734

Society of Wetland Scientists $ 1,000

Collaborative Efforts

Dr. Thomas Dudley, Researcher, University of California, Santa Barbara – collaborated on field experiments funded by the California State Coastal Conservancy and Santa Clara River Trustee Council, which are related to this Center for Water Resources Study.

Fruit Growers Laboratory, Santa Paula, CA and DANR Laboratory, UC Davis – conducted chemical (nutrient) analyses.

UCLA Bridge Program, Hosted and mentored summer research intern, Jose Arevalo, who assisted on the UCWRC project conducting lab analyses and field assistance.

Hosted masters degree intern from University in Israel. Roee Elisha assisted in field work during July 2004 and mapped the extent of riparian burned areas along the Santa Clara River for the Extended project – "Effects of Fire on Giant Reed (*Arundo donax*) Invasion in Riparian Ecosystems"

8 weeks

6 months

Rapid Giant Reed growth after the October 2003 fires

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

Cheryl Briggs
Department of Integrative Biology
UC Berkeley

Project Summary

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, introduce species, habitat loss and alteration, and climate change. Chytridiomycosis is a fatal disease of amphibians caused by the 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 populations 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 disease. In this study we are investigating why the disease is having different outcomes on frog populations in different California watersheds.

The main hypothesis that we are investigating is that differences in the pond morphology and topography of the landscape in different areas result in the frogs using the habitat differently at the different sites, altering their risk of acquiring and succumbing to the disease. We are also investigating alternative hypotheses that differences in the transmission, infectivity, and/or virulence of the disease strains, or differences in susceptibility of the frog genotypes at the different types of sites, are leading to the observed differences in the impact of the disease. Frog die-offs due to the disease in the Sierra are occurring mainly in areas consisting of deep lakes surrounded by granite bedrock, where the adult frogs spend the majority of their time in the lakes. The sites at which the frogs are persisting with the disease include extensive marsh and stream areas with emergent vegetation, in addition to lakes. At these sites the frogs are not confined to isolated lakes, and may be able to escape from areas with high concentrations of zoospores (the infectious stage of the fungus by which the disease is spread).

In a laboratory experiment we inoculated uninfected tadpoles that had been raised

So far we have found no evidence that differences in fungal strains are responsible for the different population-level impacts of the disease at the different sites.

from eggs in the laboratory with a known amount of zoospores of a fungal strain from either a die-off site or a persistent site. We found that transmission of the disease to tadpoles requires very high doses of zoospores, but we measured no differences between the fungal strains in transmission, virulence, infectivity, or tadpole survival. Thus, so far we have found no evidence that differences in fungal strains are responsible for the different population-level impacts of the disease at the different sites.

Our detailed surveys have just begun, comparing infected sites experiencing frog population die-offs, and infected sites at which the frogs are persisting with the disease. At each site we are quantifying the abundance and stage-structure frog populations, the infection status of tadpoles and adults, documenting the presence and abundance of other potential hosts for the disease, and quantifying the habitat characteristics. We have begun to tag adult individuals that will be followed over the course of the season to determine changes in their infection status and to document how the frogs at the different sites are using the habitat.

Professional Presentations

Cheryl Briggs, Lara Rachowicz, and John Parker, "Chytridiomycosis in the mountain yellow-legged frog", CA/NV Declining Amphibian Population Task Force Meeting, Reno, NV, January 15, 2004.

Cheryl Briggs, "Investigating an emerging infectious disease of mountain yellow-legged frogs", Keynote address at the 10th Annual Front Range Student Ecology Symposium (FRSES), Colorado State University, Fort Collins, CO, April 11, 2004.

Student Training

Lara Rachowicz, graduate, Ph.D.;
Integrative Biology, UC Berkeley
Eleanor Sternberg, undergraduate;
Integrative Biology, UC Berkeley
Kenneth Nguyen, undergraduate;
Molecular and Cellular Biology,
UC Berkeley

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

Paul De Ley
Department of Nematology
UC Riverside

Project Summary

Nematodes are diverse and abundant in soils and sediments, occupying a wide range of ecological roles that reflects the overall condition of the microbiological ecosystem. Our project constitutes the first study of nematode communities from vernal pools. It aims to provide the first ecological and taxonomic data from this fragile and biologically important habitat, through a combined morphological and molecular survey of two pools in the Santa Rosa Plateau Ecological Reserve (SRPER). These data will be analysed for the purposes of ecosystem health monitoring, and for possible occurrence of nematodes parasitizing the locally occurring endangered species of plants and fairy shrimp.

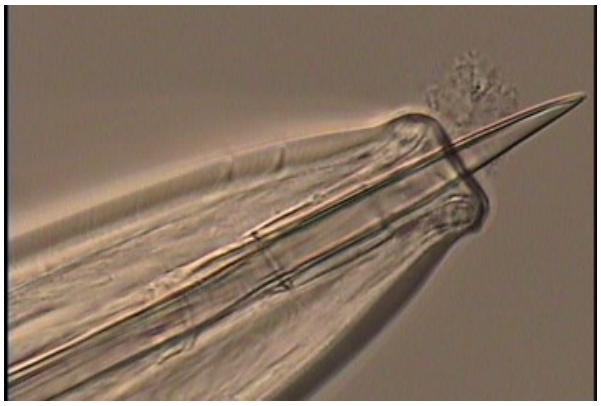
We have identified fifty-five nematode genera to date, demonstrating that the soils and sediments in and around the vernal pools sustain a highly diverse microfaunal community. Most genera are typical for grasslands and/or freshwater habitats. Surprisingly, freshwater nematodes were found in significant numbers even when the pools and their soils were quite dry. This suggests that these "aquatic" species either remain active in the dry soil, or are capable of surviving de- and rehydration (an ability that was not previously documented for many of the genera in question). Another relevant surprise is that most of the larger "aquatic" nematodes encountered to date were extracted from root and plant debris, rather than from the soil itself. Perhaps this debris provides a more sheltered environment for larger nematodes while the pools dry out after inundation.

Indicators of excessive enrichment or inorganic toxins are noticeably absent among the nematodes encountered so far in our samples. Full analysis must wait

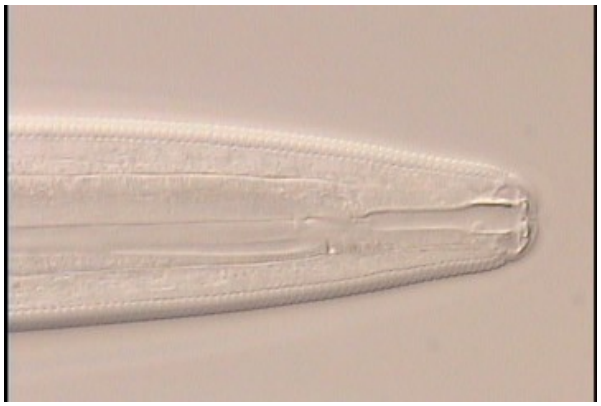
Nematode diversity in the two sampled pools turns out to be high, and identifications to date have rendered a larger fraction of undescribed species than we previously expected. The composition of the nematode fauna suggests the pools are not suffering from eutrophication or pollution. At least one of the isolated species is probably a natural predator on cysts of endangered fairy shrimp.

until completion of our last sample series, but our results so far suggest that the soils of the vernal pools are not (yet) suffering from pollution by encroaching development around the SRPER. In terms of possible predation on, or parasitism of fairy shrimp cysts by nematodes, we have not yet found any direct evidence. However, several large species of predatory nematodes have been found. One of these species belongs to a genus that has previously been found to prey on cysts in laboratory cultures.

We have also started species identifications of the nematodes extracted. Six out of fourteen species identified to date appear to be new to science based on present evidence. More extensive study of the literature is still needed to find more obscure descriptions, which may eventually lead us to recognize some of these species as known rather than new. Nevertheless, it looks likely that upon completion of the project the total species inventory will contain a substantially higher fraction of new species than we originally expected.



Living specimen of Dorylaimus n.sp. with protruding stylet (a hollow needle it uses to puncture its prey)



Preserved specimen of Plectus n.sp., a nematode that feeds mainly on bacteria

Student Training

Sheila Esfahani, undergraduate; Biology, UC Riverside

Melissa Yoder, undergraduate; Biology, UC Riverside

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

Jay Gan
Environmental Sciences
UC Riverside

Project Summary

The research focus of this project is to evaluate behavior and ecotoxicological effects of synthetic pyrethroids in runoff on aquatic organisms. Synthetic pyrethroids are considered as replacements to some of the most commonly used organophosphate insecticides. However, pyrethroids have extremely high toxicity to a wide range of aquatic organisms including invertebrates. On the other hand, synthetic pyrethroids are also strongly adsorbing to sediment and soil particles. In surface water systems, synthetic pyrethroids are expected to associate with suspended or bulk sediment, and only a fraction of the total chemical concentration will contribute to the toxicity. This suggests that the ecotoxicity of pyrethroids in surface water closely depends on their phase distribution or bioavailability.

In current monitoring studies, the whole effluent is extracted, from which the total chemical concentration is determined. As the total chemical concentration includes also the fraction that is adsorbed to suspended solids and dissolved organic matter, the measured concentration does not indicate the bioavailable concentration and will likely lead to overestimation in ecotoxicity. We developed a solid phase microextraction (SPME) method that offers selective detection of the dissolved concentration. We further used this method to evaluate phase distribution behavior of bifenthrin and permethrin in stream and runoff waters. In stream water, the majority of synthetic pyrethroids was associated with the suspended solids, and to a lesser extent, with dissolved organic matter (DOM). The freely dissolved phase contributed only 0.4-1.0%. In runoff effluents, the freely dissolved concentration was 10-27% of the overall concentration. The predominant partitioning into the adsorbed phases implies that the toxicity of SPs in surface water is reduced due to decreased bioavailability. This also suggests that monitoring protocols that do not selectively define the freely dissolved phase can lead to significant overestimation of toxicity or water quality impacts by SPs.

The level of bifenthrin and permethrin in nursery runoff flow was consistently reduced by more than 92% by inexpensive Best Management Practices that removed suspended solids from the waters.

In close collaboration with nursery growers, we have carried out studies to understand the fate and distribution of bifenthrin and permethrin in nursery runoff, and to develop best management practices (BMPs) to reduce their load in the runoff. The experimental site was a 100-acre commercial nursery located in southern California. The BMPs included optimized irrigation schemes, use of sediment traps/ponds, addition of polyacrylamide (PAM) into the effluent, and establishment of a vegetative strip. Monitoring data showed that the BMPs were highly effective in reducing the runoff of the synthetic pyrethroids. The level of bifenthrin or permethrin in the runoff flow was consistently reduced by > 92%. The mechanism for pesticide reduction was removal of suspended solids caused by the series of BMPs. These BMPs are inexpensive and of low maintenance, and therefore are feasible for implementation by other nursery growers, or at other runoff sites.

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.

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, 2003.

Professional Presentations

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

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

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

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

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

Student Training

Qin, Su-jie, graduate, Ph.D., Environmental Science, UC Riverside.

Additional Funding

Gan, J., and J.N. Kabashima, Assessment and mitigation of pesticide runoff from nursery sites, CDFA, duration: 1.2003 – 12.2004; amount: $200,000.

Gan, J., and J.N. Kabashima, TMDL implementation, Practices to reduce pesticide runoff, SWRCB 319(h), duration: 7.2004 – 6.2007; amount: $306,758.

