Center for Water Resources
Annual Technical Report
FY 2006

Introduction

The UC Center for Water Resources is a multicampus research unit and a special program within the University of Californias Division of Agriculture and Natural Resources. The major function is to support research and extension activities that will contribute to the efficient management of water resources within the state. Meeting the needs of the urban, agricultural and wildlife sections from both water quality and quantity considerations is a goal of the Center. The Center has linkages to faculty on all UC campuses in the UC system and to extension personnel in each of the 58 counties. The Center can be reached by email at cwres@ucr.edu and our web site can be accessed at http://waterreseources.ucr.edu.

The Water Resources Center funded 18 new projects and continued 10 projects for a total of $678,105.00 with nearly every UC Campus participating.

Research Program

Monitoring California Water Resources from Space, James S. Famiglietti Department of Earth System Science, University of California, Irvine

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

Plant Water Use in Owens Valley, CA: Understanding the Influence of Climate and Depth to Groundwater, Diane E. Pataki Departments of Earth System Science, and Ecology and Evolutionary Biology, University of California, Irvine

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

Investigating the Role of Nitrogen Fixation and Denitrification in a Highly Eutrophic Southern California Estuary, Peggy Fong Department of Ecology and Evolutionary Biology, University of California, Los Angeles

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

Quantitative PCR Assays for Specific Host Sources of Fecal Pollution in Watersheds Kathryn M. Ivanetich, Department of Pharmaceutical Chemistry, University of California, San Francisco.

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

Impacts of Ethanol on Anaerobic Production of Tert-Butyl Alcohol (TBA) from MTBE in Groundwater Kate M. Scow, Douglas, Department of Land, Air and Water Resources, University of California, Davis

Tertiary butyl alcohol (TBA) is an undesirable byproduct of methyl tertiary butyl ether (MTBE) biodegradation. Ethanol, which is increasingly being used as a gasoline oxygenate, appears to stimulate formation and reduce removal of TBA in groundwater.

Diuron in California's Water Supply: Transformations and Associated Risks Thomas M. Young, Department of Civil and Environmental Engineering, University of California, Davis

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

The Politics and Practice of Watershed Restoration Jeff Romm, Department of Environmental Science, Policy, and Management University of California, Berkeley

In the last two decades, watershed restoration has dramatically increased in both popularity and practice, yet the social and environmental outcomes of restoration remain ambiguous. This research addresses three central questions: 1) What is watershed restoration accomplishing on-the-ground?, 2) Who and what primarily benefit from dominant restoration practices?, and 3) How is watershed restoration influenced by social factors, including the political economy of water use along with legal and institutional frameworks of water management.

Dynamics of Point and Non-Point Source Fecal Pollution from an Urban Watershed in Southern California

Basic Information

Title:	Dynamics of Point and Non-Point Source Fecal Pollution from an Urban Watershed in Southern California
Project Number:	2003CA50G
Start Date:	9/1/2003
End Date:	8/31/2006
Funding Source:	104G
Congressional District:	48
Research Category:	None
Focus Category:	Ecology, Surface Water, Water Quality
Descriptors:	None
Principal Investigators:	Stanley B. Grant, Patricia Ann Holden, Brett franklin Sanders

Publication

This research project is focused on the fate and transport of microorganisms and suspended particles in surface waters from an urban coastal watershed along an inland-to-ocean transect (creeks, rivers, estuaries, surf zone, offshore).

Problem. Recently, surface water runoff has emerged as the primary source of pollutant loading to the urban ocean due to changes in civil infrastructure, such as damming and development. Surface waters in southern California are negatively impacted by microorganisms and suspended particles, consequently failing many total maximum daily load (TMDL) requirements and potentially affecting the health of recreational swimmers. Therefore, the sources of pollutants in urban runoff must be quantified as part of assessing pollutant loads, and there is a need to understand the fate and transport of pollutants in a watershed system in order to reduce the impact through the development and deployment of best management practices (BMPs).

Research Objectives. The objective is to elucidate the origins and fluvial transport of fecal indicator bacteria, human pathogenic viruses, and suspended particles along an inland-to-ocean transect in the Santa Ana River watershed, southern California, during dry weather and episodic storm events, and to identify coastal water quality impact from a highly urbanized coastal watershed system. This research includes the following specific goals:

- To characterize the concentrations of fecal indicator bacteria and suspended sediment in storm water runoff from the Santa Ana River.
- To understand the origin and transport mechanism of suspended particles through the characteristics of particle size spectra eroded from an urban watershed.
- To assess coastal water quality impact of storm water runoff and the correlation between in-situ measurements and remote sensing.
- To assess the impact of urban runoff and treated wastewater in the growth and die-off mechanisms of fecal indicator bacteria.
- To assess microbial community changes in storm water runoff in the Santa Ana River as indicators of fecal pollution and runoff origins

Methodology.

- High frequency sampling of stormwater runoff at three sites in the Santa Ana River watershed over three storms. Measurements on runoff samples included: fecal indicator bacteria (total coliform, *E. coli*, and enterococci), fecal indicator virus (F^+ coliphage), human pathogenic virus (human adenovirus and human enterovirus by nested polymerase chain reaction, PCR), suspended particles (mass and size distribution), and microbial community composition by analysis of terminal restriction fragment length polymorphisms (TRFLPs) of particle-associated and free-living eubacteria.
- Merging of satellite sensing of runoff plumes with shipboard measurements of runoff plumes, and in situ sensor data. Measurements included: MODIS satellite data (true color images), NEOCO in situ sensor at Newport Pier (1/4 min^{-1}, salinity, temperature, chlorophyll), fecal indicator bacteria in surf zone (conducted by Orange County Sanitation District, OCSD), offshore (UCI and Bight 03), human pathogenic virus, suspended particles.
- Dry-weather transect sampling of stretch of Cucamonga Creek. Measurements include: fecal indicator bacteria, dissolved organic carbon, nitrate, ammonium, phosphorus, dissolved oxygen, pH, salinity and conductivity.
- Microcosm studies using different combinations of Cucamonga Creek baseflow, sterilized baseflow, treated wastewater discharge, sterilized treated wastewater discharge, and nutrient broth. Sampling of microcosms over time and measuring fecal indicator bacteria.

Principal Findings. Principal findings are the following:

a. Within-watershed stormwater studies:

- Concentrations of fecal indicator bacteria and fecal indicator viruses increase sharply during the rising limb of the storm hydrographs and do not fall with the falling limb of the storm hydrographs.
- Concentrations of suspended particles follow the shape of the storm hydrographs.
- Human adenovirus and human enterovirus results were negative (below detection limits using PCR and nested PCR), except for one positive result of adenovirus during the early part of a storm, downstream of the treated discharge of a tertiary wastewater treatment plant.
- Bacterial communities were both particle-associated and free-living in storm runoff. Whether the two fractions were similar depended on the site.
- Bacterial communities differed by site and were particularly distinct in the ocean. They also varied between storms within a site, but when one site was sampled during the course of a hydrograph no temporal variations in microbial communities were observed.

b. Coastal water quality impacts:

- Storm water runoff impacts coastal ocean water quality, both in the surf zone and offshore, with water quality in the surf zone frequently exceeding marine bathing standards by >500%.
- F^+ coliphage, human adenoviruses and enteroviruses detected just offshore of the Santa Ana River outlet.
- Turbidity plumes generated by the Santa Ana River spread out over a very large area (exceeding 100 km^2).
- Bacteria and viruses appear to be associated with particles smaller than 53 microns, or they are not particle associated. This results was confirmed both by culture-dependent and culture-independent microbiological methods.

Significance.

a. Within-watershed stormwater studies:

- Fecal indicator bacteria appear to be ubiquitous across the urban landscape and are washed off into receiving water bodies during storms.
- Traditional best management practices (BMPs) for treating stormwater pollutants may not be effective for treating bacterial pollutants.
- Flow fingerprints—or changes in the concentration of stormwater constituents with volumetric flow rate in the river—appear to be a useful analytical tool for determining sources of pollutants in stormwater runoff from urban watershseds.
- Community fingerprints appear to be site-specific which implies that microbes may be tracers for runoff water quality from various, integrated sources upstream.

b. Coastal ocean studies:

- Turbidity detected by MODIS satellite sensors does not necessarily correlate with water quality, as measured by fecal indicator bacteria, fecal indicator viruses, and human pathogenic viruses.
- Coastal impact of storm water runoff depends on prevailing ocean currents and waves, within-plume processing of particles and pathogens, and the timing, magnitude, and nature of runoff discharged from the river over the course of a storm.

Distribution and toxicity of sediment-associated pesticides in the Sacramento River watershed.

Basic Information

Title:	Distribution and toxicity of sediment-associated pesticides in the Sacramento River watershed.
Project Number:	2003CA57G
Start Date:	9/30/2003
End Date:	9/29/2006
Funding Source:	104G
Congressional District:	9th
Research Category:	Not Applicable
Focus Category:	Agriculture, Non Point Pollution, Sediments
Descriptors:	
Principal Investigators:	Donald Paul Weston, Chris Ingersoll, Michael j Lydy

Publication

1. You, J. and M.J. Lydy. 2006. Determination of pyrethroid, organophosphate and organochlorine pesticides in water by headspace solid-phase microextraction. Inter J. Environ Anal. Chem. 86(6): 381-389.
2. Amweg, E.L., D.P. Weston, C.S. Johnson, J. You and M.J. Lydy. 2006. Effect of piperonyl butoxide on permethrin toxicity in the amphipod Hyalella azetca. Environ Toxicol Chem. 25(7): 1817-1825.
3. Amweg, E.L., D.P. Weston, J. You and M.J. Lydy. 2006. Pyrethroid insecticides and sediment toxicity in urban creeks from California and Tennessee, USA. Environ. Sci. Technol. 40: 1700-1706.
4. You, J., P.F. Landrum and M.J. Lydy 2006. Comparison of chemical approaches for assessing bioavailability of sediment-associated contaminants. Environ Sci Technol. 40: 6348-6353.
5. Weston, D.P., E.L. Amweg, A. Mekebri, R.S. Ogle and M.J. Lydy. 2006. Aquatic effects of aerial spraying for mosquito control over an urban area. Environ Sci Technol. 40: 5817-5822.
6. Amweg, E.L. and Weston, D.P. (In press) Whole sediment toxicity identification evaluation tools for pyrethroid pesticides: I. Piperonyl butoxide addition. Environ. Toxicol. Chem.

Problem and Research Objectives

This research project is an extension of our past studies in which we have proven the analytical feasibility of sediment analysis for pyrethroids, have shown them present in most sediment samples from agriculture-affected water bodies, and have shown pyrethroid-related toxicity to benthic invertebrates in many locations. The study involved far more work on pyrethroids, and particularly on more basic aspects of their toxicology. This study had the following objectives:

1. Conduct bioaccumulation and toxicokinetics studies that examine how pyrethroids are processed by benthic invertebrates.
2. Determine the potential enhancement of pyrethroid toxicity by piperonyl butoxide (PBO), a synergist included in some pesticide formulations and known to be present in surface waters.
3. Examine possible interactions between pyrethroids and organochlorines that may modify the expected independent toxicity of the compounds.
4. Collect sediment from urban creeks and analyze them for pyrethroids and toxicity.
5. Analyze native benthic invertebrates for tissue pyrethroid concentrations.
6. Run chronic toxicity tests on selected sediment samples collected as part of the PRISM project. Dr. Chris Ingersoll, a USGS Scientist located at the Columbia, MO laboratory, will conduct this testing.
7. Measure changes in bioavailability (toxicity tests) and aqueous desorption rates (Tenax beads) of pyrethroids in field-collected soils over time.

Bioaccumulation and toxicokinetics

Methods - Toxicokinetics is the study of the rate processes involved in uptake, distribution, metabolism and elimination of a toxic chemical in an organism. This information is critical when judging the potential for toxicity and bioaccumulation of chemicals, as well as the potential for trophic transfer of toxic substances to predators. This component of the project will determine toxicokinetic parameters such as sediment uptake clearance coefficients (k_s), elimination rate constants for both parent compound (k_{ep}) and metabolites (k_{em}), the biotransformation rate (k_m), biological half life ($t_{1/2}$) and bioaccumulation factors (BAF). Two invertebrate species that differ widely in biotransformation capabilities were used: Chironomus tentans and Lumbriculus variegates.

Findings and status – Previous studies have determined temperature directly influences pyrethroid toxicity. Therefore, we have added a component to examine the temperature dependency of the toxicokinetics. Compounds such as pyrethroids and some organochlorines (i.e., DDT) have decreased toxicity at higher temperatures. The opposite effect is observed in metabolically activated pesticides such as chlorpyrifos. The mechanism for these changes is not completely understood. One means of determining this mechanism is through toxicokinetics at two temperatures (13 and 23 °C). In water only exposures using the midge Chironomus tentans, the pyrethroid permethrin was found to have increased biotransformation at higher temperatures although uptake and elimination rates were not affected. This increase in biotransformation also decreases the bioaccumulation factor (BCF) in the organism. Biotransformation was not observed in Lumbriculus variegatus sediment exposures and uptake and elimination rates were

not altered by temperature. However in preliminary experiments with another pyrethroid, lambda-cyhalothrin, uptake rates were significantly higher at 23°C. While biotransformation was not measured due to low body residues, the concentration in the animal begins to reach steady state at the higher temperature implying biotransformation occurs. This suggests that biotransformation may be one of the underlying factors affecting the toxicity change for pyrethroids.