Collaborative Efforts

We have collaborated extensively with the following individuals:

John Kabashima, UCCE-Orange County, Irvine, Orange County
Darren Haver, UCCE-Orange County, Irvine, Orange County
Julie Newman, UCCE Ventura County, Ventura, Ventura County
Dr. Inge Werner, Aquatic Toxicology Laboratory at UC Davis
Dr. Daniel Schlenk, Department of Environmental Sciences, UC Riverside
Doug Shibberu, Santa Ana RWQCB
Kean Goh, CDPR, Sacramento, CA
FMC Incorporation, Specialty Product Group, Princeton, JN

Pre-PAM Application – water is murky

Post-PAM – water is more clear

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

Michael L. Johnson
Aquatic Ecosystems Analysis Laboratory
UC Davis

Project Summary

Although it is widely accepted that anadromous salmonid populations have declined throughout the Pacific Northwest, 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 California's 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 watershed-specific population trends are generally unknown. Our research uses long-lived trees (Douglas fir and coast redwood) living at the edges of streams to measure the declines in salmon populations in coastal watersheds. A fortunate result of feeding in the marine environment is that the tissues of adult anadromous salmon are uniquely enriched with specific forms (heavy isotopes) of many elements (e.g., nitrogen, carbon, and sulfur) relative to terrestrial or freshwater sources of these same elements. When salmon return to freshwater and die after spawning, these heavy isotopes are released into their natal streams and incorporated into aquatic and terrestrial food webs. Salmon tissues contain nearly all the nutrients essential for plant growth and often provide a large fraction of the nitrogen taken up by the trees that live in proximity to the streams. By determining the nitrogen isotope composition of annual growth rings from trees adjacent to the streams, it may be possible to infer changes in salmon abundance over time and reconstruct historic salmon returns for periods where no such information exists.

Historical changes in salmon abundance in a stream can be estimated using the nitrogen isotope composition of annual growth rings of trees growing at the edge of the stream.

To determine the relationship between tree ring nitrogen isotope ratios and salmon escapement, we initiated research in the West Branch Mill Creek watershed, a tributary of the Smith River in northern CA. (Del Norte Co.). West Branch Mill Creek was selected because continuous salmon escapement records have been maintained since 1980 providing 23 years of continuous data for our analyses. To date, we have analyzed increment cores (tree rings samples) from Douglas fir trees for annual changes in stable nitrogen isotopes, % nitrogen content, and tree growth. Our results demonstrate that riparian trees growing adjacent to salmon-

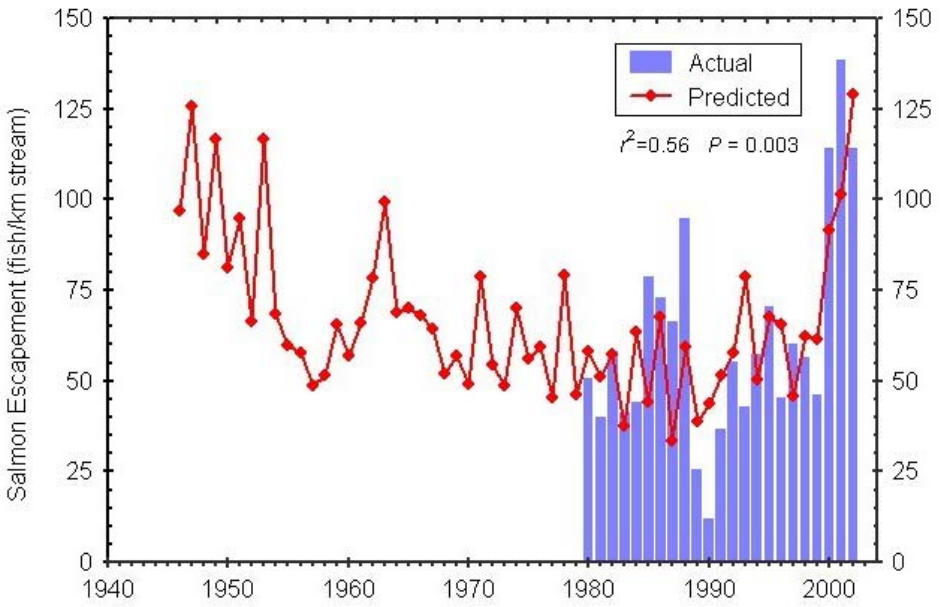
bearing streams are significantly enriched in salmon-derived nitrogen relative to control sites and the importance of this nitrogen source generally attenuates with increasing distance from the stream. Moreover, annual tree growth, % nitrogen content of the wood, and salmon-derived nitrogen are all positively related to the number of salmon returning to spawn the previous year (i.e., a one year time lag exists between salmon-derived nitrogen delivery and tree response). We developed quantitative relationships between salmon-derived nitrogen, % nitrogen content, and tree growth, and the number of spawning salmon (escapement) to create a predictive model specifically for the W. B. Mill Creek watershed. This overall efficacy of our model was validated for years of known salmon returns (1980-2003) and used to reconstruct returns for the period 1946-1979 (23 additional years; see Figure). We are currently processing samples that will enable us to further extend our reconstruction and provide many additional years of previously unobtainable salmon abundance information.

Professional Presentations

Joseph D. Kiernan and Michael L. Johnson, Using Marine-Derived Nitrogen in Riparian Tree Rings to Assess Nutrient Flux and Salmon Escapement, 22nd Annual Salmon Restoration Federation Conference, Davis CA, March 20, 2004.

Student Training

Joseph D. Kiernan, graduate student, Ph.D.; Ecology, UC Davis



Multivariate reconstruction of annual salmon returns (escapement) to the West Branch Mill Creek, a tributary of the Smith River in Northern CA (Del Norte Co.). Bars represent actual salmon escapement (# fish per kilometer of stream) and points represented predicted escapements based on annual tree growth, tree ring stable nitrogen isotope ratios, and % nitrogen content.

Linking Upland Landcover Change with Wetland Structure in Elkhorn Slough, CA

Nina Maggi Kelly
Environmental Sciences
UC Berkeley

Project Summary

Elkhorn Slough supports one of the largest coastal marshes in California. While Elkhorn Slough contains a State ecological preserve and a NOAA research reserve, agriculture, specifically strawberry farming, in the watershed has increased dramatically since 1970, especially on steep slopes adjacent to pickleweed (*Salicornia virginica*) dominated salt marshes. This land use change has led to sedimentation along the margin of the slough, where several sediment fans have formed that have filled marshes, mudflats, and channels, and altered the wetland plant community. The goal of this project is to determine how watershed land use change (i.e., increasing agriculture) over 30 years influenced changes in salt marsh soil physical/chemical properties, and in turn, plant composition through the use of remote sensing, geographic information systems (GIS) and field methods.

We used aerial photos from 1971, 1980, 1992, and 2001 at the Elkhorn Slough National Estuarine Research Reserve (ESNERR) to create a decadal record of wetland vegetation change on sediment fans in the slough. We have found that sedimentation from increased farming generated a process of plant succession on sediment fans in the marsh. Between 1980 and 1992, saltgrass (*Distichlis spicata*) replaced pickleweed, and between 1992 and 2001, arroyo willow (*Salix lasiolepis*) extended into the marsh and replaced saltgrass. The final result of this process was a reduction in salt marsh and a 70% increase in arroyo willow coverage within the study areas.

We collected field data on the following variables to determine what may be driving this successional change: salinity, elevation, soil texture, soil moisture, nitrate-nitrogen, ammonium-nitrogen, and elevation. Water draining into the fans was also analyzed for nitrate-nitrogen and ammonium-nitrogen, and winter sedimentation rates were monitored. Our initial results indicate that as sedimentation occurs, soil texture changes from silty clay loam to sand, elevation increases one meter or more above the

Sediments associated with erosion from farmlands have been deposited in the marsh creating a plant succession of pickleweed to saltgrass to arroyo willow in some portions of Elkhorn Slough.

marsh plain, soil moisture decreases, and salinity decreases greatly, gradually creating conditions more suitable for arroyo willow. High inputs of nitrate and ammonium from farm runoff also may play a role. Sedimentation on some fans during winter 2003-04 were up to 22 centimeters. Preliminary results show that the extent of wetland change may be less dependent on the area of farmland draining into the wetland and more dependent on the slope of the upland farm plus the topography and area of land between the farm and the wetland.

Findings from this study substantiate the need for Elkhorn Slough organizations to continue efforts to reduce soil erosion. As coastal watersheds in California continue to be developed, it is important to understand the impact of land use change on coastal wetlands in order to improve future wetland management and restoration planning.

Professional Presentations

Byrd, Kristin, Linking watershed land-use change and wetland vegetation response in a coastal California watershed, Ecological Society of America 88th Annual Meeting, Savannah, GA, August 3-8, 2003.

Student Training

Kristin Byrd, graduate, Ph.D.;
Environmental Science, Policy and Management, UC Berkeley

Collaborative Efforts

We would like to thank staff at the Elkhorn Slough National Estuarine Research Reserve and the Elkhorn Slough Foundation for their input, especially Eric VanDyke, Geographical Ecologist, and Dr. Kerstin Wasson, Research Coordinator. We would also like to thank Bryan Largay, Hydrologist with the Monterey County Resource Conservation District for his input on watershed hydrology and Professor Rikk Kvitek, CSU Monterey Bay for his assistance with elevation surveys.

Upstream and Upslope Translocation of River-Borne Materials by Aquatic and Riparian Organisms: Contrasts in Spatial Fluxes Along Mainstems and at Tributary Confluences

Mary Power
Integrative Biology
UC Berkeley

PROJECT SUMMARY

Nutrients and contaminants exported from watersheds to rivers can be incorporated back into terrestrial food webs via aquatic insect emergence. Emerging insects from contaminated areas deliver contaminants to terrestrial insectivores, which may be disproportionately concentrated in riparian habitats. Contaminants derived from mainstem rivers may penetrate further upslope along tributary confluences, but the impacts of tributaries on the abundances, activities, and landscape movements predators of aquatic emergence are poorly known, as are river-to-watershed fluxes in general. To evaluate backflows of contaminants across the landscape, we must evaluate how aquatic and riparian organisms move and interact across landscape boundaries in river networks.

We examined river-to-watershed fluxes of nutrients and contaminants by sampling organisms and surveying their stable carbon and nitrogen isotopic composition in an impacted river (the Truckee River north of Lake Tahoe) and in a relatively unimpacted river (the South Fork Eel River in Mendocino Co.). Isotopically heavy nitrogen indexed nutritional backflows from the Truckee River that are likely to correlate with transport of mercury to the high desert food web in the surrounding watershed. Mercury analyses are ongoing, but the nitrogen data show an exponential decline away from the river in ^{15}N enrichment in riparian birds, lizards, and spiders. Dramatic enrichment (and presumably contamination) occurs just downstream from Steamboat Creek near Highway 395, where present organic and historical mine deposit inputs into the Truckee River may increase the likelihood of transfer of bioavailable mercury into the channel food web. Our analyses will reveal the spatial scales of movements of nutrients and other substances from rivers back into watersheds, and evaluate the effect on these fluxes of tributaries. This information will allow us to evaluate positive benefits of these fluxes (e.g.

The nitrogen data show an exponential decline away from the river in ^{15}N enrichment in riparian birds, lizards, and spiders.

nutritional subsidies from mainstem rivers to riparian consumers we value, such as bats or song birds) as well as the spatial extent of adverse effects (contaminant transport into upland areas) that arise where rivers have been polluted.

Publications

Power, M. E. and W. E. Dietrich, Food webs in river networks, *Ecological Research* 17:451-471, 2002.

Fausch, K. D., M. E. Power, and M. Murakami, Linkages between stream and forest food webs, Shigeru Nakano's legacy for ecology in Japan, *Trends in Ecology & Evolution* 17: 429-434, 2002.