While the pyrethroids and the organochlorine DDT have a similar mode of action as well as a similar trend in toxicity with temperature, the mechanism for the effect of temperature may be different. Unlike the pyrethroids, neither DDT nor its metabolite DDE exhibited any biotransformation in water only experiments with C. tentans. Like lambda-cyhalothrin, an increase in temperature increased the uptake rates, because there is insufficient biotransformation that leads to an increase in BCF. So for DDT it may be toxicodynamic factors driving the toxicity alteration. In another class of compounds, the metabolically activated organophosphates, temperature has the opposite effect on toxicity with lower temperatures decreasing toxicity.

In similar experiments to those described above, chlorpyrifos uptake rates were significantly increased with temperature as was the biotransformation and elimination rates. For this compound, however, the decreased biotransformation at lower temperatures decreased the formation of the more toxic metabolite. So, similar to the pyrethroids, biotransformation may play an important role in the effects of temperature on toxicity. This data not only provides insight as to the mechanisms of these insecticides, but also may help to explain and validate toxicity identification evaluations (TIEs) for pyrethroids. The kinetics results have been included in two papers that will be submitted within about a month.

PBO synergy

Methods - Piperonyl butoxide (PBO) is a synergist used to enhance the insecticidal properties of pyrethroid insecticides. The function of PBO is to inhibit metabolic degradation of the insecticide by the target pest species. With metabolic detoxification inhibited or completely stopped, the toxic potency of the pyrethroid is increased. PBO is included in many pyrethroid pesticide formulations, and residues of the compound are detectable in surface waters of California. The demonstration of PBO in surface waters raises the possibility that PBO may be having the same synergistic effect on aquatic non-target species as on the pest for which was initially applied, and suggests that literature estimates of pyrethroid toxicity may underestimate the risks since they do not include the possibility of a co-occurring synergist.

Findings and status – We have demonstrated the synergy of PBO and pyrethroids in the laboratory, using permethrin and bifenthrin. Field studies in urban areas and at a pond that had been sprayed for mosquitoes using a PBO-containing product have documented the presence of PBO in the water, but at concentrations far too low to cause synergy. We believe the absence of environmental synergy is the norm. However, a mosquito control application over Sacramento provided an unexpected and unique opportunity to test this hypothesis under worst-case conditions. Due to an outbreak of West Nile Virus, the entire metropolitan area of Sacramento was sprayed from the air for three successive nights. We found PBO in urban creeks at concentrations 100-fold greater than our previous studies. These same creeks are known to

contain pyrethroids from general urban use, and the PBO in the water from the mosquito control effort was in sufficient concentration to approximately double the toxicity of the pyrethroids already in the creeks. Our study had the surprising conclusion that the greatest impact of the spraying was not the insecticide itself, but the interaction of the PBO synergist with pyrethroids pre-existing in creek sediments. Two papers on our PBO work have been published, and a third is in press.

Interactions between pyrethroids and organochlorines

Methods - Our understanding of interactions of pesticides in mixtures is generally limited and restricts our ability to predict impacts of environmental contamination. Little if any research has been conducted examining interactions among pyrethroid insecticides or between pyrethroids and organochlorine pesticides. There is significant potential for interactions as both pesticide groups are neurotoxins with similar modes of action. The objective of this study component is to investigate, for selected species, potential interactions among pyrethroids and among pyrethroids and organochlorines, and classify these interactions as additive, synergistic or antagonistic.

Findings and status – Research conducted to date included examining the toxic effects of binary mixtures of both Type I and Type II pyrethroid insecticides in order to determine if these compounds interact additively. The mixtures that were examined can be categorized in one of three possible combinations: Type I – Type I; Type II – Type II; or Type I – Type II. The Type I pyrethroids used in this study were permethrin and bifenthrin, and the Type II pyrethroids were cypermethrin and lambda-cyhalothrin.

Completed goals of the research are as follows:

1. Conducted 10-d sediment toxicity tests, each consisting of two single-compound components and a binary mixture component;
2. Generated toxicity curves for each of the individual pyrethroids and the concentration-summed mixture;
3. Compared the experimental mixture toxicity curves to those predicted using single-compound data; and
4. Determined if the mixtures deviate from additivity based upon mixture LC50 values, their corresponding fiducial limits, and the slopes of the mixture toxicity curves.

Juvenile (~14-d old) amphipods (*Hyalella azteca*) were used for all toxicity tests. Results indicated that all of the mixtures were additive in nature with the exception of permethrin-bifenthrin and bifenthrin-cypermethrin which were both less than additive. Research examining pyrethroid and organochlorine interactions will be completed this summer. A draft manuscript has been prepared detailing the pyrethroid-pyrethroid interaction data and will be submitted to a peer-reviewed journal this summer. It is expected that an additional paper detailing the pyrethroid-organochlorine interactions will be prepared this fall.

Urban creek sampling

Methods – Our prior work with pyrethroids has focused on agriculture-dominated water bodies. However, urban use of pyrethroids in California is approximately twice that of agricultural use. Despite this, there has been no previous monitoring for pyrethroids in urban water bodies in the U.S.

Findings and status – We had initially proposed using USGS funding to sample three sites in the San Francisco Bay area. Instead, we actually sampled six, and took samples on 2-3 occasions at each one. With matching funds we sampled Sacramento area creeks on four occasions. Briefly, this work has shown pyrethroids are widespread in urban creeks, and in fact, were detectable in every one of our samples. The sediments in nearly all Sacramento creeks are acutely toxic to our tests organism, Hyalella azteca, due to pyrethroids. In the San Francisco Bay area pyrethroids were the primary toxicant in some creeks, but were not in sufficient concentration to explain the toxicity in most of them. One paper on this work has been published. Our initial plans to look at pyrethroid tissue levels in resident macroinvertebrates in the creeks failed to materialize due to lack of sufficient biomass.

Chronic toxicity testing

Methods – Dr. Chris Ingersoll of USGS had intended to do chronic toxicity testing of our urban sediments to supplement the acute testing we had planned.

Findings and status – Dr. Ingersoll was not able to perform the chronic tests because of the demands of other projects in his laboratory.

Changes in pyrethroid bioavailability over time

Methods - USGS support was used to measure relative changes in bioavailability and aqueous desorption rates of pyrethroids in field-collected soils as they age after the initial pesticide application. Acute toxicity tests were used as the measure of bioavailability, while desorption rates were determined using Tenax beads. Soil was collected from agricultural sites at multiple time points up to 270 days post-application.

Findings and status – We tracked pyrethroid bioavailability over time at three farms (pear orchard, tomato, and rice). Results were not conclusive due to both erratic performance of the Tenax extractions and the growers' repeated applications of pesticides on the farms (rather than the single application assumed in the study design). We have, however, continued to pursue Tenax extraction methods, with greater success in these more recent trials, and one paper has been published.

Notable Achievements and Awards

Two graduate students in Dr. Lydy's laboratory (Andrew Trimble, doctoral student; Amanda Harwood, Masters student) have received EPA STAR graduate fellowships to continue this research. These fellowships began August 2006 and are the result in part due to USGS/NIWR funding.

Due in large part to the urban creek findings from this study, as well as our agricultural findings from prior work, the California Department of Pesticide Regulation (DPR) has announced their intent to put pyrethroid pesticides in to the process known as "re-evaluation". It is extremely rare for DPR to put pesticides in re-evaluation based on water quality data, but our studies provided strong evidence of agricultural and urban aquatic toxicity due to the pyrethroids.

Under re-evaluation, DPR will require the registrants to provide additional data on sources, potential mitigation practices, and environmental fate and effects of pyrethroids so that the State of California can manage them more effectively.

We have received four supplemental awards as a result of this study, three from EPA funding via the Sacramento River Watershed Program. The first award of $23,000 provided for sampling at an additional farm site in connection with our studies on changes in pyrethroid bioavailability over time, as described above. The second award, for $91,000, provided for the development of procedures to identify when pyrethroids are the causative agent for mortality when observed in sediment toxicity tests (i.e., Toxicity Identification Evaluation). The third award, for $28,000, was for continued development of pyrethroid toxicity identification evaluation procedures.

A fourth award of $60,000 was just received from the University of California Water Resources Center for research on transport of pyrethroid pesticides in to the coastal waters of Monterey Bay, and their effect on benthic invertebrates of the shelf and deep sea canyon.

Institutional Re-arrangements: forging smart use water policy coalitions at the intersection of geo-technical engineering with urban open space

Basic Information

Title:	Institutional Re-arrangements: forging smart use water policy coalitions at the intersection of geo-technical engineering with urban open space
Project Number:	2004CA110G
Start Date:	9/1/2004
End Date:	6/30/2007
Funding Source:	104G
Congressional District:	48
Research Category:	Social Sciences
Focus Category:	Law, Institutions, and Policy, Hydrology, Recreation
Descriptors:	
Principal Investigators:	Helen Ingram

Publication

1. No reports or articles were published during this period.
2. Callon, M. (1986). Some elements of a sociology of translation: domestication of the scallops and fishermen of St. Brieuc Bay. Power, Action and Belief: A New Sociology of Knowledge. J. Law. London, Routledge: 196-233.
3. Latour, B. (1986). The powers of association. Power, Action, and Belief: A New Sociology of Knowledge? J. Law. London, Routledge: 264-280.
4. Latour, B. (2005). Reassembling the Social: An Introduction to Actor-Network-Theory. Oxford, UK, Oxford University Press.
5. Law, J. (1992). "Notes on the Theory of the Actor-Network: Ordering, Strategy, and Heterogeneity." Systems Practice 5(4): 379-393.
6. Law, J. (1999). After ANT: Complexity, Naming and Topology. Actor Network Theory: And After. J. Law. Oxford, UK, Blackwell.

RESEARCH PROGRAM:

1. Include Problem and Research Objectives, Methodology and Principal Findings and Significance for your project.

Problem and Research Objectives:

The problem is an operational gulf between the best available water management technology, and the political intransigence of existing patterns of urban land use and development planning. The research question was framed in the following way: *How are new waterfront urban spaces that combine non-structural flood control, economic development, neighborhood improvement, and recreational amenities planned, funded and implemented?*

The research objectives include identifying successful modes of urban collaborative governance, which integrate water management with land use planning; characterizing the constraints, opportunities, and management strategies involved; and making appropriate recommendations for future practice and research.

Methodology and Principal Findings:

Four western cities with strong "watershed park" coalitions were identified: Denver, Colorado; Los Angeles, California; Phoenix, Arizona; and San Jose, California. The planning and construction of their riverfront/watershed management parks were studied using an in-depth, interpretive, qualitative case research method.

During an exploratory research project in 2003, the completed parks in Denver, Phoenix, and San Jose were presented and continually referenced by public officials seeking to build support for new waterfront open spaces along the Los Angeles River in Los Angeles, California. This research program was designed to capitalize on and learn from this historic perspective: how were these projects (Denver, Phoenix, and San Jose) accomplished? What did their leaders, managers, and advocates have to say about how they were promoted, negotiated, and implemented? How is this information being used in the early-stage construction of the Los Angeles projects? What are the challenges and opportunities being faced by the watershed park planners in Los Angeles?

Data collection in each city relied on both primary and secondary sources. To begin with, thorough media surveys were conducted on the parks, rivers, and history of watershed management in each region, as well as a review of the pertinent organizational literature and project documentation (plans, meeting minutes, website information, brochures, press releases, public review materials, etc.) From these sources, interview subjects were identified. These interviewees were the policy actors who comprised the "watershed park" coalitions in each

city. In Los Angeles, because the park projects are still in the stage of being planned and negotiated, it was also possible to conduct fieldwork as a participant observer at river walks, planning meetings, public participation events, and so on. This ethnographic work was undertaken continually between 2004 and 2006, and Los Angeles field notes were recorded and transcribed for analysis.

Interviews were scheduled and conducted on-site in each city, and followed a standardized format approved by the Institutional Review Board at the University of California, Irvine. The standard interview questionnaire included twelve open-ended questions, designed to pursue specific theoretical directions with respect to urban policy change and management innovation. Interviewees were provided with a Study Information Sheet before the interview began, and permission to tape record the interview was requested. Interviews lasted, on average, sixty minutes. The interview sample in each city relied on a technique known as "snowballing," where each interviewee is asked to identify additional actors who were involved, and in this way subsequent interviews are arranged and conducted. The taped conversations were transcribed and analyzed using atlas.ti qualitative research software.

During the last reporting period, data analysis was conducted and completed. Our findings emphasize three important aspects of successful watershed park coalitions. First, they are not comprised of organizational actors with discrete and unchanging belief systems and operational imperatives (for instance, community activists – flood control engineers – restoration ecologists). Rather, they are very dynamic networks of citizens, government officials, and other governance actors who consistently demonstrate a capacity for organizational learning, over time. This is an important characteristic of collaboration, and it is difficult to trace adequately without a historic and practice-based perspective such as the one permitted by this research design.

Second, we find that innovations in land use programs are not driven primarily by the state of the art in engineering, urban design, or environmental management technology. This was a hypothetical premise of the study, and it has been verified through our research. What we have found instead is that the adoption of new, multi-objective land use development initiatives depends most crucially on a working knowledge of the existing governance arrangements which operate within a particular region, in order for the successful transformation of those arrangements to be possible. We have chosen to understand these governance arrangements as an actor-network (Callon 1986; Latour 1986; Law 1992; Law 1999; Latour 2005), for two insights this concept provides – that the institutional landscape is comprised not only of people, but of documents, discourses, policy tools, plant and animal species, and above all else, rivers; and that these institutional arrangements are held together not by some over-arching structural power, but by the repetitive actions and tacit understandings of the actors involved.

Finally, we build on this to arrive at our third finding, which has to do with the nature and performance of sustainable leadership in urban governance settings. We find that lasting institutional change, which, when accomplished, results in new kinds of land use projects and new inter-organizational relationships, is the product of a very specific kind of collaborative political leadership. It is tied less to the traditional notion of a highly visible, charismatic leader, than to the existence of less-visible, embedded, strategic leader-managers, who both understand their own realm of the region's existing institutional arrangements, as well as how their realm might be broadened, leveraged, or otherwise transformed in order to link into others. These leader-managers are able to act deliberately and repeatedly within their actor-network, with a more idealistic vision in mind - to shape new expectations, forge new relationships, and transform governance institutions into arrangements where the state of the art in environmental restoration or water management technology (for instance) *can* be adopted and implemented.

Significance:

The significance of these research findings speaks to the most important ongoing focus of urban water policy in the twenty-first century. While it is true that we need the best available science, and we need well-funded government agencies and active, well-supported citizen groups in order to pursue meaningful advances in urban water policy and environmental management, we also need a more inclusive, less linear institutional landscape to facilitate the uptake of relevant information and the sharing of implementation responsibilities across sectors. This study argues that in the realm of urban water policy and land use management, what we need above all else are more adaptive institutions of urban governance.

2. Provide publication citations associated with the research project.

   Publications are still pending. We are drafting three journal papers, based on this research, that build on current theoretical work in each of the following fields: policy studies, water resource management, and urban planning.

3. You have the option of providing introductory text regarding your overall research program.

   (not necessary)

INFORMATION TRANSFER PROGRAM: Information transfer activities supported with section 104 and required matching funds during the reporting period.

1. Provide a brief description of the information transfer activity for your project.

Project staff Anne Taufen Wessells gave a public teaching lecture based on this research at the University of California, Irvine in the Department of Environmental Analysis and Design; May 2, 2006.

Ms. Wessells also made presentations based on this research at the *Greening XVI* conference (environmental policy scholars), April 21, 2007 at the Claremont Colleges, Claremont, CA; and at the *Theorizing Ways of Knowing: Beyond Interest* conference (public policy scholars), May 18, 2007 at the Virginia Polytechnic University, National Capital Region, Alexandria, VA.

Anne Taufen Wessells will also be presenting portions of this research at three upcoming national conferences: the *Council of Educators in Landscape Architecture (CELA)* annual conference, August 15-19, 2007, State College, PA; the *American Political Science Association (APSA)* annual conference, August 30-Sept 2, 2007, Chicago, IL; and the *Association of Collegiate Schools of Planning (ACSP)* annual conference, October 18-21, 2007, Milwaukee, WI.

Model Development for Conjunctive Use Planning and Aquifer Protection in Semi-arid Regions

Basic Information

Title:	Model Development for Conjunctive Use Planning and Aquifer Protection in Semi-arid Regions
Project Number:	2005CA137G
Start Date:	9/1/2005
End Date:	8/31/2008
Funding Source:	104G
Congressional District:	30
Research Category:	Ground-water Flow and Transport
Focus Category:	Nitrate Contamination, Management and Planning, Models
Descriptors:	None
Principal Investigators:	William W-G. Yeh

Publication

1. Tu, M-Y, F. T-C. Tsai and W. W-G. Yeh, 2005, "Optimization of Water Distribution and Water Quality by Hybrid Genetic Algorithm," Journal of Water Resources Planning and Management, ASCE, 131 (6): 431-440.
2. McPhee, J. and W. W-G. Yeh, 2007, Groundwater Management using Model Reduction via Empirical Orthogonal Functions, to appear in Journal of Water Resources Planning and Management.

Project summary:

In the semi-arid region of the Southwestern U.S., population and economic growth are making increasing demands on the water supply. For example, almost 40% of the water supply in Southern California is from groundwater. To protect groundwater from over-pumping and contamination, there is a critical need to develop surface water and groundwater management tools that can be used to predict water level variations and solute concentrations in the aquifer under different management scenarios. By controlling the total water resources of a region, conjunctive use planning can increase the efficiency, reliability, and cost-effectiveness of water use, particularly in river basins with spatial and temporal imbalances in water demand and natural supplies.

Typical of Southern California, the Warren Basin, located in San Bernardino County, has seen sustained population growth and increased water demands since the 1950's. Since groundwater is the only local source of water supply available, water levels experienced a steady decline of up to 300 ft in some areas between 1956 and 1994. In 1995, the Hi-Desert Water District (HDWD) implemented a recharge program using imported State Water Project (SWP) water and two recharge pond sites. As a consequence, water levels rose up to 200 ft in some areas. However, nitrate concentrations increased drastically, from a baseline level of approximately $10\,mg/l$ to values in excess of $100\,mg/l$. A study conducted by the USGS showed that the increase in nitrate concentrations is due to entrainment of seepage from septic tanks and irrigation, previously stored in the unsaturated zone, by the artificially elevated water table.

The goal of this research is to develop a decision support system (DSS) for sustainable groundwater management, including conjunctive use planning of surface water and groundwater, and aquifer protection. The proposed DSS will encompass a management framework that links simulation to optimization. We will use the geological information and historical data collected by the USGS for the Warren Basin for the development of the simulation model. The developed simulation model will be linked to an optimization model for conjunctive use planning and aquifer protection. Additionally, we will develop algorithms for parameter structure identification, model reliability analysis, data sufficiency evaluation and monitoring network design.
Currently, we have completed the development and calibration of a flow and transport simulation model for the Warren Basin. We are in the process of linking the developed simulation model to an optimization model for conjunctive use planning.

Award No. 04HQAG0001 Spatially Explicit Modeling and Monitoring of Hydroclimatic Extremes: Reducing the Threat to Food Security in the Developing World

Basic Information

Title:	Award No. 04HQAG0001 Spatially Explicit Modeling and Monitoring of Hydroclimatic Extremes: Reducing the Threat to Food Security in the Developing World
Project Number:	2005CA187S
Start Date:	10/1/2003
End Date:	9/30/2006
Funding Source:	Supplemental
Congressional District:	
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	

Publication

1. Funk, C. and Brown,. M., 2006, A maximum-to-minimum technique for making projections of NDVI in semi-arid Africa for food security early warning, Int. J. of Remote Sensing. 101. 249-256.
2. Verdin J., Funk C., Senay, G., Choularton, R., 2005. Climate Science and Famine Early Warning, Philosophical Transactions of the Royal Meteorological Society, B. 360. 2155-2168.
3. Husak, Gregory. Methods for Statistical Evaluation of African Precipitation. Ph. D. Dissertation, Geography, University of California, Santa Barbara, Santa Barbara, CA.
4. Freund, Jeremy, Aids for Estimating Crop Area and Production in Kenya: A Multi-Temporal Remote Sensing Approach, M.A. Thesis, Geography, University of California, Santa Barbara, Santa Barbara, CA.
5. Funk, Chris, Jeremy Freund, Mike Budde, Elijah Mukhala and Tamuka Magadzire, 2006, Analysis of MODIS -NDVI for 2000 through 2006. FEWS NET Report. ftp://hollywood.geog.ucsb.edu/pub/AnalysisOfMODIS_NDVIforZimbabwe_JTF4.zip. 8 pages.
6. Funk, C. and J. Michaelsen, 2004: A simplified diagnostic model of orographic rainfall for enhancing satellite-based rainfall estimates in data poor regions, Journal of Applied Meteorology, V43. October, 2004
7. Funk, C., J. Michaelsen, J. Verdin, G. Artan, G. Husak, G. Senay, H. Gadain, and T. Magadazire, 2003: The Collaborative Historical African Rainfall Model: Description and Evaluation. International Journal of Climatology, 23, 47-66

Project Information Summary

The UCSB Climate Hazard Group combines the efforts of researchers in Santa Barbara, Washington, Nairobi, Niamey, Harare and Guatemala City. Scientists at the UCSB, with guidance from the National Center for EROS, focus on developing new techniques for modeling and monitoring drought and flood events. Field scientists apply these tools and techniques while providing training and information to institutions in their regions. The CHG research focus is "geospatial hydroclimatology", with an emphasis on the early detection and forecasting of hydroclimatic hazards. We perform basic research into the climatic processes that govern drought and flood hazards in food insecure countries. We develop techniques, algorithms, and modeling applications that can exploit the tremendous potential benefits of remote sensing and other geospatial data.

Problem and Research Objectives, Methodology and Principal Findings and Significance

This project addresses issues associated with monitoring, modeling and mitigating the effects of hydrologic extremes in food insecure countries. Our research methods combine remote sensing and agro-climatology with hydrologic forecasting and diagnostics. Our principal findings are as follows:

Remote sensing and agro-hydrology: the latest generation of satellites, combined with new analytic approaches, supports the remote measurement of two critical food parameters: cropped area and crop productivity.

Applied forecasting and diagnostics: the Indian Ocean influences strongly the weather of food insecure Africa. This provides a basis for successful forecasts as well as climate change analysis. We have successfully predicted drought and flooding in eastern and southern Africa, and completed climate change analysis suggesting anthropogenic impacts in these regions.

These results have both scientific merit and significance to the food security community; our work helps describe the hydrologic state of the planet, now and in the future, supporting effective decision making.

Peer Reviewed Reports

Funk, C. and Brown,. M., 2005, A maximum-to-minimum technique for making projections of NDVI in semi-arid Africa for food security early warning, Int. J. of Remote Sensing, v101, p249-256. March 2006.

Verdin J., Funk C., Senay, G., Choularton, R., 2005. Climate Science and Famine Early Warning, Philosophical Transactions of the Royal Meteorological Society, B. v360, p 2155-68. October 2005.

Funk, C. and J. Michaelsen, 2004: A simplified diagnostic model of orographic rainfall for enhancing satellite-based rainfall estimates in data poor regions, Journal of Applied Meteorology, V43. October, 2004.

Funk, C., J. Michaelsen, J. Verdin, G. Artan, G. Husak, G. Senay, H. Gadain, and T. Magadzire, 2003: The Collaborative Historical African Rainfall Model: Description and Evaluation. *International Journal of Climatology*, 23, 47-66.

FEWS NET reports

Funk, C., Overview of FEWS NET Rainfall validation/enhancement activities, Crop and Rangeland Monitoring Network for the Greater Horn of Africa, Working Group Report, March 2006.

Funk, C., Afghanistan Rainfall Data Assimilation Project Report, USGS International Program, Data set and technical report, September 2005.

Funk, C., Senay, G., Asfaw, A., Verdin, J., Rowland, J., Michaelsen, J., Eilerts, G., Korecha, D., Choularton, R., Recent Drought Tendencies in Ethiopia and equatorial-subtropical eastern Africa, FEWS NET Special Report, August 2nd 2005.

Magadzire, T., Funk, C., Verdin, J., Regional Flood Watch: Flooding intensifies in upper Zambezi basin area of Zambia, FEWS NET/SADC Flood Alert, March 5th , 2004.

Funk, C., Magadzire, T., Masundire, T., Special Agromet Update, Follow-up analysis of Drought Situation in Southern Africa 2003/04 Growing Season, SADC/RRSU Special Agromet Report, Feb 17th 2004.

Magadzire, T., Masundire, R., Funk, C., Special Agromet Update: Rainfall Vegetation and Crop Monitoring, Feb 19th, 2004

Funk, C., Michaelsen, J.; SADC 2004 Downscaled Forecasts: Technical Description. FEWS NET technical report. December, 2003.