Finlay, J.C., Khandwala, S. and M.E. Power, Spatial scales of energy flow in food webs of the South Fork Eel River, *Ecology* 83: 1845-1859, 2002.

Bastow, J. L., J. L. Sabo, J. C. Finlay, and M. E. Power, A basal aquatic-terrestrial trophic link in rivers: algal subsidies via shore-dwelling grasshoppers, *Oecologia* 131:261-268, 2002.

Strayer, D.S., M.E. Power, W.F. Fagan, S.T.A. Pickett and J. Belnap, A classification of ecological boundaries. *BioScience (Special Section on Ecological Boundaries)*, 53:723-729, 2003.

Power, M.E., W. E. Rainey, M.S. Parker, J. L. Sabo, A. Smyth, S. Khandwala, J.C. Finlay, F.C. McNeely, K. Marsee, and C. Anderson, River to watershed subsidies in an old-growth conifer forest. Pp. 217-240 In: G.A. Polis, M.E. Power and G. Huxel. (eds.) Food webs and Landscapes. U. *Chicago Press*, Chicago, IL, 2004.

Power, M.E., M.J. Vanni, P. Stapp and G.A. Polis, Subsidy effects on managed ecosystems: Implications for sustainable harvest, conservation, and control. G.A. Polis, M.E. Power, and G. Huxel (eds.) *Food webs and Landscapes.* University Chicago Press, Chicago, IL. In press.
Polis, G.A. M.E. Power and G. Huxel. (eds.), Food webs and Landscapes. U. Chicago Press, Chicago, IL, 2004.

Suttle, K.B., M.E. Power, J.A. Levine and F.C. McNeely, How fine sediment in river beds impairs growth and survival of juvenile salmonids, *Ecological Applications.* In press.

Professional Presentations

Mary Power, Food webs in River Networks, Arizona State University, Biology Departmental seminar, University of California Berkeley (Integrative Biology departmental seminar)

Rivard, A, Cabana, G, Rainey, W, and ME Power, Tracing fluxes of aquatic production into desert terrestrial food webs, Annual GRIL (Inter-university Limnology Group), St-Hippolyte, Québec, Canada, March 2003.

Student Training

Alexandre Rivard, Graduate Student (MS), Univ. du Quebec a Trois Rivieres,
Gregory Bulté, Undergraduate, Univ. du Quebec a Trois Rivieres,
Jesse Walker, Undergraduate, Integrative Biology, UC Berkeley
Mike Limm, Graduate Student, Ph.D., Integrative Biology, UC Berkeley

Additional Funding

Cabana, Gilbert, NSERC of Canada (National Science and Engineering Research Council): Using contaminants and stable isotopes from rivers to dissect the structure of terrestrial flood plain food webs, 2003, $40,000.

Power, Mary, National Center for Earth Surface Dynamics, NSF Science and Technology Center subcontract as co-PI, 2002, $130,000 per year for 5 years.

Collaborative Efforts

Ongoing collaborations with Gilbert Cabana, a former postdoc in the Power lab and now a professor at the Universite de Quebec a Trois Rivieres have led us into investigations of the role of river-to-watershed trophic export as a potential pathway for contaminant transport from rivers into terrestrial ecosystems. Cabana's student Alexander Rivard is preparing a Master's thesis from this work. Analyses of mercury are ongoing in their laboratory.

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.

Experimental Determinations of Henry's Law Constants of Polybrominated Diphenyl Ethers (PBDEs) to Evaluate Exposure to Aquatic Biota

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UC Davis

Project Summary

Polybrominated diphenyl ethers (PBDEs) are an important class of fire retardants commonly used in plastic-containing products such as televisions, computers, furniture upholstery, paints and packaging. Their chemical structures are very similar to polychlorinated biphenyls (PCBs), so they may bioaccumulate in a similar fashion as PCBs. Concentrations of PBDEs found in Harbor Seal (*Phoca vitulina*) blubber and human breast tissue from the San Francisco Bay Area are the highest reported in the world to-date. Evidence is emerging that these compounds are bioaccumulating. Concentrations in harbor seals in the Bay area increased dramatically in the past twelve years. Concentrations in human tissues were correlated inversely with age, which may be due to increasing use during recent years.

In order to understand what impact these compounds may have on the environment, it is important to understand how they behave physically and chemically. Physical-chemical properties, such as vapor pressure, water solubility and Henry's Law Constants (K_H) determine the fate and transport of chemicals in the environment.

The measured K_H values of PBDEs were in a range similar to those measured for PCBs suggesting that they may partition in lakes similar to PCBs.

Henry's Law Constants are essential in understanding the flow of compounds between aqueous and gaseous phase; and thus, how the chemicals are transported between the atmospheric and aquatic systems. Compounds with low K_H values are more likely to reside in surface waters and sediment where they are bioavailable to aquatic organisms, whereas, compounds with high K_H values are more likely to volatilize into the air.

We utilized the gas-stripping method for the determination of K_H of PBDEs since this approach has been used for K_H measurements of many different compounds, including the PCBs. We have obtained values of PBDEs containing one to six bromine atoms using this method along with K_H of PCBs of corresponding degrees of chlorination. PBDE K_H values

ranged from 17.2±8.6 to 45.8±9.3 Pa m^3 mol^{-1} which are very similar to that of the PCBs. This suggests that PBDEs may partition into large bodies of water in a similar fashion as PCBs, thus large lakes may be "sinks" for PBDEs.

Henry's Law determinations of PBDEs are complicated by their low water solubility. In order to improve the precision and accuracy in these values, we have modified the method by: 1) improving the introduction of the analytes into the aquaeous solution, 2) refining the extraction technique, and 3) increasing the length of the water column to ensure chemical equilibrium between the air bubbles and the water.

Currently, we are using a modified approach to the gas-stripping method by collecting the PBDEs that volatilized into the gas-phase as well. This approach gives a larger number of data points and avoids the problem of concentration buffering due to sorption/desorption of analytes on to glassware over time. Since the original gas-stripping calculation can also be performed by the modified approach, results from the two methods can be compared to ensure that the results from the two methods are consistent, thus providing greater confidence in the determined values.

We plan to determine temperature-dependence by measuring K_H at different temperatures (5°C to 35°C). Temperature-dependent relationships are indispensable in predicting K_H values at different environmental conditions. These values can be used for flux calculations for large bodies of water to determine which compounds would reside in the aquatic phase or gas phase. They can also be compared to actual field concentrations of air and water samples, which would indicate whether the compounds of interest are at equilibrium and the K_H values can predict direction of transport.

Publications

Fiona Lau, Hugo Destaillats, M. Judith Charles, Experimentally Determined Henry's Law Constants for Six Brominated Diphenyl Ether Congeners, *Organohalogen Compounds*, pp.333-336, 2003

Professional Presentations

Fiona K. Y. Lau, Optimization of the Measurement of Henry's Law Constants of Polybrominated Diphenyl Ethers, UC Toxic Substance Research & Teaching Program 17th Annual Research Symposium, Bahia Resort, San Diego, CA, April 23-24, 2004.

Student Training

Fiona K. Y. Lau, graduate, Chemistry Graduate Group, UC Davis

Nature of Flow and Gas Dynamics Below Spreading Ponds

Jordan Clark
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Project Summary

During the last 50 years, the soaring demand for freshwater has placed unprecedented stress upon many aquifers in California and elsewhere. One recent development in groundwater/surface water management aimed at augmenting water supplies has been artificial recharge. This practice consists of recharging recycled or surplus surface water into permeable aquifers and extracting this recharged water at some later date. While it is recognized that the quality of recharge water usually improves during transit in the subsurface, water agencies are often required to document the improvement prior to gaining credit that can be used during the permitting process. In order to document the *in situ* changes in water quality, travel times and flow paths between recharge areas and production wells must be known very well. Recently, methods have been developed using gas tracers for the direct determination of travel times between recharge areas and wells over the time period of 0 to 5 years. A surprising result of our initial gas tracer experiments performed in Orange County, CA, was the observation that the gases were transported through the vadose zone to the water table without significant loss or retardation. We postulated that the absence of retardation indicates that the gas tracers were infiltrating primarily through saturated pathways contained within the vadose zone.

The experiment demonstrates that at artificial recharge sites with high infiltration rates and moderately deep water tables, transport times between recharge locations and wells determined with gas tracer experiments are reliable.

In order to gain a better understanding of gas transport and trapped air below an artificial recharge pond, a dual gas tracer experiment using sulfur hexafluoride (SF_6) and an isotope of helium (^3He) and measurements of dissolved noble gases were preformed at the El Rio Spreading Grounds (Ventura County). Our experiment was designed to quantify gas transfer from percolating recharge water to the soil air in a field setting and to quantify the amount of trapped air. SF_6 and ^3He were chosen as tracers because they are conservative, not retarded in saturated porous media, and have Henry's Law coefficients that differ by about 50%.

The gas tracers were injected into Pond #2 for one week beginning on September 27, 2002. At this time, the artificial recharge rate was ~4 m day^{-1} and the water table was ~12 m below the ground surface. Breakthrough curves of SF_6 and ^3He at two nearby production wells were very similar. At one well screened between 50 and 90 m below ground, both tracers were detected after 5 days and reached a maximum at ~24 days. Despite potential dilution caused by mixing within the production well, the maximum concentration observed at this well was ~25% of the mean pond concentration. The tracers were detected at this well for more than sixteen months. Noble gas concentrations in the groundwater were much higher than in the pond due to the dissolution of trapped air. However, significant retardation (absolute and relative) of the gas tracers was not detected suggesting that the amount of trapped air was small, less than 10%. The experiment demonstrates that at artificial recharge sites with high infiltration rates and moderately deep water tables, transport times between recharge locations and wells determined with gas tracer experiments are reliable.

Professional Presentations

Clark, J. F., "Dynamics of gases below a spreading ponds at an artificial recharge site in Ventura, CA: Insights from a dual gas (SF_6 and ^3He) tracer experiment," CSIRO-Land and Water, Adelaide, Australia, April 2004.

Avisar, D. and J. F. Clark, "A Gas Tracer Study in the El – Rio Spreading Pond: Ventura County, California," United Water, Ventura County, CA, September 2003.

Student Training

Dror Avisar, post-doctoral researcher, Institute of Crustal Studies, UC Santa Barbara

Erik Blumhagen, graduate student, Dept. of Geological Sciences, UC Santa Barbara

Additional Funding

J. F. Clark and G. B. Hudson, Gas Dynamics Below Artificial Recharge Ponds, IGPP-Lawrence Livermore National Laboratory, $32,000

J. F. Clark, "Big Bear Tracer Study," Big Bear Area Regional Waste Water Agency, $24,000

Collaborative Efforts

Dr. G. Bryant Hudson, Lawrence Livermore National Laboratory

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

Patricia A. Conrad
Department of Pathology, Microbiology, and Immunology
UC Davis

Project Summary

The distribution of fecal parasites such as *Cryptosporidium* spp. that cause diarrheal disease in humans and animals along the California coast is largely unknown. *Cryptosporidium* spp. may be useful protozoal indicators for investigating sources of fecal pollution because some genotypes of the parasite are host specific while other genotypes are shed by a variety of human and animal species. For example, *C. felis, C. andersoni*, and *C. hominis* are shed mainly by cats, cattle, and humans, respectively, while *C. parvum* is shed by both humans and animals. *Cryptosporidium* parasites survive for long periods of time in the environment and are often spread by ingestion of fecal-contaminated water. Bivalve shellfish may be useful sentinels of water quality because they filter large volumes of water, have a wide habitat distribution, and can be tested for pathogens using molecular techniques. The objective of this study is to obtain critical data on the epidemiology of *Cryptosporidium* in freshwater, estuarine, and nearshore marine ecosystems along the California coast. We hypothesize 1) that *Cryptosporidium* parasites are present in bivalve shellfish collected at sites exposed to fecal contamination, including sites near human sewage outfalls and livestock runoff, and 2) that *Cryptosporidium* genotypes will differ in bivalves collected at sites exposed to human feces compared with bivalves collected at sites contaminated with livestock feces.

Bivalve shellfish may be useful bioindicators of fecal contamination in aquatic environments, and that the sources of fecal contamination may include domestic animals, livestock, wildlife, and humans.

Over the past two years, we have optimized parasite detection methods and performed tank experiments showing that *Cryptosporidium* oocysts are detectable in freshwater clams (*Corbicula* spp.) and marine mussels (*Mytilus* spp.) exposed to parasite doses and water temperatures that might naturally occur. We have also used sentinel clams and mussels at freshwater, estuarine, and marine sites along the California coast considered at 'higher risk' or 'lower risk' for fecal pollution based on their proximity to sewage outfalls and livestock runoff. From the 26 study sites, over 5000 shellfish have been collected, dissected, and are now being tested for *Cryptosporidium* spp.

Thus far, we have detected *Cryptosporidium* in shellfish collected from sites considered at higher risk but not from shellfish collected from sites considered at lower risk for fecal pollution. Parasites have been detected in the wet and dry seasons, suggesting that year round exposure to fecal parasites is possible via contaminated water. Genotypes of *Cryptosporidium* spp. detected include *C. parvum, C. felis,* and *C. andersoni.* These data support the fact that bivalve shellfish may be useful bioindicators of fecal contamination in aquatic environments, and that the sources of fecal contamination may include domestic animals, livestock, wildlife, and humans. Data analyses are underway regarding the distribution and risk factors for *Cryptosporidium* exposure in coastal California ecosystems.

Publications

Conrad P.A., M. Miller, A.J. Kjemtrup, W. Smith and I.A. Gardner, The human-wildlife-domestic animal interface provides exciting research opportunities for parasitologists, *Journal of Parasitology* 89: S27-S36, 2003.

Dr. Woutrina Miller (right) with California Department of Fish & Game biologists Jack Ames and Mike Harris during sentinel mussel deployment in Morro Bay, California.

Sentinel clams (*Corbicula* spp.) used for monitoring freshwater rivers for the fecal parasites *Cryptosporidium* and *Giardia* spp. that cause diarrheal disease in humans and animals.

Professional Presentations

Conrad, P.A., Adventures and new discoveries at the wildlife-domestic animal-human interface, Schalm Lectureship, School of Veterinary Medicine, Davis, California, September, 2003.

Miller, W.A., E.R. Atwill, K. Tate, D.J. Lewis, M. Lennox, M. Pereira, and P.A. Conrad, *Cryptosporidium* and *Giardia*: epidemiology and control on California farms, World Association for the Advancement of Veterinary Parasitology, New Orleans, Louisiana, 2003.

Conrad, P.A., Exciting protozoological discoveries at the human-wildlife-domestic animal interface, American Veterinary Medical Association Conference, Colorado; Society for Tropical Veterinary Medicine, Brazil; Institute for Parasitology, School of Veterinary Medicine, Bern, Switzerland, July-August, 2003.

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

Smith, W.A., E.R. Atwill, I.A. Gardner, M.A. Miller, J. Ames, S. Jang, A. Melli, D. Jessup, Conrad, Sea otters, shellfish, and fecal pathogens: can we connect the dots?, Defenders of Wildlife Carnivore Conference, Monterey, CA, November, 2002.

Smith, W.A., M.A. Miller, I.A. Gardner, E.R. Atwill, S. Jang, D. Jessup, C. Leutenegger, A. Melli, P.A. Conrad, Shellfish as indicators of fecal borne protozoa and bacteria in the California marine ecosystem, Wildlife Disease Association Annual Meeting, Humboldt, CA, July, 2002.

Student Training

Woutrina Miller, graduate, DVM, MPVM, Ph.D Candidate; Comparative Pathology, UC Davis

Heather Fritz, graduate; Veterinary Medicine, UC Davis

Additional Funding

$60,000, UC Center for Food Animal Health

Collaborative Efforts

California Department of Fish & Game, California State Mussel Watch Program, Central Coast Regional Water Quality Control Board, University of California Extension Program.

Fate of Viruses, and Nitrogen in Non-Conventional Onsite Wastewater Treatment Processes: A Technical and Economic Analysis

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Project Summary

As much as 10% of residential households in California rely on onsite wastewater disposal systems. The conventional onsite wastewater systems (utilizing a septic tank and soil adsorption system) are not always adequate for meeting the increasingly challenging onsite treatment and reuse needs in California. The ability of advanced and conventional onsite wastewater treatment systems to remove viruses, nitrogen, and endocrine disrupters are under evaluation. The advanced treatment systems represent the state of the art in onsite wastewater treatment systems, namely, an aerobic biofilter system utilizing high porosity media, an aerobic suspended growth system, and an aerobic suspended growth system with bioaugmentation. The performance of soil adsorption systems is assessed by applying effluents to soil basins and sampling at incremental depths to assess the attenuation of wastewater constituents with depth.

In contrast to previous studies that have characterized the performance of these treatment systems in terms of conventional water quality parameters such as the BOD and total suspended solids, the current study evaluates the capability of onsite wastewater treatment systems to remove viruses and endocrine disrupters and the potential for bioaugmentation to improve treatment. The onsite wastewater treatment systems have been constructed and are currently in operation at the UC Davis wastewater treatment facility include (a) three high porosity, high surface area multi-pass biofilm reactors, (b) two submerged aerated biofilm reactors; one to be inoculated with specific bacteria (i.e., bioaugmentation) for enhanced performance, and (c) a traditional septic tank followed by sand leach beds. In addition, soil lysimeters have been assembled to further evaluate the effect of upstream processing on the performance of soil adsorption systems (i.e., standard leach field).

Nitrogen is not removed in a septic tank or sand leach bed. About 40% nitrogen removal occurred in the multi-pass aerobic biofilter. Viruses were not removed in a septic tank but were partially removed in aerobic biofilters and sand leach beds.

As shown in Fig. 1, nitrogen is not removed in a septic tank or in sand leach beds (although nitrogen transformation may occur). In addition, submerged aeration systems with and without bioaugmentation have not been able to achieve nitrogen removal, even after the onset of nitrification (data not shown). In the multi-pass aerobic biofilters, about 40 percent total nitrogen removal (see Fig. 1) has been achieved when anoxic recirculation is used; this method of denitrification is not likely to achieve significantly greater levels of nitrogen removal without additional facilities. Alternate forms of denitrification will need to be used in areas sensitive to nitrogen inputs.

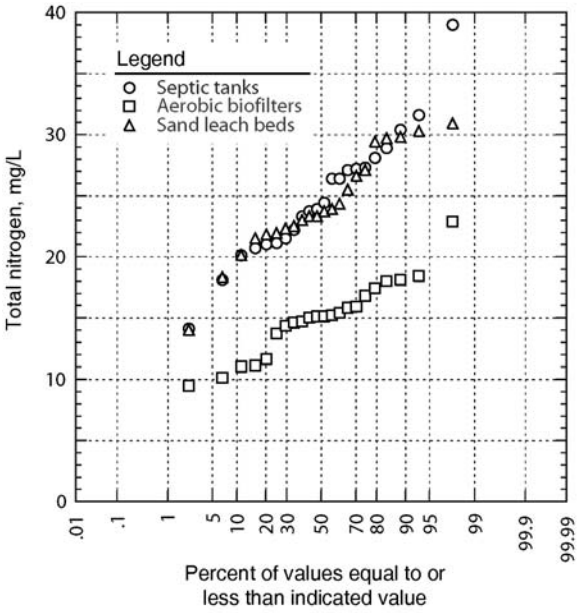


Figure 1
Concentration of nitrogen in effluent from various onsite wastewater treatment processes

The removal of viruses, as evaluated using indigenous coliphage, is shown for septic tanks, sand leach beds, and aerobic biofilters in Fig. 2. Virus removal is not expected in a conventional septic tank system, however, in the sand leach beds a virus removal of 95 percent was obtained. Although there was a high degree of variability in the performance of the sand beds, the high removal rate may be used to assess the importance of properly designed soil infiltration systems in protecting groundwater resources. The virus removal in the aerobic biofilter was about 90 percent. While the removal in the sand leach bed is greater than in the biofilter, the loading rate to the biofilter is higher by a factor of thirty. Additional studies are being conducted to determine the removal mechanism and the importance of process design variables, such as loading rate, in the removal of viruses. In addition to the results presented above, a number of observations have been made regarding the reliability of the various processes, including maintenance requirements, mode of failure, and clogging of sand and emitters. The factors related to reliability will be useful in assessing the economic viability of the processes in question.

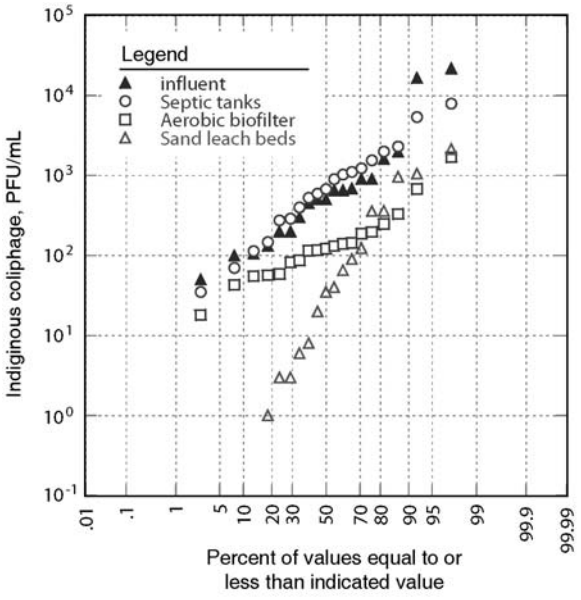


Figure 2
Concentration of indiginous coliphage in effluent from various onsite wastewater treatment processes

Publications

Leverenz H., G. Tchobanoglous, and J. Darby, Review of Technologies for the Onsite Treatment of Wastewater in California, *Center for Water Resources Engineering,* University of California Davis, No. 2002-2, 2002.

Leverenz H., L. Ruppe, G. Tchobanoglous, and J. Darby, Evaluation of High Porosity Media for the Treatment of Onsite Treatment of Wastewater, (peer reviewed) *Small Flows Journal,* Vol. 2, No. 2, 2001.

Professional Presentations

Leverenz, H.L., The use of pretreatment technologies for the removal of wastewater constituents, National Symposium on Individual and Small Community Sewage Systems (ASAE), Sacramento, CA, March 21-24, 2004.

Student Training

Gina Choi, undergraduate; Civil and Environmental Engineering, UC Davis
Ian Maki, undergraduate; Civil and Environmental Engineering, UC Davis
Erin Oneida, undergraduate; Civil and Environmental Engineering, UC Davis
Olivia Virgadamo, graduate, M.S.; Civil and Environmental Engineering, UC Davis
HsinYing Liu, graduate, Ph.D.; Civil and Environmental Engineering, UC Davis
Harold Leverenz, graduate, Ph.D.; Civil and Environmental Engineering, UC Davis

Additional Funding

- Survey of Alternative Onsite Sewage Treatment and Disposal Systems for the State Water Resources Control Board, $48,365, 6/15/01 - 12/31/02
- Research Experiences for Undergraduate Students, National Science Foundation, $249,800 (not all for this project), 7/1/97 - 6/30/03
- 4 septic tanks, $5,000 (Delta Precast & Jensen Precast)
- 3 biofilm reactors, $6,000 (Orenco Systems Inc.)
- 2 aeration systems, $4,000 (Pirana Inc.)
- 6 soil lysimeters basins, $3,000 (Orenco Systems Inc.)
- Miscellaneous pumps, basins, control systems, supplies $10,000 (Infiltrator Systems Inc., Orenco Systems Inc., & Pirana Inc.)