Funk, C., Magadzire, T., Verdin, J, Rowland, J.; Michaelsen, J.; Outlook for Crop Growing Conditions in Southern Africa for 2004. FEWS NET Special Report. December, 2003

Funk, C., Asfaw, A., Steffen, P., Senay, G., Rowland, J., Verdin, J.; Estimating *Meher* Crop Production Using Rainfall in the 'Long Cycle' Region of Ethiopia. FEWS NET Special Report. October, 2003

Ecohydrologic Effects of Stream Restoration

Basic Information

Title:	Ecohydrologic Effects of Stream Restoration
Project Number:	2006CA168B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	44
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Ecology, None
Descriptors:	None
Principal Investigators:	Jeffrey Mount

Publication

RESEARCH PROGRAM:

Ecologic and hydrologic conditions in rivers and streams throughout the developed world have been degraded by changes in land use and water management activities. One cause of river degradation is channelization, which alters the functions of riparian and floodplain wetlands by fundamentally changing the hydrologic, sedimentologic and biogeochemical connectivity between channels and floodplains. A growing recognition of the functions that seasonal floodplain wetlands provide has prompted global interest in the restoration and rehabilitation of many of these degraded ecosystems. While restoration activities are abundant, sound scientific basis for various actions, protocols for design, and post-project monitoring are generally lacking. Specifically, the effects of geomorphic channel restoration upon floodplain hydrology and wetland vegetation remain relatively un-documented.

Through assessment and modeling of an exceptionally well-documented stream restoration project, this research seeks quantitative answers to two fundamental questions: 1) *what are the hydrologic effects of geomorphic stream restoration*? It is widely believed that geomorphic channel restoration re-establishes the hydrologic drivers that support floodplain wetlands. However, this has rarely been demonstrated or quantified. 2) *How will these hydrologic changes impact the distribution of native wetland plant species*? This also is assumed to be a direct benefit of geomorphic restoration, but is rarely assessed. The proposed research will focus on a recently restored meadow reach of Bear Creek, the most significant tributary to the Fall River, Shasta County, California.

The research plan involves two, linked programs, hydrology and vegetation response. 1) *Hydrology* - In order to quantify the impact of restoration activities on hydrologic storage and fluxes, a hydrologic model was developed. The hydrologic model was used to simulate the hydrologic connectivity of the restoration site comparing the pre- and post-project topographic conditions. 2) *Vegetation Response* – The distribution of floodplain wetland plants is controlled by many factors including the availability of suitable substrate, seed sources, duration of inundation, in addition to the access to and rate of change of shallow groundwater. To evaluate the change in wetland plant distribution based upon hydrologic parameters, a probabilistic vegetation model will be coupled to the hydrologic model described above using a direct gradient analysis. Vegetation data were classified into community types using Two-Way Indicator Species Analysis (TWINSPAN), and a habitat suitability statistical approach will be used to determine the distribution of various community types throughout the restored meadow as a function of depth to groundwater during the growing season and the range of depth to groundwater during the growing season. The coupled hydrologic-vegetation model will be used to simulate the effect of the restoration upon the availability of suitable physical habitat for native species and the spatial extent of various plant communities will be compared.

Results of the coupled ecohydrologic modeling effort will provide a better understanding of the potential impacts of geomorphic restoration upon native wetland plant distribution to help guide future restoration efforts aimed at the conservation of rare, threatened, and endangered species. The results of the study will benefit land managers, restoration practitioners and regulators by establishing baseline information regarding the potential benefits of stream restoration, as well as developing new predictive tools to assess potential design considerations.

INFORMATION TRANSFER PROGRAM:

Elements of the monitoring data have been used toward the preparation of a Post Project Appraisal of the Bear Creek Meadow Restoration Project, for inclusion on the National River Restoration Science Synthesis database (http://nrrss.nbii.gov/). No additional information transfer has been conducted.

STUDENT SUPPORT:

	Total Project Funding		Supplemental Awards	Total
	Federal Funding	State Funding		
Undergrad.				
Masters				
PhD.	1	1		1
Post-Doc.				
Total	1	1		1

* One PhD student, Chris Hammersmark has been supported by these project funds.

NOTABLE ACHIEVEMENTS AND AWARDS:

Chris Hammersmark was awarded an Honorable Mention for his presentation “Hydrologic Effects of A Pond and Plug Stream Restoration in A Mountain Meadow” presented at the 2007 Society of Wetland Scientists International Conference: Water, Wetlands, and Wildlife – Resolving Conflicts and Restoring Habitat, held in Sacramento, CA, June 10-15, 2007.

PUBLICATIONS FROM PRIOR PROJECTS.

Not Available.

PUBLICATIONS & CITATION FORMAT:

None.

Monitoring California Water Resources from Space

Basic Information

Title:	Monitoring California Water Resources from Space
Project Number:	2006CA169B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	44
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Climatological Processes, None
Descriptors:	None
Principal Investigators:	James Famiglietti

Publication

Introduction

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

Year 1 Progress

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

Research on the use of GRACE data for estimating changes in total water storage is progressing well. A key step towards application of the GRACE data towards water resources problems at the relatively small spatial scale of California (by GRACE standards) has been the development of new techniques for utilizing GRACE data at these higher resolutions [Swenson et al. 2006]. This work will now allow, for the first time, monitoring of water storage changes within the major drainage basins and mountain ranges of the state. Undergraduate student Shaunna Head is currently working on delineating these GRACE-compatible regions for the state so that we can map the GRACE data to the Sierras, the Central Valley, the coastal regions, etc.

We have also made important progress towards remote sensing of groundwater using GRACE, AMSR and in situ data. In a preliminary study using the hydrologically data rich area of Illinois, Yeh et al. [2006] used GRACE and observed soil water to successfully estimate groundwater storage variations. This work opens the door for groundwater remote sensing in the Central Valley aquifer and the Coastal Plain aquifers, which we are now ready to attempt.

Year 2 Plans

Goals for year 2 will be to complete the major objectives of this work. In fact, given the preliminary work described here, most goals should be achievable in a one-year time frame. Our plan is to map the total water storage, snow water equivalent and soil moisture to the major drainage basins of the state, to explore the potential of satellite altimetry to monitor surface water variations, and to attempt to monitor groundwater storage variations using the methods of Yeh et al. [2006] in the Central Valley. An

implicit goal is to demonstrate the utility of these data at spatial-temporal scales that are relevant to statewide water resources management.

Referenced Publications

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

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

Presentations

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

Plant water use in Owens Valley, California:

Basic Information

Title:	Plant water use in Owens Valley, California:
Project Number:	2006CA170B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	44
Research Category:	Climate and Hydrologic Processes
Focus Category:	Climatological Processes, Groundwater, None
Descriptors:	None
Principal Investigators:	Diane Pataki

Publication

Plant water use in Owens Valley, California:
Understanding the influence of climate and depth to groundwater

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Project Summary

Desert phreatophytic communities are increasingly experiencing hydrologic change due to redistribution of water resources. Water exports have been occurring in Owens Valley, California for almost a century, leading to questions about possible interactions between groundwater availability and community composition in phreatophytic ecosystems. While many studies of vegetation change in Owens Valley have focused on depth to groundwater as the primary factor influencing competitive interactions among grasses and shrubs, nutrient relations likely play an additional, important role in mediating changes in plant cover and composition. We evaluated differences in access to groundwater in grass and shrub species in Owens Valley via measurements of the isotopic composition of root, stem, soil, and groundwater. We also measured leaf nitrogen (N) and soil inorganic N availability in order to determine if differential access to water sources was associated with distinct patterns of N relations in grasses versus shrubs. Finally, we assessed the relative importance of water vs. nutrient relations in influencing plant transpiration and photosynthesis. We found that grasses accessed isotopically enriched water sources in the shallow surface soil in the late season while shrubs utilized groundwater throughout the growing season. Soil inorganic N concentrations declined from June to September at both grassland and shrubland study sites, likely due to gaseous loss of N from ammonia volatilization, nitrification, and denitrification. Correspondingly, leaf nitrogen declined throughout the season in both grass and shrub species at all sites. Grasses showed a large seasonal decline in transpiration; however, this pattern was more closely related to seasonal declines in leaf N than to plant water sources. These results suggest that seasonal N limitations are an important and somewhat overlooked control on temporal patterns of transpiration in the central Owens Valley, and that interactions between N availability, groundwater depth, and plant water relations are important governing features of plant community composition in shallow groundwater plant communities.

Problem and Research Objectives

Owens Valley, California is a closed hydrologic basin at the base of the Sierra Nevada Mountains. In 1913, the Los Angeles Department of Water and Power (LADWP) began diverting water from this semi-arid basin, which supports vegetation from both the Great Basin and the Mojave Deserts. Despite several decades of water management and monitoring in the valley, the current and potential impacts of water redistribution on local vegetation and ecosystem processes remain highly uncertain, in part due to a limited understanding of the interactions between vegetation dynamics and hydrology.

Research focusing on altered and reduced streamflow has provided us with a fairly good understanding of the dependence of riparian trees on groundwater (see reviews by Friedman et al. 1997; Stromberg 1993a; Stromberg 1993b; Stromberg 2001). Desert shrub and grassland communities may also use groundwater (Robinson 1958), but the impacts of altered water tables on these communities has been less studied than in riparian ecosystems. Semi-arid, shallow groundwater ecosystems are generally dominated by species that are not obligate phreatophytes. These species can occur in areas where they do not have access to groundwater and show great tolerance to water stress, as well as in shallow groundwater sites with abundant available water (Naumburg et al. 2005). Several uncertainties limit our ability to predict responses of these ecosystems to hydrologic change, including a limited understanding of species differences in rooting depths and distribution, and of linkages between nutrient availability, groundwater uptake by vegetation, and community composition. A quantitative understanding of these interactions is critical for a variety of resource and land management issues in Owens Valley and in other arid and semi-arid ecosystems experiencing hydrologic change.

Previous studies have attempted to quantify linkages between hydrologic change and shifts in the proportion of grass and shrub cover in Owens Valley. Groeneveld and Or (1994) attributed changes in the proportion of grasses and shrubs at an "ecotone" site to variations in groundwater depth, although local managers have suggested that land management played a more important role in community composition at this site than originally assumed. Elmore et al. (2006; 2003) attributed declines in herbaceous plant cover detected with remote sensing to lowered water tables caused both by groundwater pumping and drought. Several studies have suggested the importance of rainfall as a driver of plant productivity in the region, despite abundant groundwater resources that often are within reach of plant rooting zones. Sorensen et al. (1991) experimentally drew down the water table at four sites supporting a mixture of grasses and shrubs. Pumping did not achieve the planned drawdown goals, but leaf area index declined during the experiment relative to the pre-pumping year irrespective of the proximity to the pumping wells (Sorenson et al. 1991). Leaf area index also declined throughout the valley, at least in part due to above-average precipitation in the pre-pumping year followed by below-average precipitation (Sorenson et al. 1991). Over the study period, leaf area indices were impacted by variation in precipitation and not just the degree of water table decline (Groeneveld et al. 1994; Sorenson et al. 1991). Similar results were seen by Naumburg *et al.* (2005), who found that the two major grass species in the valley (*Distichlis spicata* and *Sporobolus airoides*) responded with declining aboveground biomass to a low rainfall year despite constant water tables. This was true even for locations where water tables were well within the rooting zone, indicating the importance of rainfall for plant productivity in these facultatively phreatophytic communities.

The strong correlation between productivity and precipitation in the valley, even at sites with shallow groundwater and unlimited water availability, highlights the potential importance of nutrient limitation and availability in this region. Mean annual precipitation at the valley floor is only 150 mm yr^{-1}, and rainfall occurs primarily in the

winter such that soil moisture becomes increasingly limited at shallow depths during the growing season (Steinwand et al. 2006). This likely inhibits decomposition and N mineralization at the end of the summer. While many studies of vegetation change in Owens Valley have focused on depth to groundwater as the primary factor influencing competitive interactions among grasses and shrubs, the responsiveness of these ecosystems to precipitation suggests that nutrient relations may also play an important role in mediating changes in plant cover and composition.

In this study, we evaluated species differences in plant water and nitrogen sources to explore potential drivers of the success of grass and shrub functional types within the central Owens Valley. Specifically, we posed the questions:

- ***How does groundwater withdrawal by vegetation vary with depth to the water table (DTW) for different species and plant functional groups in Owens Valley****?* There remains a paucity of data on plant rooting depths and distributions, particularly in semi-arid communities. Therefore, it is difficult to ascertain *a priori* the maximum DTW at which various species no longer have access to the saturated zone. This information is critical in order to quantify the temporal and spatial pattern of transpiration, as well as the sensitivity of the ecohydrologic system to change. The natural abundance of stable isotopes of water in ecosystems with seasonally varying water sources has been shown to be a useful tracer of shallow vs. groundwater or deep soil water uptake (Dawson and Ehleringer 1991; Ehleringer and Dawson 1992; Ehleringer et al. 1991). We hypothesized that if grasses are generally more shallowly rooted than shrubs, the isotopic composition of water in grass stems/rhizomes would be isotopically enriched relative to stem water of deeply rooted shrubs due to uptake of enriched water in the surface soil. To test this hypothesis, we measured the isotopic composition of plant stem water, soil water, and groundwater. We also collected other measurements of water stress such as predawn water potential.