Development of an Autonomous O_2 Delivery System for In-Situ Aerobic Bioremediation

Marc Dushusses
Department of Chemical and Environmental Engineering
UC Riverside

Project Summary

In some cases groundwater has been contaminated with organic compounds such as gasoline. Because of treatment costs the approach for groundwater remediation has been to allow for natural attenuation of the contaminants, i.e., dispersion and biodegradation by indigenous microorganisms. However, natural attenuation can be slow, and as contaminants are degraded, oxygen is depleted in the aquifer. Anaerobic conditions result in expanding plume sizes and much slower bioremediation. In many instances, a corrective action has to be taken and oxygen has to be supplied to the aquifer to avoid anaerobic conditions. This is usually done by sparging air or pure oxygen in the aquifer, or by injecting liquid or solid peroxide which will slowly release oxygen in-situ. Irrespective of the method, delivering oxygen to a contaminated aquifer is expensive.

We have developed a new and autonomous system for the delivery of oxygen to contaminated aquifers. The principle of this new system is based on the electrolysis of water, which releases oxygen and hydrogen. The electrolyzer is powered by an autonomous fuel cell that uses hydrogen and air. The hydrogen supply for the fuel is from a small tank as well as all of the captured hydrogen from the electrolysis of water, thereby increasing the efficiency of the system. The oxygen from the electrolysis is used in the subsurface to aerate the groundwater, while the hydrogen is captured and recycled.

A prototype that utilizes the newest proton exchange membrane (PEM) fuel cell, PEM electrolyzer, and porous membrane oxygen diffusing technology was constructed, and tested. After two years of research, the proof of concept has been demonstrated, and a UC disclosure of invention has been submitted. From the initial concept, several issues not initially considered to be critical have arisen. For example, direct electrolysis of groundwater is not feasible as it leads to fouling of the PEM membrane and reduced efficiency of

A fully working prototype has been operating for weeks in the laboratory. Overall, the projected system cost-effectiveness appears promising, and the system may have a significant impact on the way active in-situ bioremediation is conducted.

the electrolyzer over time. This necessitated the addition of a deionised water supply tank in to the system. Another issue has been to keep the fuel cell running in a regime where it is highly efficient. This has been difficult as the electrical resistance of the electrolyzer is low, resulting in high loadings on the fuel cell. A final issue was selecting efficient means to dispense oxygen into groundwater. This is accomplished using a module of hollow fibers membranes which act as a micro-diffuser. A fully working prototype has been operated for weeks in our laboratories. The prototype is small enough to fit into a 4" well, i.e. a common size for wells installed at groundwater contaminated sites. Overall, the projected system cost-effectiveness appears promising, and the system may have a significant impact on the way active in-situ bioremediation is conducted.

Student Training

Anthony M. Avila, graduate student, Department of Chemical and Environmental Engineering, UC Riverside.

Collaborative Efforts

This project is a collaborative effort of Dr. Deshusses (for bioremediation aspects) and Dr. Yan (for fuel cell aspects), both in the Department of Chemical and Environmental Engineering at UC Riverside.

Anthony M. Avila, graduate student

The Catalysis of Perchlorate Ion Electroreduction at Transition-Metal Electrodes

Ronald Fawcett
Chemistry Department
UC Davis

Project Summary

Perchlorate contamination of ground water has become an important problem in the southwestern part of the U.S.. The perchlorate anion is very difficult to remove from water, and is a serious health problem because it accumulates in the thyroid gland. Considerable effort has been made to develop techniques to remove perchlorate from drinking water and water used to irrigate crops.

Our research involves using an electrochemical technique to reduce the perchlorate anion to the harmless chloride ion. Usually perchlorate is considered to be inert to electrochemical reduction. However, with suitable catalysts the perchlorate contamination can be significantly reduced. We have shown that using a nickel electrode of high surface area, together with ultraviolet light significantly accelerates the reduction of perchlorate in concentrated aqueous solutions.

The effectiveness of the electrochemical reduction process was measured using a perchlorate ion selective electrode (ISE) to follow the decrease of perchlorate concentration in the aqueous solution.

Using a nickel electrode of high surface area, together with ultraviolet light significantly accelerates the reduction of perchlorate in concentrated aqueous solutions.

Irradiation by UV light was tried to accelerate removal of perchlorate using both electrochemical reaction on a Ni foil electrode and chemical reaction with Raney Nickel. A low pressure mercury vapor lamp was used as a source of ultraviolet (UV) light. Perchlorate ions first undergo excitation by UV light, and then they are reduced to chloride ions. While UV light without any Ni could not reduce the perchlorate concentration, simultaneous application of Ni and UV light was effective in perchlorate removal. In order to efficiently degrade perchlorates, the UV reaction system requires a high output UV lamp capable of producing radiation at 185nm wavelength and a high quality quartz sleeve that allows efficient passage of the desired radiation wavelengths from the lamp into the reaction vessel. In the presence of UV light, 0.1M perchlorate was reduced by 35% by Ni in 3 h, whereas the removal was only 25% without UV. No significant improvement of reduction degree was found in the electrochemical experiments.

Perchlorate removal was observed only at acidic pH values. These experiments were conducted in unbuffered acidic solutions (pH about 2) where the pH increased by up to 2.0 units at the end of the experiments.

At present we are studying the effectiveness of the perchlorate removal process for concentrations in the ppm range. All indications are that the UV catalysis of perchlorate reduction will be more effective in solutions of very low perchlorate concentration.

Professional Presentations

Pavla Polášková, Maria Yu. Rusanova, W. Ronald Fawcett, Chemical Reduction of Perchlorate Ions on Nickel, 55th Annual Meeting, International Society for Electrochemistry, Thessaloniki, Greece, September 2004.

Student Training

Pavla Polášková, post-doctoral, Chemistry Department, UC Davis

Abiotic Nitrogen Removal Mechanisms in Rapid Infiltration Wastewater Treatment Systems

Mark Matsumoto
Chemical and Environmental Engineering
UC Riverside

Project Summary

Nitrogen management is an important element of a water reuse plan, especially where groundwater recharge using reclaimed wastewater is practiced. In these situations, land based municipal wastewater treatment systems such as rapid infiltration (RI) treatment are desirable because of the direct recharge associated with the system and for their lower costs. In RI systems, biological nitrification-denitrification is considered to be the primary nitrogen removal mechanism. However, depending on the soil characteristics of the RI systems, other mechanisms such as adsorption within the soil matrix may also provide significant nitrogen removal. Ongoing monitoring at a 150,000 m^3/d (40 MGD) RI facility in southern California (Rapid Infiltration and Extraction (RIX) Facility, City of San Bernardino) found that as the percentage of ammonium nitrogen in the influent increased, the apparent nitrogen removal efficiency improved. It was hypothesized that this phenomenon was related to the high mica content the soils found at this RI facility, and that the major nitrogen removal mechanism may be ammonium adsorption rather than biological nitrification-denitrification, however, it was determined that little or no ammonium adsorption occurred within the 20 feet of soil depth before the groundwater level. Therefore, if the ammonium adsorption did indeed occur at the RIX facility, the adsorption capacity of the soil has been exhausted.

The fact that nitrification and denitrification occurs simultaneously within the same soil volume is unusual and suggests that both conditions those favoring nitrification and those favoring denitrification, exist in close proximity within the soil column.

Results from laboratory testing, demonstrated that biological nitrogen removal reactions were significant and predominant. These results were also supported from analyses of samples collected from subsurface samplers (lysimeters), which were installed at the RIX facility by the plant personnel. An interesting observation has been that a relatively large amount of nitrogen is removed biologically with a small amount of organic content in the wastewater. Generally, much higher amounts of biodegradable organic matter is needed to achieve the amount of nitrogen removal experienced at the RIX facility. In addition, the denitrification process occurs deeper

in the soil column than has been noted in other studies and reports.

Results from our recent study indicate that nitrification (biological conversion of nitrogen in the form of ammonium to nitrate) and denitrification (biological conversion of nitrogen in the form of nitrate to nitrogen gas, which is released into the atmosphere) are the predominant removal mechanisms responsible for nitrogen removal, and that both processes occur throughout the soil column, from the soil surface to the underlying groundwater. High oxygen and low organic carbon concentrations are needed for nitrification, whereas low oxygen and high organic carbon concentrations are needed for denitrification. Thus, the fact that nitrification and denitrification occurs simultaneously within the same soil volume is unusual and suggests that both conditions, those favoring nitrification and those favoring denitrification, exist in close proximity within the soil column.

While nitrification was observed to occur steadily throughout the depth of the soil column at a constant rate, the denitrification rate was found to be greatest in the upper 2.5 ft of soil column, where the organic carbon concentration is highest. Thereafter, the denitrification rate decreased and became similar in magnitude to the nitrification rate.

The pilot study also confirmed that the denitrification process at RIX appears to be occurring well below the organic carbon levels recommended and/or theoretically derived and reported in the literature. The reason for this phenomenon is still unclear at this time and may be an appropriate focus for a future study.

An additional experiment was conducted with the pilot systems to determine the impact that additional organic carbon would have on nitrogen removal, The results were that additional organic carbon in the RIX influent water improved the denitrification rate within the upper portions of the soil column. After the organic carbon was depleted, the denitrification rates of the columns with and without added organic carbon were the same

However, despite improvement in the denitrification rate, it was not apparent that the overall nitrogen removal rate will improve. As previously noted, the nitrification process is favored when organic concentrations are low. By adding organic carbon, the rate of nitrification decreased and less ammonium was converted to nitrate for potential removal via denitrification. Thus, the overall rate of nitrogen removal in the upper portion of the soil column was similar with and without organic carbon addition. Interestingly, improvement in the rate of overall nitrogen removal was observed at the lower depths, however, after the added organic carbon was depleted.

Student Training

Kevin Bell, graduate, M.S., Chemical and Environmental Engineering, UC Riverside
Desirea Quam, graduate, M.S., Chemical and Environmental Engineering, UC Riverside
Araceli Arellano, undergraduate, Chemical Engineering, UC Riverside
Tuong-Phu Ngo, undergraduate, Environmental Engineering, UC Riverside
Lena Downar Herron, undergraduate, Environmental Engineering, UC Riverside)

Collaborative Efforts

Valerie Housel, City of San Bernardino
Chris Amrhein, UC Riverside
City of San Bernardino in providing personnel assistance in setting up and operating the pilot systems.

Kinetics of Inorganic Arsenic Contamination in Surface and Ground Waters

Michael A. McKibben
Department of Earth Sciences
UC Riverside

Project Summary

Arsenic in water even at low ppb levels poses a human health hazard. The World Health Organization, and more recently the US FDA revised previously established maximum contaminant levels for arsenic from 50ppb to 10ppb. The actual US FDA recommendation was as low as 5ppb, but that level was deemed too expensive to be practical for water suppliers. In combination with the widespread arsenic poisoning disaster in Bangladesh and India, this has sparked a high interest in natural arsenic contamination worldwide. High levels of arsenic in ground and surface water are the result of complicated processes that initiate from the breakdown of primary source minerals. Our research is designed to provide general-applicable equations describing the rate at which naturally-occurring arsenic sources break down and react in such environments.

There are a wide variety of natural arsenic minerals that could serve as primary sources, but two are more common than all the others by a degree of magnitude. Arsenical pyrite (arsenic-containing pyrite) and arsenopyrite (chemical formula FeAsS) are the most common natural sources.

A strong pH dependence and non-stoichiometric release of As, Fe and S from the mineral arsenopyrite suggest that prior models for arsenic release rates are insufficient to develop reliable predictions.

Arsenical pyrite, although more common than arsenopyrite, is difficult to quantify thermodynamically, as it varies in formula to a wide degree. Pyrite is already well-researched, and its thermodynamic properties are readily available. By determining the thermodynamic properties of arsenopyrite (which has not been thoroughly completed to date), the second-most common natural arsenic source will be quantified, and the understanding of background arsenic levels will be advanced. Due to the similarities in formula, a proxy for arsenical pyrite may be derived from the available information on pyrite combined with the current arsenopyrite research. This would greatly improve the ability to model ground and surface water arsenic contamination in present and potential drinking water sources, and could also aid in arsenic remediation.

Current progress includes a variety of preliminary results involving arsenopyrite—a common natural arsenic mineral with a chemical formula of FeAsS. The rate of reaction of arsenopyrite is strongly influenced by pH between pH 2.0 and pH 6.0. Even more importantly, the solubility (the ability of a compound to dissolve in water) decreases rapidly from pH 4.0 to pH 6.0, particularly for iron. This also affects the arsenic levels remaining in solution as arsenic is strongly absorbed by solid iron oxide products. At pH levels above about 4.5, the products are not soluble enough to provide a reliably measurable rate, thus a practical limitation between pH 2.0 and near 4.5 exists. The stoichiometry (the relative amounts of the different products) is not as simple as the mineral formula, and varies with the pH as well. Particularly iron is produced in greater amounts below pH 4.0, and arsenic becomes more prevalent above pH 4.0. One of the three components, sulfur, does not appear to be reacting in significant amounts, mostly remaining below detection limits. This seems to indicate that sulfur remains on the mineral surface as a solid at the pH levels used in the current research. Scanning electron microscope (SEM) examinations and analyses of products and mineral samples have been conducted as well.

The preliminary results show a strong pH dependence and non-stoichiometric release of As, Fe and S from arsenopyrite suggest that prior models for arsenic release rates (based on dissolution rates of pyrite as a proxy for As minerals) are insufficient to develop reliable predictions. Specific pH-dependent dissolution rate laws for each major arsenic mineral will have to be developed from experiments and incorporated into water speciation and fluid flow models.

Student Training

Bryan Tallant, graduate, M.Sc., Geological Sciences, UC Riverside

Tricia Menchaca, undergraduate; B.Sc., Geology, UC Riverside

DNA Apatmers-Based Detection of Atrazine in Water

Ashok Mulchandani
Chemical and Environmental Engineering
UC Riverside

Project Summary

Agricultural producers rely on atrazine for weed control. Many crops, commodities and services in the U.S. could not be supplied in an economic fashion without the use of these herbicides. However, the economic benefits from herbicide usage are not achieved without potential risks to human health and the environmental due to the toxicity and potency of these herbicides. Extensive pollution of the environment by atrazine is of major concern as an increasing number of studies reveal contamination of rivers and groundwaters by these herbicides. Because of their toxicity, EPA has set the maximum contaminant level (MCL) for these herbicides at 3 parts per billion (ppb). A survey by the Cal/EPA's Depart. of Pesticide Regulation on water samples taken from 3,564 wells in 48 of California's 58 counties revealed the detection of atrazine above regulatory limits in many areas, where the soil conditions favor movement of pesticides to ground water.

The objective of the proposed research is to develop novel single-stranded (ss) DNA aptamers that find atrazine for the selective and cost-effective detection of atrazine in drinking water supplies. Systematic evolution of ligands by exponential combinatorial chemistry approach, was used to generate these high-affinity aptamers. The principle of SELEX is based on the selection of random oligonucleotides of greater than 30 bases in length, and high-affinity (nM) aptamers could be selected after only four to five rounds of screening under progressive stringent conditions.

Multiple rounds of SELEX were performed to obtain atrazine binder ssDNA. Aptamers obtained were cloned in *Escherichia coli* and the clones sequenced. Several methods for determining binding affinity of ssDNA aptamer with atrazine were evaluated. The method based on radiolabeled DNA was found to give best results. Several aptamers with 10 μM binding affinity for atrazine have been identified. Work is planned to perform further rounds of SELEX to obtain stronger atrazine binder aptamers and to develop a fluorescence polarization immunoassay for atrazine using the best atrazine binder aptamers.

Of the methods for determining binding affinity of ssDNA aptamer with atrazine, the method based on radiolabeled DNA was found to give best results.

Student Training

Pablo Sanchez, graduate, Ph.D.,
Microbiology, UC Riverside.

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

Kara Nelson
Department of Civil & Environmental Engineering
UC Berkeley

Project Summary

Current detection methods and monitoring approaches are inadequate for developing successful and cost-effective strategies for reducing fecal pollution. One of the main limitations of the current culture-based detection methods is that they do not distinguish between bacteria that originate from different hosts, such as a human, cow or bird. Because any particular water (e.g., lake, river, estuary, or beach) is likely to receive pollution from multiple point and non-point sources, the inability to distinguish host-specific indicators significantly limits the ability to identify and target the main sources, placing a major constraint on the management of fecal pollution. A variety of new approaches that exploit host-specific fecal bacteria to conduct microbial source tracking (MST) studies are being explored. While many of the methods may eventually provide powerful tools for identifying the wide range of human and animal point and non-point sources that contribute fecal pollution to a water body, none of the molecular methods currently has the potential to provide a direct quantitative measure of the fractional contribution from each of the sources to the total concentration of fecal pollution. Quantitative methods are needed 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. Therefore, the goal of our 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 goal of our 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 emphasis of our research to date has been the development of a qPCR method for the detection of total *E. coli*. The amplified sequence (primer and probe

targets) is in the uidA gene and is unique to *E. coli* and *Shigella* bacteria. We do not believe that detection of *Shigella* will limit the application of the method because *Shigella* spp. are typically present in much lower concentrations than *E. coli*. We tested the specificity of the primers and probe by screening 11 *E. coli* strains, 3 *Shigella* strains, and 6 enteric bacteria. As expected, all of the *E. coli* and *Shigella* strains were detected, whereas none of the other enteric bacteria were detected. One of the main challenges we faced is that the polymerase solution used for PCR contains traces of *E. coli* DNA (the polymerase is produced using *E. coli*), which interferes with the detection of low concentrations of *E. coli* in a sample. We were able to remove the contaminant DNA by treating the PCR mastermix and primers with DNAse. Finally, to make the method quantitative, the PCR signals were converted to cell concentrations using a standard curve based on either acridine orange direct count or spread plate. Currently we are developing an alternative method of quantification based on the copy number of the target sequence. The next stages of this work will be to test the method on environmental samples and to develop a method for distinguishing viable and non-viable cells. Then, we will begin investigating host-specific sequences.

Student Training

Sarah Stafford, PhD, Environmental Engineering, UC Berkeley

Use of Bioassays to Assess the Water Quality of Wastewater Treatment Plants for the Occurrence of Estrogens and Androgens

Daniel Schlenk
Dept of Environmental Sciences
UC Riverside

Project Summary

Over the past decade, there has been a global concern regarding the discharge of chemicals that have the potential of altering the endocrine system of aquatic organisms in waterways. Entering the aquatic environment via wastewater discharge and other point sources, a variety of compounds may bind to the estrogen receptor of resident biota and elicit responses in the animals similar to those when the organisms are exposed to the endogenous hormone: 17β-estradiol (E2). Receiving waters and effluent of sewage treatment plants contain these chemicals in concentrations that have demonstrated adverse effects on the normal physiology and endocrinology of the exposed organisms.

Numerous strategies have been implemented in an effort to ameliorate the adverse effects of insufficiently treated wastewater in eliminating endocrine-disrupting compounds. Two processes that have been commonly employed include enhanced wastewater treatment and wetland treatment. The objectives of this study was to use *in vivo* (rainbow trout VTG) and *in vitro* (yeast estrogen screening) assays to:

1) Investigate the estrogenic potencies of tertiary-treated wastewater, and,
2) Evaluate the estrogenic activities of wastewater following wetland treatment

Wastewater from two different treatment plants (Tertiary treatment; and Wetlands treatment) were evaluated for estrogenic activity using two biological methods that evaluate direct acting estrogens and indirectly acting estrogens. The treatment plant receives non-disinfected secondary treated water from the Orange County Sanitation District, and provides flocculation, dual-media filtration, and chlorine disinfection prior to distribution. Wastewaters from the Green Acres Plant had environmental estrogens which induced vitellogenin (egg yolk proteins) in juvenile

These data indicate that wetland treatment within the Prado site may not totally alleviate *in vivo* estrogenic activity, and ER-based *in vitro* ligand-based assays may underestimate estogenic activity.

rainbow trout. Entering and exiting water from the Prado wetland also had an estrogenic activity in trout. *In vitro* activity of tertiary-treated water was 10 times less than *in vivo* activity. Wastewater dominated surface water of the Santa Ana River possessed 10-fold greater *in vivo* activity than YES estrogenicity. These data indicate that wetland treatment within the Prado site may not totally alleviate *in vivo* estrogenic activity and ER-based *in vitro* ligand-based assays may underestimate estrogenic activity.

Publications

Lingtian Xie, Yelena Sapozhnikova, Ola Bawardi, and Daniel Schlenk, Evaluation Of Wetland And Tertiary Wastewater Treatments For Estrogenicity Using In Vivo And In Vitro Assays, *Archives of Environmental Toxicology and Chemistry, 2004.* (in press).

Presentations

L. Xie, Y. Sapozhnikova, O. Bawardi, G. Woodside, D. Schlenk, Evaluation of estrogenicity in tertiary treated wastewater effluent reused at landscape irrigation and industrial sites in Orange County, California, USA Society of Environmental Toxicology and Chemistry (poster Presentation), Austin TX, November 9-13, 2003.

L. Xie, Y. Sapozhnikova, O. Bawardi, G. Woodside, D. Schlenk, Evaluation Of Wetland And Tertiary Wastewater Treatments For Estrogenicity Using In Vivo And In Vitro Assays, Southern California Chapter of the Society of Environmental Toxicology and Chemistry (Platform Presentation), San Diego, CA, May 22, 2004.

Schlenk, Daniel, Use of Bioassays to Assess the Water Quality of Wastewater Treatment Plants for the Occurrences of Estrogens and Androgens, Kwangju Institute of Science and Technology, Environmental Estrogens in Surface Waters of North America, Kwangju, South Korea, November 2003.

Schlenk, Daniel, Use of Bioassays to Assess the Water Quality of Wastewater Treatment Plants for the Occurrences of Estrogens and Androgens, UC Water Resource Institute Annual Board Meeting, Use of Bioassays to Assess the Water Quality of Wastewater Treatment Plants for the Occurrence of Estrogens and Androgens, Ontario, CA, April, 2004.