- ***Are differences in water sources between grasses and shrubs coupled with differences in N relations?*** Because varying root distributions may lead to species differences in N availability and uptake, grasses may also take up N at a shallower depth than shrubs. This may result in isotopic enrichment of N in grasses, as shallow soil N is often isotopically enriched due to gaseous losses of N in the surface soil of semi-arid ecosystems (Amundson et al. 2003; Högberg 1997; van Groenigen and van Kessel 2002). By evaluating possible linkages between water and N relations, we hoped to elucidate the extent to which water and N sources may govern vegetation community composition in the region. To address this question, we sampled a variety of species and locations in the valley for the total leaf C:N ratio, the isotopic composition of leaf N, and the abundance of plant available nitrate and ammonium in the soil.

- ***How do spatial and temporal variations in access to water and nutrients affect plant gas exchange and transpiration****?* If plants have a continuous supply of groundwater, higher rates of transpiration are expected than if roots can only

access unsaturated soil with a limited water supply. In addition, N availability is a major constraint on photosynthesis and subsequently leaf transpiration that has seldom been measured in the central Owens Valley. Studies on the shores of Owens and Mono Lakes at the southern and northern borders of the valley have shown co-limitation of water and nutrients in playa plant communities (Donovan and Richards 2000; Drenovsky and Richards 2003; Drenovsky and Richards 2004; Drenovsky and Richards 2005; James and Richards 2005; James and Richards 2006; James et al. 2005). We evaluated the controls on leaf gas exchange at our study sites near Bishop to determine the relative importance of water and nutrient availability in influencing photosynthesis and transpiration in grass vs. shrub species.

Methodology

Owens Valley lies in the rainshadow of the Sierra Nevada and receives approximately 150 mm precipitation per year, of which ~75% falls from Nov-Mar. Precipitation increases with proximity to the Sierra Nevada. Depth to groundwater (DTW) ranges from the ground surface to well below maximal plant rooting depths of ~6 m (Groeneveld 1990). The majority of groundwater recharge comes from Sierra Nevada precipitation that infiltrates in the upper reaches of alluvial fans and through tributary stream channels (Hollett et al. 1989). Vegetation in the valley varies depending on groundwater depth and salinity, and has been classified into four major groups: 1. alkaline meadow on saline sites with 0-1.5 m DTW, 2. alkaline scrub on saline sites with 1-3 m DTW, 3. dryland alkaline scrub on saline sites with deeper groundwater, and 4. dryland scrub on coarse soils of low salinity and deep water tables (Griepentrog and Groeneveld 1981). Dominant species in the valley are the shrub species *Artemisia tridentata*, *Sarcobatus vermiculatus*, *Ericameria nauseosa,* and *Atriplex* spp., and the grass species *Distichlis spicata*, *Leymus triticoides*, and *Sporobolus airoides.*

Study sites – In 2005 we selected three sites which varied in the proportion of grass vs. shrub cover for intensive plant and soil sampling. These sites consisted of: 1) an alkaline meadow near Chalk Bluffs north of the town of Bishop ("grassland" site); 2) an intermediate, mixed grass-shrub community near the Owens River south of Bishop ("intermediate" site); and 3) a shrub dominated site with very sparse grass cover ("shrubland" site). The grassland site was dominated by *Distichlis spicata*, *Sporobulus airoides*, and *Leymus triticoides*; grass cover is nearly continuous at this site. Both the intermediate and shrub sites were dominated by the shrubs *Atriplex torreyi*, *Ericameria nauseosa*, and *Sarcobatus vermiculatus*, and the grasses *Distichlis spicata* and *Sporobolus airoides*. The depth to groundwater (DTW) was < 3 m at all three sites throughout the study. In 2006, we measured leaf gas exchange, predawn leaf water potential, and the isotopic composition of stem and soil water during 3-4 sampling periods from May to September. We also collected leaf material for analysis of chemical and isotopic composition, as well as soil samples for analysis of inorganic N availability. A detailed description of each measurement is given below.

Stable isotope measurements – Sampled leaves were dried for at least 48 hours at 70°C and ground to a fine powder. Nitrogen isotope ratio ($\delta^{15}N$), leaf %N, and C:N ratio were measured with an elemental analyzer coupled to an Isotope Ratio Mass Spectrometer (Delta Plus IRMS, Thermofinnigan, San Jose, CA). Plants were sampled for stable isotope analysis of water by removing small sections of non-green woody stems for shrubs, and non-evaporating rhizomes extracted from the just below the soil surface for grasses. Samples were placed in vacutainers, sealed with parafilm, and stored in a cooler in the field. Soil samples at 10-20 cm increments from 0 – 200 cm depth were also stored in a cooler in sealed vacutainers. In the laboratory, stem, rhizome, and soil samples were stored at freezing temperatures until extraction by cryogenic vacuum distillation (West et al. 2006). Water samples were analyzed for oxygen isotope ratio ($\delta^{18}O$) by pyrolysis after Gehre *et al*. (2004) using a TCEA interface coupled to an IRMS (Delta Plus XP, Thermofinnigan, San Jose, CA). All isotope measurements were conducted at the University of California, Irvine IRMS facility. Nitrogen isotopes were referenced to atmospheric N_2 and oxygen isotopes were referenced to Vienna Standard Mean Ocean Water (V-SMOW).

Leaf-level gas exchange and water potential – Photosynthesis, transpiration and stomatal conductance were measured at the three sites at midday in June and August of 2005 and June, July, and August of 2006 with a LI6400 leaf gas exchange system (Licor, Lincoln, NE). Three replicate individuals of *Distichlis spicata*, *Ericameria nauseousa*, and *Atriplex torreyi* were measured at saturating light (1500 $\mu mol \cdot m^{-2} s^{-1}$) and ambient temperature and relative humidity. Measured shoots were harvested after each sampling period to correct each gas exchange estimate for true shoot leaf area. Predawn and midday water potential were measured during the same periods with a Scholander-type pressure chamber (PWSC 3000, Soil Moisture Equipment Corp, Goleta, CA). Three to five individual shoots of *Distichlis spicata*, *Ericameria nauseousa*, *Atriplex torreyi,* and *Sarcobatus vermiculatus* were measured at each site during each sampling period.

Soil assays – Twelve soil samples were collected at each site from 0-10 cm depth in June and September of 2006. At the two shrub sites, sampling was stratified to collect three replicates under each of three shrub species as well as in intershrub (grass-dominated) spaces. Samples were transported at 4°C to the University of Kansas, where they were extracted in 2M KCl. Soil extracts were analyzed colorimetrically for NH_4^+ and NO_3^- on a Lachat autoanalyzer.

Principle findings and significance

Repeated sampling of stem water isotopes during the summer showed that there was temporal variability in water sources in *Distichlis*, but not in the shrub species, which remained isotopically depleted throughout the season (Figure 1). In May and August, *Distichlis* appeared to be transpiring isotopically enriched local precipitation in the shallow surface soil rather than groundwater (Figure 1). In contrast, the shrubs appeared to be accessing groundwater at both shrub sites and all time periods. Soil water profiles for the two shrub sites in June showed the typical evaporative enrichment in the surface

soil, where the isotopic composition of water was as enriched as -3 ‰ (Figure 2). In contrast, estimates of the isotopic composition of local groundwater as measured in tap water samples were approximately –17 ‰. At the grassland and intermediate sites, which were characterized by a very fine textured soil, soil water isotopes became indistinguishable from groundwater at about 50 - 60 cm depth (Figure 2). At the shrubland site, the isotopic composition of soil water approached groundwater at about 150 cm (Figure 2). Soils at this site are much sandier and therefore less likely to be influenced by capillary action from the saturated zone.

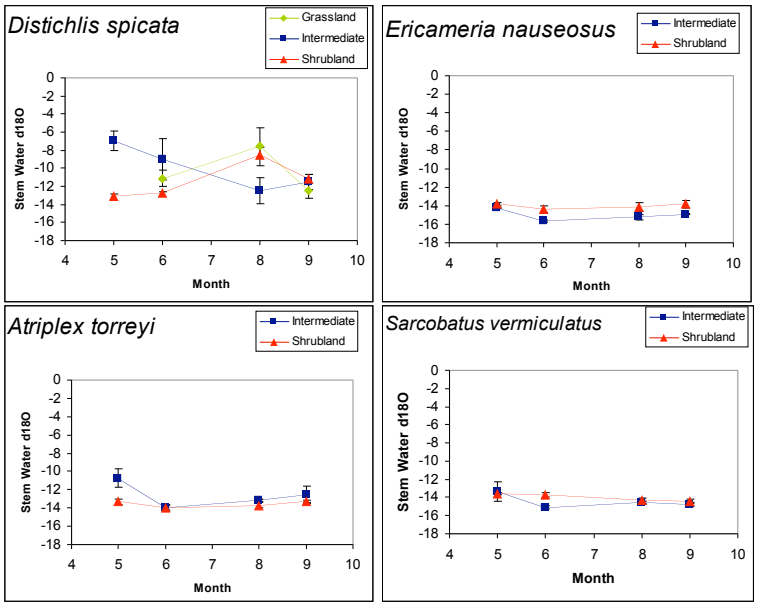

Figure 1 - The oxygen isotope composition of plant stem water at each site.

The water potential of plants measured before dawn (ψ_{PD}) provides an estimate of the average soil water potential in the rooting zone, assuming that there is negligible transpiration at night such that plants and soils are in equilibrium. ψ_{PD} remained relatively constant throughout the growing season for all species except *Sarcobatus vermiculatus* (Figure 3). Hence, there was little evidence of progressive seasonal water stress in most species. Even in *Sarcobatus*, it is unlikely that declining seasonal water potentials reflected increasing water stress during the growing season. Donovan et al. (1996) suggested ψ_{PD} may not accurately reflect xylem water potential in halophytic *Sarcobatus* due to high solute concentrations and the subsequent effect on osmotic potentials. In addition, *Sarcobatus* has been found to have relatively high rates of nighttime transpiration, resulting in disequilbrium between plants and soils predawn (Donovan et al. 2001).

Leaf C:N ratio increased throughout the growing season at all species and sites, indicative of a decline in total leaf N content (Figure 4). This corresponded to a decline in inorganic N availability at all three sites from June to September, although the total amount of soil inorganic N varied among sites (Figure 5). Total inorganic N was lowest at the shrubland

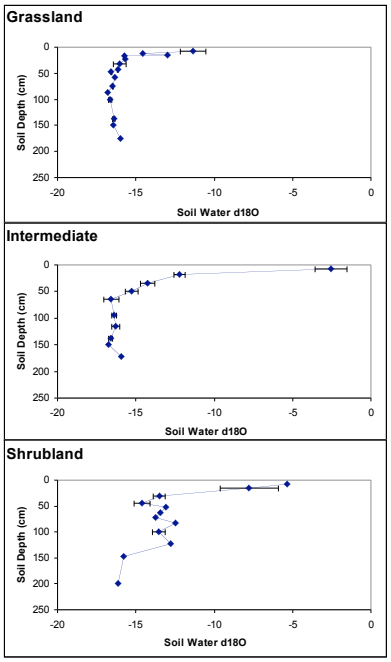

Figure 2 - The isotopic composition of soil water with depth at each site.

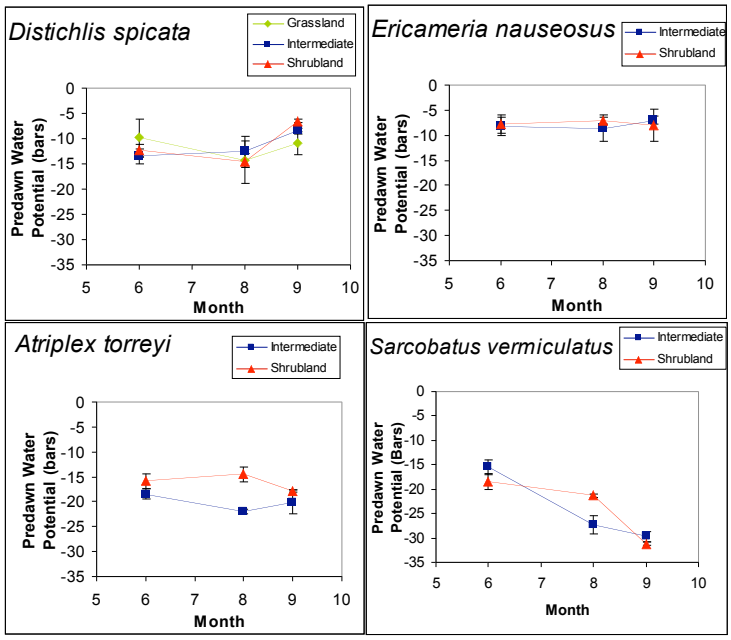

Figure 3 - Predawn shoot water potential at each site.

site and similar at the two high grass cover sites. Ammonium dominated inorganic N availability at the grassland site, while nitrate dominated inorganic N under shrubs (Figure 5). Despite differences in N availability among sites and microsites, the nitrogen isotope ratio ($\delta^{15}N$) of leaves was not correlated with site fertility, soil organic matter, or soil isotopic composition, but instead was most strongly correlated with leaf C:N (Figure 6). This likely indicates that species with greater leaf N concentrations accessed isotopically enriched soil N pools. Enriched N pools may be in the surface soils, which are isotopically enriched due to gaseous loss, and/or associated with mycorrhizal uptake or varying N sources, such preferences for nitrate vs. ammonium uptake. In the 2004 and 2005 growing seasons, we found that the halophytic (salt-adapted) shrubs, particularly *Atriplex torreyi*, contained the most isotopically enriched leaf N across all sites (Pataki et al. 2007), which was confirmed by the 2006 data. These species are well adapted to nutrient uptake in the saline surface soil, where N is most available but

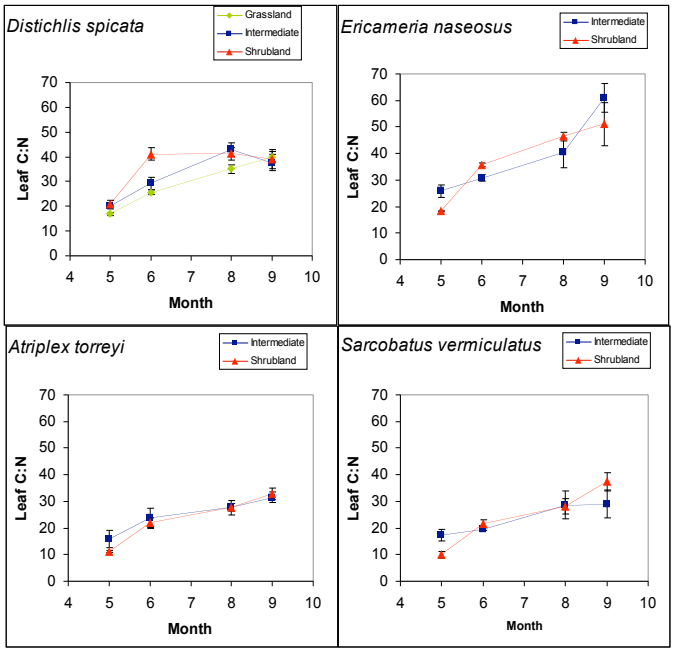

Figure 4 - The C:N ratio of live leaves.

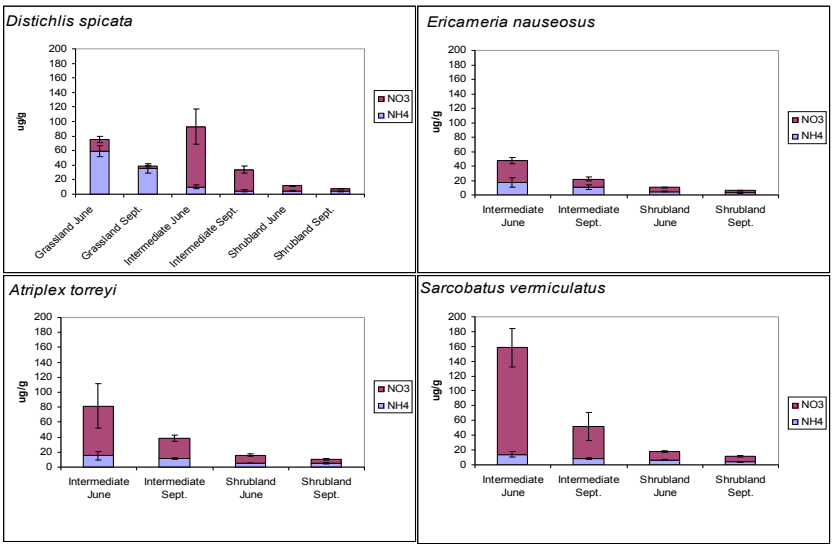

Figure 5 - Soil inorganic nitrate (NO3) and ammonium (NH4) concentrations from 0-10cm.

also highly isotopically enriched. Notably, the relationship between leaf $\delta^{15}N$ and C:N showed a seasonal trend (Figure 6) that reflected the decline in soil inorganic N pools (Figure 5) and subsequently leaf C:N (Figure 4) from May to September.

Our measurements of leaf-level gas exchange showed a large reduction in transpiration of grasses at the grassland site from June to September (Figure 7). While stem water isotopes indicated that grasses were more shallowly rooted than shrubs (Figure 1), our measurements of predawn leaf water potential did not reveal significant seasonal water stress of grasses at any site (Figure 3). Instead, leaf level gas exchange of the grass species *Distichlis* was correlated with leaf N content (Figure 8). Our results suggest that the seasonal pattern of transpiration at the grassland shown in Figure 7 is largely a consequence of N limitations to photosynthesis caused by progressive gaseous N losses and declining inorganic N availability throughout the season (Figure 5). In particular, losses of nitrate appear to be high at the grassland site, possibly due to high rates of denitrification associated with high soil moisture and high soil organic matter. Our 2005 measurements showed that soils at the grassland site contained 14 % carbon vs. 1.3 % at the intermediate site and 0.4 % at the shrubland site (Pataki et al. 2007). In addition, N_2O fluxes at the grassland site were three times higher than the two shrubland sites in 2005 (Pataki et al. 2007), also indicative of large losses of N from denitrification.

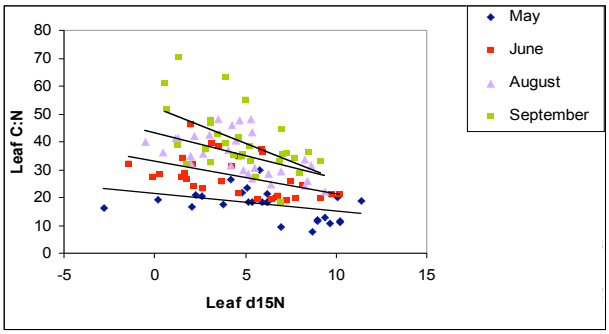

Figure 6 – Live leaf C:N ratio versus nitrogen isotope ratio (d15N) from May to September in all species and sites combined.

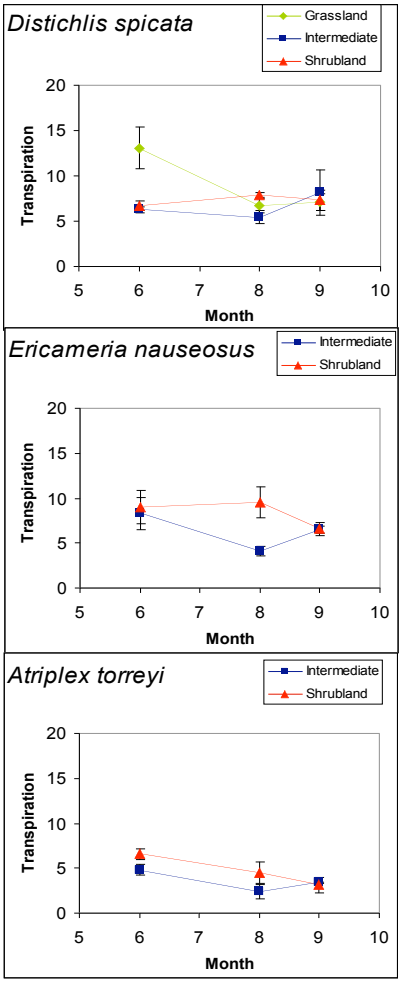

Figure 7 - Leaf level transpiration at each site.

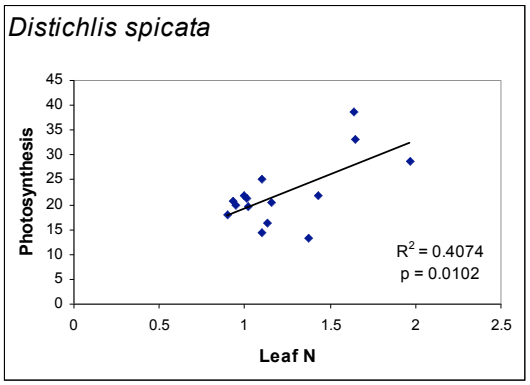

Figure 8 – Leaf level photosynthesis vs. leaf % N.

These results are highly significant given that previous studies have focused almost exclusively on depth to groundwater as the primary factor that influences plant cover, physiology, and composition at phreatophytic sites in the central Owens Valley (Elmore et al. 2006; Elmore et al. 2003; Groeneveld 1990; Groeneveld and Or 1994; Groeneveld et al. 1994; Sorenson et al. 1991). Additionally we have shown that large seasonal N limitations strongly influence temporal patterns of photosynthesis and transpiration, particularly at the grassland site. Hence, previous observations of increases in leaf area and productivity in high rainfall years, even at sites with shallow water tables, are likely due to increased N availability associated with higher rates of N mineralization in water limited surface soils. More significantly, our results point to ecosystem N cycling as an important mechanism mediating the balance between grasses and shrubs in these ecosystems. Halophytic shrubs appear to be particularly well adapted to accessing limited N pools in these saline soils, while grasses appear to be particularly sensitive to seasonal cycles of nitrate availability and its effect of leaf gas exchange. This study strongly suggests that N cycling must be incorporated into conceptual and quantitative models of woody encroachment following hydrological change. Studies that examine groundwater depth, plant water sources, and water relations without consideration of interactions with nutrient availability will be unlikely to provide a predictive capacity for determining the response of local communities to future hydrologic change.

Student Support

	Total Project Funding		Supplemental Awards	Total
	Federal Funding	State Funding		
Undergrad.	3			
Masters				
PhD.	1			
Post-Doc.				
Total	4			

This project provided a summer stipend, travel expenses, and supplies for Ph.D. student Christine Goedhart from May to Sept. 2006. The project also provided funds for three undergraduate students to travel to our field sites in Bishop, CA to collect data during the 2006 growing season.

Publication citations associated with the project

Peer-reviewed manuscripts

Pataki DE, Billings SA, Naumburg E, Goedhart CM. 2007. Water sources and nitrogen relations of grasses and shrubs in phreatophytic communities of the Great Basin Desert. In review.

Goedhart CM, Pataki DE, Billings SA. In preparation. Controls on plant gas exchange across a grassland to shrubland gradient in Owens Valley, California.

Conference presentations

Goedhart CM, Pataki DE, Billings SA. Controls on plant gas exchange across a grassland to shrubland gradient in Owens Valley, California. Ecological Society of America meeting, San Jose, CA, August 2007.

Pataki DE, Billings SA, Naumburg E, Goedhart CM. Water sources and nitrogen relations of grasses and shrubs in phreatophytic communities of the Great Basin Desert. Ecological Society of America meeting, San Jose, CA, August 2007.

Goedhart CM, Pataki DE, Billings SA. 2007. Controls on plant gas exchange across a grassland to shrubland gradient in Owens Valley, California. Annual Meeting of the Southern California Academy of Sciences, Fullerton, California.

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Diuron in California's Water Supply:

Basic Information

Title:	Diuron in California's Water Supply:
Project Number:	2006CA171B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	44
Research Category:	Water Quality
Focus Category:	Water Supply, Water Quality, None
Descriptors:	None
Principal Investigators:	Thomas Michael Young

Publication

Project Summary

Diuron is the third most used herbicide in California (over 1.5 million pounds annual usage in 2005). Nearly all applications (95%) are in late fall through early spring. Diuron has been frequently detected between 1992 and 2002 during spot surface water monitoring conducted by the Department of Pesticide Regulation. The Department of Water Resources has also monitored various organic compounds for the state water project two or three times a year, and diuron is frequently detected.

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

chlorinated anilines, may also impart unacceptable risks. The objectives of the project are to:

1. Determine the kinetics of toxic byproduct formation during chlorination or chloramination of diuron containing waters supplied by the California Aqueduct.
2. Assess the human exposure to diuron's byproducts via treated waters derived from the California Aqueduct through a combination of field sampling and modeling.

The first phase of the project is to test the potential for NDMA formation during chlorination of diuron. Reactions are performed in 1 L mixed batch reactors shielded from light. Diuron of 20 mg/L concentration (the highest observed diuron concentration in California source waters is 20 ug/L) is mixed with deionized water. The pH of samples is adjusted at 8. Sodium hypochlorite (3.45 mM as Cl_2) was injected to simulate the disinfection process. The concentration of NDMA in samples was measured using GC-MS analysis after solid phase extraction. Total chlorine is determined by DPD ferrous titrimetric method at the end of each reaction. The results acquired support the hypothesis that appreciable amount of NDMA can be produced from the chlorination of diuron (Figure 1). Similar experiments were also conducted to investigate the effects of different initial diuron concentrations and pH values. Results indicate that lower concentrations of diuron produced lower concentrations of NDMA at the end of experiments (Figure 2), and the optimal pH range of NDMA formation from diuron is 6 to 10, which is similar to the proposed optimal pH range of NDMA formation from DMA (Figure 3).