Student Training

Ola Bawardi, Undergraduate and Graduate, Environmental Science, UC Riverside
Nadia Shin, graduate, Environmental Science, UC Riverside
Thi Mai, undergraduate, Environmental Science, UC Riverside
Hector De Haro, undergraduate, Environmental Science, UC Riverside
Dalin Shi, graduate, Environmental Science, UC Riverside
Dr. Lingtian (Peter) Xie, Postdoctoral researcher, Environmental Science, UC Riverside

Additional Funding

$439,044 - Water Environment Research Foundation (2003-2005)

Collaborative Efforts

Orange County Water District
Duke University

The Speciation and Reactivity of Wastewater-Derived Organic Nitrogen

David L. Sedlak
Department of Civil and Environmental Engineering
UC Berkeley

Project Summary

Nitrogen often is the limiting nutrient for the growth of algae and phytoplankton in estuaries and surface waters in California. To control cultural eutrophication (i.e., excessive growth of algae and plankton related to anthropogenic sources) regulatory agencies often focus on the control of point source discharges, including municipal wastewater effluent. Recent attempts to control cultural eutrophication in nitrogen-limited systems have focused on the simultaneous control of all forms of nitrogen (i.e., nitrate, nitrite, ammonia and organic nitrogen) with the underlying assumption that inorganic and organic nitrogen are equally bioavailable. To assess the validity of this assumption, algal growth bioassays were conducted using denitrified wastewater effluent samples that contained mainly organic nitrogen. The growth assays were performed with a species of algae (*Selenastrum Capricornutum*) that is commonly used for regulatory compliance monitoring. Results of the study indicate that wastewater-derived dissolved organic nitrogen (DON) is not bioavailable to the algae in the absence of bacteria. However, approximately half of the wastewater-derived organic nitrogen was available to the algae in the presence of bacteria during a two-week incubation. These results suggest that while it is inappropriate to assume that wastewater-derived DON does not cause cultural eutrophication, it will not cause as much eutrophication as inorganic nitrogen. These results will be useful in the design of watershed protection plans, such as those being implemented in the Truckee River system near Lake Tahoe.

Our results indicate that while it is inappropriate to assume that wastewater-derived dissolved organic nitrogen does not cause cultural eutrophication, it will not cause as much eutrophication as inorganic nitrogen.

Wastewater-derived organic nitrogen also plays an important role in the formation of the carcinogenic disinfection byproduct, N-nitrosodimethylamine (NDMA). NDMA is formed when wastewater effluent is disinfected with chlorine. It also can be formed when surface water or groundwater that has been impacted by wastewater effluent discharges undergoes disinfection in drinking water treatment plants. Recently, concerns associated with NDMA have caused great concern among utilities that practice indirect

potable water reuse (i.e., use of highly treated wastewater effluent to recharge drinking water aquifers or use as a water supply of surface waters that receive significant inputs of wastewater effluent). Most of the attention to date has focused on the removal of NDMA from the treated wastewater effluent. However, the presence of NDMA precursors also could be a problem if the NDMA precursors in drinking sources are stable after they are discharged because they could result in additional NDMA formation during drinking water treatment. To assess the stability of NDMA precursors in wastewater-derived organic nitrogen, NDMA precursor concentrations were measured in effluent samples before and after incubation with bacteria under aerobic conditions. Results of the experiments indicate that the NDMA precursors are stable for at least 30 days. Additional research is needed to assess the transport of NDMA precursors in the surface water and groundwater.

Publications

Elif Pehlivanoglu and David L. Sedlak, Bioavailability of wastewater-derived organic nitrogen to the alga Selenastrum Capricornutum Water Research, In Press.

Student Training

Elif Pehlivanoglu, graduate, Ph.D., Civil and Environmental Engineering, UC Berkeley

Collaborative Efforts

We have worked closely with the Truckee Meadows Water Reclamation Facility (the source of the wastewater effluent that we used in our research) during this study. We have communicated the results of our research to them and they have been very interested in using the results as part of their watershed protection efforts.

Evaluating the Effectiveness of Vegetated Buffers to Remove Nutrients, Pathogens, and Sediment Transported in Runoff From Grazed, Irrigated Pastures

Kenneth W. Tate
Agronomy and Range Science
UC Davis

Project Summary

Irrigated pastures serve a critical role in the economic stability of California's livestock industry by providing low cost, high quality summer forage. Surface water runoff from irrigated pastures can transport pollutants to nearby waterbodies. We examined the potential for vegetative buffers positioned at the bottom of flood-irrigated, foothill pastures to attenuate nutrients, fecal borne bacteria, dissolved organic carbon and suspended solids contained in pasture runoff during irrigation – runoff events. The project was conducted on at the UC Sierra Foothill Research and Extension Center near Browns Valley in Yuba County. Buffer treatments investigated were a 3:1 pasture area (240 m^2) to buffer area (80 m^2 or 16 m long buffer) ratio, a 6:1 pasture (240 m^2) to buffer area (40 m^2 or 8 m long buffer) ratio, and a no buffer control. The water quality impact of off-setting the timing of grazing by beef cattle (2, 15, 30 days rest from grazing before irrigation) and of managing buffer vegetation with regular cutting and removal of vegetation were also examined.

Pasture runoff water quality can be improved through integration of irrigation efficiency improvement to reduce runoff, offset of grazing events from irrigation events, and establishment of managed (cut or moderately grazed) vegetative buffers.

We found no significant ($P<0.05$) reduction in runoff volume or total *E. coli* flux due to either buffer treatment compared to the no buffer control. There were apparent, but not statistically significant ($P>0.10$), decreases in total P for both buffer treatments. The 8 m buffer decreased flux of nitrate (introduced as ^{15}N) by 28% and the 16 m buffer decreased flux by 42%. For ammonium (introduced as ^{15}N) the decrease was 34% and 48%, and for dissolved organic nitrogen the decrease was 21% and 9% for the 8 and 16 m buffers, respectively. Under both buffer treatments there was an apparent ($P>.10$) increase in total particulate organic carbon and turbidity. There were significant increases ($P<0.05$) in dissolved organic carbon at the 16 m pasture to buffer area treatment. The buffer areas were serving

as sources for particulate and dissolved organic carbon as well as organic nitrogen.

Discharge volume (m^3/ha) was positively related to loss of all pollutants, illustrating the dominating influence of hydrologic transport capacity in this system. Duration of rest from grazing (2, 15, and 30 days) prior to irrigation event was significantly related to both the concentration and flux of all pollutants examined. Reduction in pollutant fluxes ranged from 10 to 40% for irrigations events occurring 30 days post grazing compared to irrigation occurring 2 days post grazing. Grazing intensity and duration, and thus pollutant loading, was held constant across all plots and trials. Regular cutting of buffer vegetation was found to significantly increase total N (introduced as ^{15}N) sequestration in vegetation regrowth with a resulting improvement in water quality.

Pasture runoff water quality can be improved through integration of irrigation efficiency improvement to reduce runoff, off-set of grazing events from irrigation events, and establishment of managed (cut or moderately grazed) vegetative buffers. Regular removal of vegetation in buffers is critical to maintain the buffer vegetation's nitrogen uptake capacity and to reduce the build up of organic matter which can serve as a source for organic particulate matter, dissolved organic nitrogen and carbon.

Publications

Bedard-Haughn, A., K.W. Tate, C. van Kessel, Using ^{15}N to Quantify Vegetative Buffer Effectiveness for Sequestering N in Runoff, *Journal of Environmental Quality,* 2004. In Press.

Bedard-Haughn, A., K.W. Tate, C. van Kessel, Quantifying the Impact of Regular Cutting on Vegetative Buffer Efficacy for ^{15}N Sequestration. *Journal of Environmental Quality*. Accepted.

Professional Presentations

Results were reported to CA State Water Resources Control Board – Surface Water Ambient Monitoring Program Continuing Conference. 2003, Sacramento, CA, March 7, 2003

USDA NRCS Continuing Education Field Day 2003 - site was a stop on the field tour and presentations were made to the group by project leaders and graduate students. UC Sierra Foothill Research and Extension Center, Browns Valley, CA, March 27, 2003.

Bedard-Haughn, A., Tate, K.W., and C. van Kessel, Oral presentation, Vegetative buffer efficiency in an irrigated pasture system. Canadian Society of Soil Science Annual Meeting, Montréal, QC. Awarded: C.F. Bentley Student Presentation Awarded 1st place for Excellence in Oral Presentations, August 12, 2003.

Bedard-Haughn, A., Tate, K.W., and C. van Kessel, Oral presentation, Attenuation of nitrate-^{15}N by vegetated buffers in an irrigated pasture system. American Geophysical Union Fall Meeting, San Francisco, CA, December 10, 2003.

SFREC Annual Field Day 2004 – site was a stop on the annual field tour and presentations were made to the group by project leaders and graduate students, UC Sierra Foothill Research and Extension Center, Browns Valley, CA, April 15, 2004.

Bedard-Haughn, A., Tate, K.W., and C. van Kessel, Oral presentation, Using ^{15}N to quantify vegetative buffer efficiency in an irrigated pasture system. Riparian Ecosystems and Buffers: Multi-scale Structure, Function, and Management. American Water Resource Association, Summer Specialty Conference, Olympic Valley, CA, June 29, 2004.

Bedard-Haughn, A., Tate, K.W., and C. van Kessel, Oral presentation, Using ^{15}N to quantify vegetative buffer efficiency for sequestering N in runoff. Ecological Society of America Annual Meeting, Portland, OR, August 5, 2004.

Bedard-Haughn, A., Tate, K.W., and C. van Kessel, Oral presentation, Increasing the demand: The impact of regular cutting on vegetative buffer ^{15}N uptake. Soil Science Society of America and Canadian Society of Soil Science Joint Annual Meeting, Seattle, WA, November 3, 2004.

Student Training

Angela Bedard-Haughn, Ph.D. Candidate, Soil Science, UC Davis
Christiana Peterson, Undergraduate, Agronomy, UC Davis
David Sok, Undergraduate, Agronomy, UC Davis

Additional Funding

Tate, K.W., E.R. Atwill, C. Van Kessel, R. Dahlgren, J. Six, and A. Bedard-Haughn, Implementation of Vegetative Buffer, Irrigation, and Grazing Best Management Practices to Reduce Pathogens, Organic Carbon, and Colloids in Runoff from Rangelands and Irrigated Pastures. CALFED Prop. 50 Drinking Water Quality Program, 2004-2008, Amount: $885,376.