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

Impacts of Ethanol on Anaerobic Production of Tert-Butyl Alcohol (TBA) from Methyl Tertiary Butyl Ether (MTBE) in Groundwater

Basic Information

Title:	Impacts of Ethanol on Anaerobic Production of Tert-Butyl Alcohol (TBA) from Methyl Tertiary Butyl Ether (MTBE) in Groundwater
Project Number:	2006CA172B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	44
Research Category:	Water Quality
Focus Category:	Groundwater, Water Quality, None
Descriptors:	None
Principal Investigators:	Kate M. Scow

Publication

1. Mackay, D., de Sieyes, N., Einarson, M., Feris, K., Pappas, A., Wood, I., Jacobsen, L., Justice, L., Noske, M., Wilson, J., Adair, C., Scow, K., 2007. Impact of ethanol on the natural attenuation of MTBE in a normally sulfate-reducing aquifer. Environmental Science & Technology, 41, 2015-2021.
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Introductory text

The widespread use of the gasoline oxygenate MTBE and subsequent spills or leaks of MTBE- laden fuel into the environment has resulted in numerous groundwater supplies becoming contaminated with MTBE. In California alone it is estimated that at least 10,000 groundwater sites currently have MTBE levels above the CA drinking water standard (> 5 ppb). MTBE is a human health concern and relatively recalcitrant under the anaerobic conditions commonly found at gasoline spill sites. Therefore, ethanol is rapidly replacing MTBE as the preferred fuel oxygenate. The increasing use of ethanol amended gasoline (gasohol) is the motivation for this work. The preferential degradation of ethanol in anaerobic environments rapidly consumes predominant electron acceptors (e.g. nitrate, sulfate, iron), and thus spills of gasohol can reduce an aquifer's redox potential to methanogenic conditions. Recent evidence indicates that MTBE may be partially degraded to tert-butyl alcohol (TBA) under methanogenic conditions. Whereas MTBE is a suspected carcinogen and a nuisance chemical in drinking water, TBA is a known toxin, more water soluble than MTBE, and more difficult to remove from water. The biological, geochemical, and environmental factors that influence the formation of TBA from MTBE under methanogenic conditions are not well understood. With an improved understanding of which organisms and environmental factors are involved in anaerobic TBA formation we may be able to design remediation protocols that could prevent TBA from becoming California's next major environmental problem.

This research has the potential to lend insight into the mounting evidence that MTBE partially biodegrades under methanogenic conditions to TBA. Due to the widespread nature of MTBE contamination in California and the current ubiquity of gasohol, the potential for future gasohol releases impacting MTBE contaminated groundwater is high. This research is necessary to understand the potential outcome of gasohol release on MTBE contaminated water supplies.

Problem and Research Objectives

MTBE appears to be biologically converted to TBA under anaerobic conditions. This phenomenon is enhanced by the presence of ethanol, a readily degradable oxygenate that has rapidly replaced MTBE in formulated gasoline. It is important to determine whether TBA formation can be linked to microbial processes in the field and lab, to demonstrate whether ethanol truly enhances its formation and to determine changes in microbial communities during TBA formation.

Our approach to understanding the effect of ethanol on TBA formation at MTBE contaminated sites involves integrating data describing contaminant levels and microbial communities, measured in field and from microcosm studies, using molecular biology techniques and a numerical model of our field site (a contaminated aquifer at the Vandenberg Air Force Base). Controlled release experiments were performed at the site between September 2005 and April 2006. A plume of a mixture of ethanol and MTBE was released alongside a plume of TBA in order to monitor the effect of ethanol on MTBE transformation and to observe degradation of TBA under sulfate reducing conditions, respectively. Specific objectives include:

1. to determine whether TBA concentrations appearing during a controlled ethanol release can be linked to transformation of MTBE concentrations in vicinity by mapping groundwater concentrations of MTBE/TBA in the field and developing a mathematical model to try to understand the mechanisms underlying the patterns of distribution.

2. to measure whether MTBE is converted to TBA under controlled conditions in microcosms, simulating aquifer conditions.

3. to measure changes in microbial communities, both numbers and diversity, when exposed to ethanol and during conversion of MTBE to TBA.

Methodology

Three approaches are used to investigate the potential conversion of MTBE to TBA and the persistence of TBA:

1) Numerical modeling of the aquifer. We are developing a numerical model of the site to quantify the effects of ethanol on MTBE transformation and explore hypotheses regarding TBA formation and persistence. Concentrations of injected contaminants over time are being used to calibrate a finite elements model made with HYDROGEOCHEM 5.0, to determine the most significant factors affecting TBA distribution in the aquifer. Preliminary modeling of diffusion between aquifer layers has been carried out using HydroGeoSphere and validated with field data.

2) Nucleic acid-based microbial analyses. Quantitative polymerase chain reaction (qPCR) and terminal restriction fragment length polymorphisms (TRFLP) are being used to track changes in diversity and abundance of key microbial groups over time.

3) Microcosms. Microbially mediated degradation of MTBE (complete mineralization or partial conversion to TBA) is being confirmed in the lab with anaerobic microcosms of site material. The potential of site microorganisms to degrade TBA is also being tested. Active microcosms and killed controls from site material have been constructed from site material to evaluate the potential of the native microbial communities to carry out the conversion of MTBE to TBA and the complete mineralization of TBA. A second set of microcosms is being used to enrich for these organisms with the goal of identifying the key species or consortia involved.

Principal Findings

Microbial community fingerprints show that the bacterial community experiences a large shift in composition over time (Fig 1a). Additionally, overall diversity appears to have decreased. The extent of change in both parameters was greater over the two months before cessation of contaminant injected than in the first five months of the experiments. At the same time, the selective enrichment of an operational taxonomic unit (OTU) associated with the changing geochemical conditions at the site, is apparent (Fig 1a).

Over the same period, 1) TBA injected into the aquifer did not degrade and 2) MTBE injected into the aquifer together with ethanol resulted in a plume of TBA forming beyond the zone of ethanol depletion, i.e. several feet down gradient of the injection area (Fig. 1b).

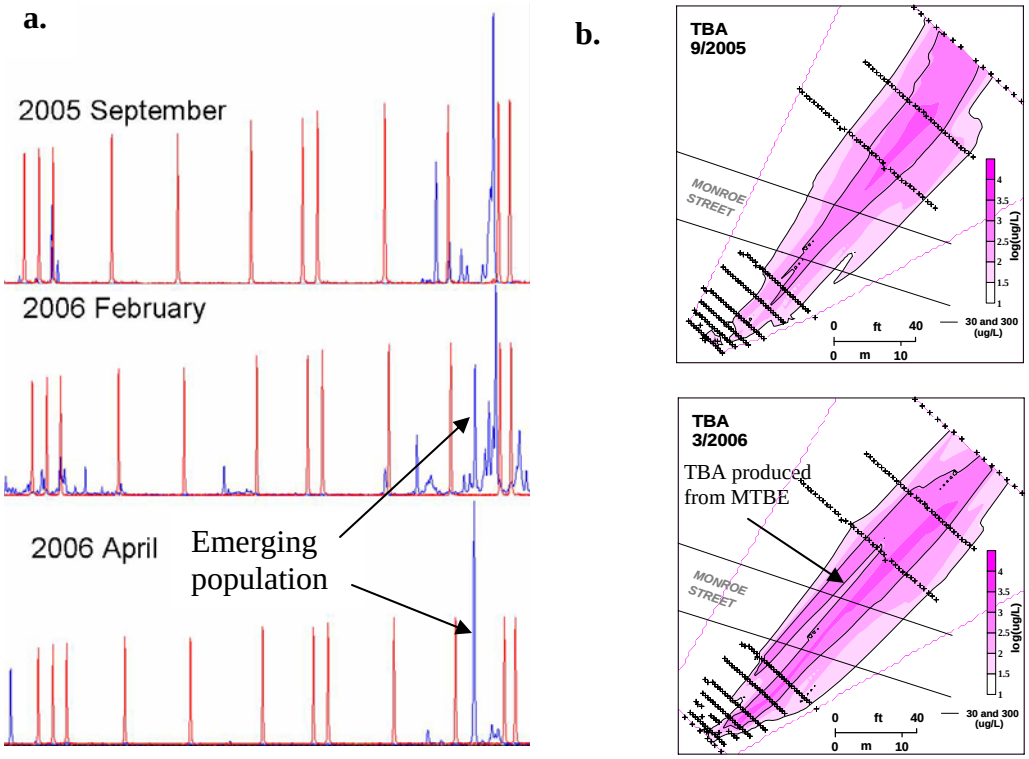

Figure 1. a) Changes in bacterial community structure as determined by TRFLP. Red chromatogram is size standard ROX GS-500. Blue peaks represent bacterial OTUs based on 16S RNA gene. Black arrows highlight emerging population over time (note absence of peak of interest in September 2005). b) Changes in distribution of TBA in the aquifer. Black arrow indicates plume derived from MTBE injection, in a region of the aquifer where TBA was absent at the start of the experiment in September 2005.

Microorganisms of interest, e.g. based on dominant bands and relationships of bands to contaminant concentrations, will be sequenced to determine phylogeny. qPCR methodologies will be used to link changes in their population sizes with macro-scale geochemical data obtained at the site.

Acetogen pure cultures (*Clostridium magnum* and *Sporomusa silvacetica*) were not shown to be capable of carrying out MTBE degradation in pure culture studies, although these results are inconclusive due to possible methodological uncertainties. Primers developed to target the tetrahydrofolate synthetase gene (indicative of acetogenic metabolism) produced a positive result in one out of four site groundwater samples tested. Validation of this result and comparison of acetogenic bacterial abundance to contaminant levels at the site will be carried out next.

An important observation at VAFB is that the persistence of TBA extends well beyond what would be expected, based on the behavior of bromide. Bromide, a conservative tracer similar to TBA in solubility, was co-injected during the experiment. Numerical modeling using HydroGeoSphere was carried out to explore the possibility of diffusion of TBA into the low permeability layer above the layer (S3) containing much of the contamination and the focus of our studies at VAFB. Soil cores were collected from the site (BR04 and BR05 in Fig. 2), divided into sub-sections and concentrations of bromide were measured in each section. Based on these results, it appears that basic assumptions regarding aquifer geology and tracer properties used in conducting the simulation of diffusion of the bromide from the aquifer (S3 sand) into the lower permeability layer above (silt/clay) are valid (Fig 2). In fact, fits to field data could be improved by increasing the extent of mass transfer of TBA from the S3 layer to low permeability layers. However, the high concentrations of TBA persisting in the field cannot be explained with this model alone, due to the more complex history of TBA at the site. The next phase of our research is to develop a more sophisticated numerical model that would improve our understanding of TBA behavior.

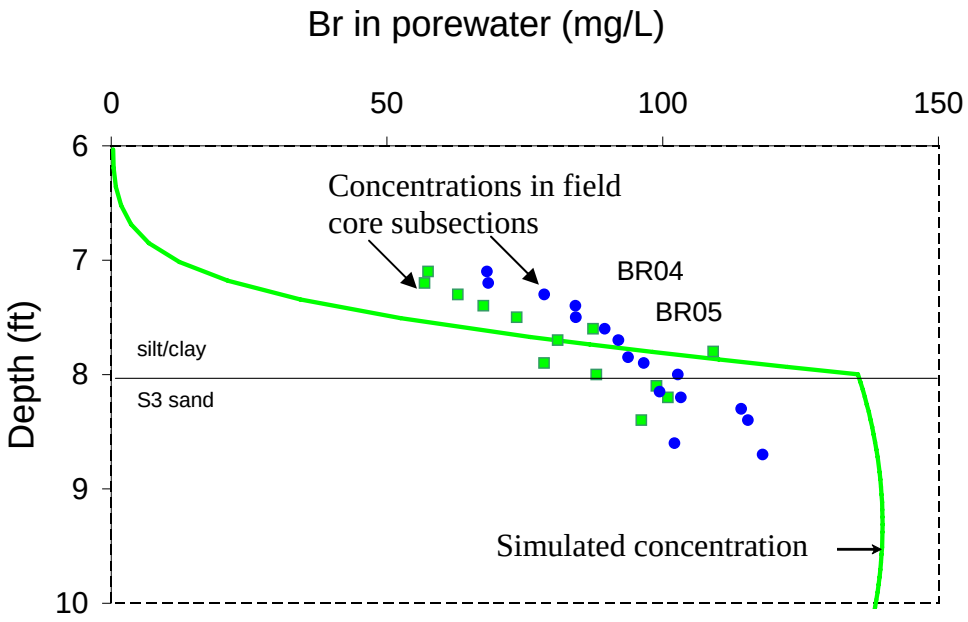

Figure 2. Comparison of simulated results with concentrations measured in field core samples.

Significance

Our results show that TBA behaves unexpectedly at the VAFB field site. We hypothesize that a previously uncharacterized retardation mechanism is impeding the flushing of TBA from the aquifer at a rate that would be expected based on its solubility and sorption properties. TBA is being detected increasingly frequently, throughout the US, at numerous sites previously contaminated with MTBE and thus it is crucial to understand the processes involved in its formation. A better understanding of TBA behavior will lead to improved strategies for its remediation.