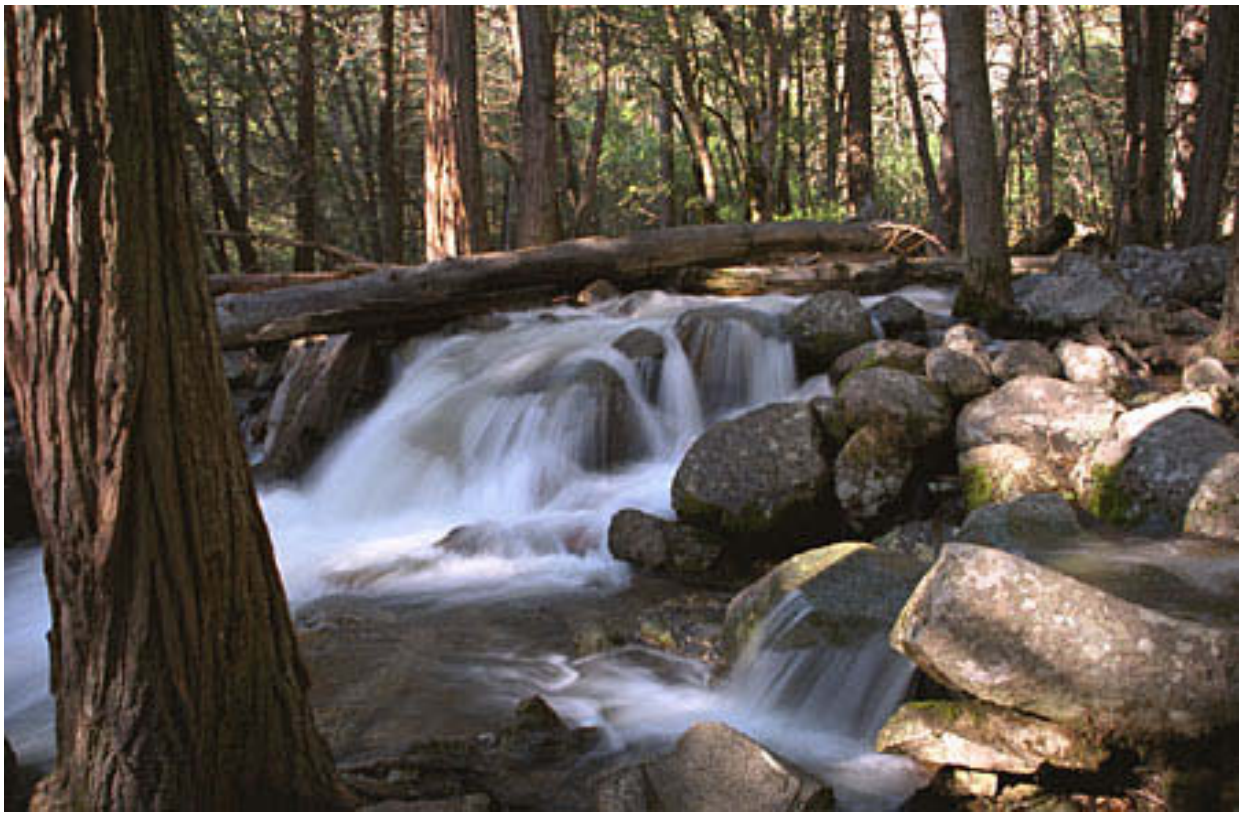
Collaborative Efforts

We are currently working with the Instituto Nacional de Investigación Agropecuario (INIA) of Chile to arrange a 3 day tour and short course on buffer design and management to be held at SFREC in Fall 2004

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.



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

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

Project Summary

Seawater (saltwater) intrusion is a problem that threatens many coastal aquifers around the world. The problem may occur for many reasons but is generally a result of over-pumping of groundwater in the coastal area. An effective way of mitigating seawater intrusion has been the use of hydraulic barriers, or simply barriers. A barrier is essentially an array of injection wells arranged parallel and in close proximity to the coastline. The wells inject freshwater into the lower aquifers to raise the water level and to create a hydraulic barrier to stop seawater intrusion and to protect freshwater pumping wells in the coastal plain. Today, there are three major barriers in operation in Los Angeles County which protect a 20,300,000 acre-foot groundwater reservoir that is used to meet approximately 35% of the potable water supply for 3.2 million residents.

Though the barriers in Los Angeles County have been in operation since 1950's, no systematic procedures exists to guide the operation. Recently, various deficiencies have been noticed in their performance and some regions of the aquifers have suffered leakage. This leakage of seawater through the barrier has degraded the groundwater basin water quality, reduced the net groundwater basin storage, caused shutdowns of freshwater pumping wells, and caused significant losses in basin management activities. Furthermore, a significant loss of injected water (20%) has been identified due to seaward migration of the injected water. These deficiencies can be mitigated by optimizing the operation of the barrier facilities or, if necessary, constructing additional injection wells, or both.

A validation and sensitivity study has been conducted on the calibrated groundwater model that simulates the flow and transport of the barrier operations. The validated groundwater model will be coupled with an optimization model.

The goal of this research is to use state-of-the-art groundwater modeling and optimization techniques to develop optimal management strategies for the Alamitos barrier, one of the three barriers operated by the Los Angeles County Department of Public Works. Specifically the objectives are to:

(1) first calibrate and validate a groundwater model to simulate the complex barrier operations,

(2) to determine the optimal management strategy of the existing barrier facilities,

(3) to identify the optimal candidate sites for additional injection wells, and,

(4) to use multiobjective optimization to investigate alternative and competing management strategies that may be cost effective in addressing the seawater intrusion problem.

This study is still in early stages of development with research ongoing. At this point a validation and sensitivity study has been conducted on the calibrated groundwater model that simulates the flow and transport of the barrier operations. A final set of simulations is still slated for fine tuning the boundary conditions and transport parameters. In the near future the validated groundwater model will be coupled with an optimization model.

Student Training

Ben Bray, graduate, Ph.D; Civil and Environmental Engineering, UC Los Angeles.

Collaborative Efforts

There has been significant collaboration in the development and calibration phase of the groundwater model with Dr Y. Sim, Los Angeles County Department of Public Works.

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.

Voluntary Compliance Versus Mandatory Sanctions: A Natural Experiment in Water Quality Regulation

Paul Sabatier
Environmental Science and Policy
UC Davis

Project Summary

The primary goal of the project is to understand what motivates dairy producers to manage environmental impacts, and in particular, to understand the relative importance of various factors such as regulatory enforcement, education and outreach, financial incentives, farm economics, peer pressure, environmental ethics, the Sonoma-Marin Animal Resource Committee, and the Dairy Quality Assurance Program. A related goal is to better understand the needs and constraints of local dairy producers, and to help government agencies forge a more productive relationship with the dairy industry.

In early 2004, a survey was administered to all 106 dairies in Marin and Sonoma Counties. Fifty-nine surveys were completed and returned. The survey data are currently being analyzed with the goal of drawing statistical inferences about the relationships between the various factors listed above. The final report will be submitted September 2004.

A preliminary, descriptive summary of the survey data suggests the following:
The dairies in the sample are distinctive in that they are relatively small (averaging approximately 300 milk cows), two-thirds are owner-operated and one-third leased.

Incentives that dairy producers identified as being most helpful to manage water quality were, grants, low-interest loans, and a "one-stop shopping" clearing-house for required government permits.

Fifty-nine percent of dairies have been in the same family for over 50 years. Fifty-nine percent report that the dairy will probably remain in the family for the foreseeable future. Twenty-five percent believe the dairy will be sold. For the vast majority of respondents, the dairy accounts for 80-100% of family income. Nearly half of the responding dairies are enrolled or certified through the California Dairy Quality Assurance Program.

When asked to rank the severity of various obstacles to profitability of their dairy, the top obstacle was low milk prices. Other significant obstacles included high feed prices, and costs of complying with environmental regulations.

When asked to rank various agency programs and incentives that would most help dairy producers manage water

quality, the top three choices were grants, low-interest loans, and a “one-stop shopping” clearinghouse for required government permits. When asked to name the minimum amount of grant money that would enable significant site improvements, the median response was $100,000 or 75% of the total project cost.

When asked to rank the effectiveness of various water quality management strategies, dairy producers generally focused on strategies that store or divert runoff from manured areas and silage. The two strategies rated as least effective were planting riparian vegetation and fencing creeks to exclude pastured livestock.

Publications

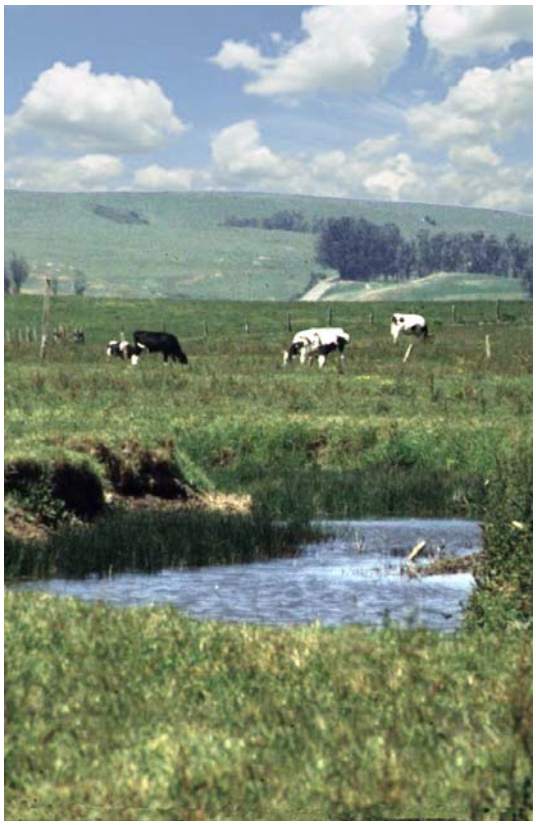
Center for Collaborative Policy and UC Cooperative Extension, *Dairies, Water Quality, and Environmental Regulation: Questionnaire Summary Report,* July 2004.

Student Training

Christal Love, undergraduate, Environmental Science and Policy, UC Davis

Collaborative Efforts

The survey was administered in collaboration with Stephanie Larson — Livestock & Range Management Advisor, UC Cooperative Extension, Marin and Sonoma Counties.



Economic Incentive and Policies to Improve Water Quality in a Binational Watershed

Linda Fernandez
Environmental Sciences
UC Riverside

Project Summary

Efforts on the project addressing water quality in the Tijuana binational watershed are enabling cost and benefit measures to compare policy options for the U.S. and Mexico to pursue in handling shared transboundary pollution. The project has generated information to determine that it is feasible to clean up the Tijuana binational watershed through enhanced fiscal resources by passing on costs to the larger public served by the watershed. The watershed is 1731 square miles along the Baja California-California border. Water flows from south to north, out of Tijuana, Mexico into San Diego, California coastal area used for recreation and habitat. This coastal area is referred to as the Tijuana Estuary and contains approximately half of the most valued salt marsh wetlands habitat remaining in Southern California. The Tijuana Estuary is designated as a National Estuarine Research Reserve and a National Wildlife Refuge for a diverse array of terrestrial and aquatic species including six different endangered species.

The project has generated information to determine that it is feasible to clean up the Tijuana binational watershed through enhanced fiscal resources by passing on costs to the larger public served by the watershed.

Thus far, I have learned the following information from different project tasks:

1) The economic value of public health and environmental costs from water quality degradation constitutes a significant amount of value even with limited data for a conservative, lower bound estimate. Damages were quantified by correlating increased incidences of illness to recreational exposure to poorer water quality in coastal areas downstream in the U.S. (San Diego beaches). These estimated benefits from improved water quality outweigh the costs for improvement. The specific costs for improvement have been obtained through various sources focused on abating sediment and wastewater

pollution flowing from upstream Tijuana into downstream San Diego County.

2) From the GIS modeling of researchers at San Diego State University, it has been possible to correlate the urban runoff concentrations of pollutants from particular land uses upstream in Tijuana. Data collection efforts have been focused on the Tijuana River National Estuarine Research Reserve to obtain cost and restoration measurement information for Mexico, in Canon de los Laureles or Goat Canyon that is the 4.6 square mile area of the binational watershed where sedimentation control and riparian habitat restoration have taken place in addition to the model restoration marsh downstream in the U.S. part of the Estuary.

3) The institutional payments through NAFTA to address specific water quality problems in the Tijuana estuary must be supplemented by policy alternatives implemented at a local and regional level of the two binational cities. The quantitative analysis I explore focuses on the form of financial transfers from downstream to upstream sources of sedimentation from uncontrolled urban sprawl in the Tijuana estuary. There is evidence that the value and scope of the transfer can and should be increased as well as the feasibility for the upstream sediment controls to be implemented.

4) Through assessing current expenditures of local, regional, national and binational spending for various types of water pollution control, it has been possible to quantify the downstream transfer payments that currently exist (mostly on a local scale through California state and municipal public funding) to Tijuana for sediment abatement related to urban sprawl. The numerical simulation over time and space has enabled projections of how the transfers can be augmented in order to truly address the size of the

Professional Presentations

Fernandez, Linda, Integrated Water Management along the U.S.-Mexico Border, 24th Biennial Groundwater Conference, Ontario, CA, October 28, 2003.

Student Training

Monica Das, graduate, Economics Dept., UC Riverside

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