INFORMATION TRANSFER PROGRAM

Numerous research presentations have been given based on this work, including a special symposium on MTBE research at VAFB held at the Association of Environmental Health and Sciences (AEHS) meeting in San Diego, CA, this past spring (see notable achievements section). The following are citations of presentations of work specifically related to the UC CWR funded project (all are from the Seventeenth Annual AEHS Meeting and West Coast Conference on Soils, Sediments, and Water: Analysis, Fate, Environmental and Public Health Effects, and Remediation, San Diego, Mar 19-22, 2007).

Feris, K., Mackay, D., Hristova, K., Scow, K., De Sieyes, N.R., Murray, E. **Linking impacts of ethanol on subsurface microbial ecology and anaerobic transformations of BTEX.**

Kaiser, P., Nozawa-Inoue, M., Chakraborty, I., Scow, K., Mackay, D., Murray, E. **Impact of Ethanol on Anaerobic Transformation of MTBE to TBA**

Mackay, D., Chakraborty, I., Nozawa-Inoue, M., Goyal, S., Ginn, T., Scow, K., Einarson, M., Chapman, S. **Flushing of MTBE and TBA from layered media**

STUDENT SUPPORT

	Total Project Funding		Supplemental Awards	Total
	Federal Funding	State Funding		
Undergrad.	1	1	10	12
Masters			1	1
PhD.	1		6	7
Post-Doc.		1	3	4
Total	2	2	20	24

NOTABLE ACHIEVEMENTS AND AWARDS

- Symposium sponsored by the American Petroleum Institute entitled “Review Of Gasoline Oxygenate Research At The Vandenberg AFB Site”, at the Association of Environmental Health and Sciences: Seventeenth Annual AEHS Meeting and West Coast Conference on Soils, Sediments, and Water: Analysis, Fate, Environmental and Public Health Effects, and Remediation. The symposium was a three hour session dedicated to highlighting new findings by our collaborative team at Vandenberg, as part of a whole day session on the environmental impact of fuel oxygenates.
- API graduate student award to Irina Chakraborty (2006)
- Superfund Basic Research and Training Program Fellowship to Irina Chakraborty (2005-2007)

Quantitative PCR Assays for Specific Host Sources of Fecal Pollution for Test Watersheds

Basic Information

Title:	Quantitative PCR Assays for Specific Host Sources of Fecal Pollution for Test Watersheds
Project Number:	2006CA173B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	44
Research Category:	Water Quality
Focus Category:	Water Quality, None, None
Descriptors:	None
Principal Investigators:	Katheryn Ivanetich

Publication

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

RESEARCH PROGRAM:

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

Project Overview:

The purpose of this study is to develop and validate Quantitative PCR assays for host specific and reference targets and apply the assays to the San Pedro Creek Watershed in Pacifica, CA in order to identify sources of fecal pollution and focus remediation efforts.

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

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

San Pedro Creek Watershed sampling focused on areas suspected of contributing fecal pollution to the main stem of the creek, namely sites on the North Fork, above the Park Mall Shopping Center culvert (Figure 1, upper right corner - Big Bend area), and sites associated with tributaries that feed into the main stem from the South, primarily between Adobe and Highway 1 (Figure 1, lower left area). Eight to 11 sites were sampled on each of six wet/rainy events, and E. coli, total coliform and Enterococcus levels were enumerated. Fifty (96.2%) of the watershed samples had elevated levels of Enterococcus (> 35 CFU/100 ml geomean), and were utilized for isolation of mixed Enterococcus cultures.

Four methods for isolation of genomic DNA were applied to a representative sampling of Enterococcus and E. coli cultures (Epicentre Masterpure, Qiagen Genomic Tip 100/G, Sigma GenElute 5 Minute Plasmid and Sigma Genomic DNA kit) and evaluated by DNA yield from bacterial cultures, and by assay cost, overall time and technical time. Because of its speed, the Sigma GenElute 5 Minute Plasmid kit method was modified with the inclusion of lysozyme or incubation at elevated temperatures, but although this method gave yields of 60-200 ng DNA from E. coli cultures (used as a positive control), yields from Enterococcus cultures were unacceptably low (0-16 ng DNA). The Epicentre Masterpure and Sigma genomic DNA kits provided the highest yields of genomic DNA and were of comparable low cost (ca. $1 per isolation). The Sigma method was preferred since it required only 3 hours, i.e. half as much time as the Epicentre method.

Enterococcus cultures were prepared and genomic DNA isolated from 12 fecal samples, 10 sewage samples, and 80 watershed samples. In addition, BCS on North Florida provided

isolated genomic DNA from 10 known bacterial species and strains and from Enterococcus cultures from 30 fecal, sewage and watershed samples.

An automated protocol for the quantification of Enterococcus genomic DNA with PicoGreen dye, for the Beckman Biomek 2000 was developed and optimized. The protocol performed all pipetting steps, except for transfer of 1 ul of DNA unknowns into the read plate, all mixing, and transfers, and calculations, including generation of the standard curve and calculation of the DNA concentration of unknown samples.

Significant progress has been made in the development and validation of Quantitative PCR (QPCR) assays for host-specific microorganism targets: (1) the esp gene of Enterococcus faecium, as a specific marker for human fecal pollution, and (2) two gene targets in Enterococcus faecalis as indicators for avian and human fecal pollution, plus two reference gene targets diagnostic for total Enterococcus, as indicators of total fecal pollution.

All QPCR assays were applied to fecal, sewage and environmental samples (Table 1). The human specific E. faecium target (Esp2b2) was positive for sewage and environmental samples with suspected human contamination, and did not react with avian, cow, dog, human or rabbit fecal samples. Furthermore, the human specific gene target identified 5 of 7 environmental samples with human fecal contamination (Table 2). All of the above data are fully consistent with the putative assay specificity, as the gene target is not found in all human individuals. In contrast, the Ace1a and Esp1a gene targets in E. faecalis, with putative specificity for human and/or bird hosts, reacted across all samples, and were non-specific with regard to host. These gene targets were therefore not useful for MST and were not studied further. The reference target (16Sb) reacted with all fecal, sewage and environmental samples, and exhibited similar levels of gene expression across all samples, confirming its efficacy as a reference marker for total Enterococci (Table 1).

In summary, in the period under review the project has demonstrated significant progress in assay development and validation, and methodology development. In addition, sites in the San Pedro Creek Watershed with anticipated fecal pollution have been sampled, and a high percentage (96.2%) of these watershed samples were found to contain elevated levels of fecal indicators, i.e. Enterococcus. These samples are being processed for future analysis by QPCR.

Final results of this study (to be completed with funding from the University of California Center for Water Resources) are anticipated to facilitate the identification of the sources of fecal pollution in watersheds, and thus enable more efficient watershed management and provide specific data on sources of fecal pollution in the San Pedro Creek. In particular, the focus on development of assays for human fecal pollution will impact the sources of pollution from which humans experience the highest health risk.

Professional Presentations:

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

The Politics and Practice of Watershed Restoration: Insights from the Russian River Watershed, Northern California

Basic Information

Title:	The Politics and Practice of Watershed Restoration: Insights from the Russian River Watershed, Northern California
Project Number:	2006CA174B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	44
Research Category:	Social Sciences
Focus Category:	Law, Institutions, and Policy, Management and Planning, None
Descriptors:	None
Principal Investigators:	Jeff Romm

Publication

1. Bernhardt, E.S., M.A. Palmer, J.D. Allan, G. Alexander, K. Barnes, S. Brooks, J. Carr, S. Clayton, C. Dahm, J. Follsted-Shah, D. Galat, S. Gloss, P. Goodwin, D. Hart, B. Hassett, R. Jenkinson, S. Katz, G.M. Kondolf, P.S. Lake, R. Lave, J.L. Meyer, T.K. O'Donnell, L. Pagano, B. Powell, and E. Sudduth, Synthesizing U.S. river restoration efforts, Science, 2005, 308:636-637.

Project Summary

In the last two decades, watershed restoration has dramatically increased in both popularity and practice. California has lead the way with multi-billion dollar bonds being approved by voters for environmental improvements and a plethora of public and private funding sources providing grants for restoration activities. Yet, the social and environmental outcomes of restoration remain ambiguous and critics charge that restoration has not fulfilled its promise. This research addresses three central questions: 1) What is watershed restoration accomplishing on-the-ground?, 2) Who and what primarily benefit from dominant restoration practices?, and 3) How is watershed restoration influenced by social factors, including the political economy of water use along with legal and institutional frameworks for water management?

Our main research objective is to enhance watershed management in California by improving our understanding of the coupled social – environmental systems. To do this, we integrate institutional analyses, archival research, document and literature reviews, interviews, post-project appraisals, and spatial data analysis in order to make explicit the broader webs of social relations that shape restoration and explore the consequences for different groups of people and organisms. Thus far, we have collected data on nearly 800 restoration projects in the Russian River watershed, creating a Geographic Information Systems (GIS) database of this data along with land use and demographic information. We are in the process of analyzing dominant practices and trends over time. Preliminary results suggest that restoration projects most often occur at a site-specific scale and the majority are characterized as riparian, in-stream, or road-related improvements. One of the co-PIs, G. Mathias Kondolf, co-authored an important article on restoration accomplishments nation-wide utilizing this data, which was recently published in the journal *Science*.

In addition, nearly 50 interviews have been completed with individuals involved in restoration in the Russian River watershed. These interviews have revealed the dynamic nature of restoration as a concept, signifying everything from the revival of a cultural connection to the land, to the restoration of particular ecosystem processes, to the creation of a new industry. Interestingly, one of the major issues absent from discussions of watershed restoration is the role of water management. California Senate Natural Resources and Water Committee Principal, Bill Craven, remarked that restoration has been limited in its impact by not addressing important issues like water use (California Watershed Day). Current research is examining why this disconnect has developed by analyzing the political economy and institutional framework of water management in the Russian River area and how it creates both opportunities and constraints for watershed restoration.

Investigating the role of nitrogen fixation and denitrification in ameliorating deteriorating water quality in a highly eutrophic southern Californian estuary

Basic Information

Title:	Investigating the role of nitrogen fixation and denitrification in ameliorating deteriorating water quality in a highly eutrophic southern Californian estuary
Project Number:	2006CA176B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	44
Research Category:	Biological Sciences
Focus Category:	Ecology, Water Quality, None
Descriptors:	None
Principal Investigators:	Peggy Fong, Catherine M Borrowman

Publication

RESEARCH PROGRAM:

Estuaries are highly productive ecosystems that support many endangered and commercially important species. In most estuaries, nitrogen limits primary productivity. However, if present in excess, nitrogen can lead to eutrophic conditions, which can adversely affect water and habitat quality. Southern California's estuaries have highly developed watersheds, often resulting in high loads of nitrogen from anthropogenic sources and eutrophication. Our overall goal is to understand the role of two biogeochemical processes, nitrogen fixation and denitrification, that affect processing of nitrogen in estuaries and to investigate their response to increased nitrogen loads from the watershed. Ultimately, we aim to aid in protecting these important aquatic ecosystems by understanding the constraints and controls that function to balance these two processes and how these processes, especially denitrification, may act to ameliorate the negative effects of eutrophication.

Nitrogen fixation transforms elemental nitrogen (N_2) into ammonium ions (NH_4^+) that can be used by primary producers, and therefore is considered a "new" source of nitrogen. Denitrification transforms nitrate (NO_3^-) into atmospheric nitrous oxide (N_2O) or nitrogen (N_2), and is therefore a loss of nitrogen from aquatic ecosystems. As these processes either contribute or remove nitrogen from the system, they have the potential to affect water quality and ecosystem health. However, little is known about nutrient dynamics in southern California estuarine environments, and only one study addresses these microbial nitrogen transformations.

We measured spatial and temporal variability of nitrogen fixation and denitrification and investigated relationships to abiotic/biotic factors in a eutrophic southern California estuary through four field surveys and three experiments in Upper Newport Bay Ecological Reserve, a large estuary in Orange County, California. This combined approach allows us to understand the factors that control these important processes in the nitrogen cycle that potentially may limit eutrophication. All field and laboratory work for this project has been completed, with the exception of running gas samples for denitrification measurements. Analysis and interpretation of data is in progress.

Field surveys of the estuary encompassed both the wet and dry seasons and took place in March 2005, Sept 2005, Feb 2006, and Sept 2006. We sampled the intertidal mudflat along 5 locations in each of two tidal creeks spanning the spatial gradient of the estuary. During each survey sediment was taken for nitrogen fixation and denitrification measurements, via acetylene reduction and acetylene block techniques, respectively. Samples were also taken to determine other characteristics of the sediments, including sediment type and nutrient content, organic material present, benthic chlorophyll content, and water nutrients. This will allow us to determine any correlations between the nitrogen processing rates and ecosystem characteristics.

It is clear from the surveys that there is a great deal of spatial and temporal variability in nitrogen fixation rates within the estuary (Figure 1). Overall, with notable exceptions, fixation rates were low relative to those found in other, less eutrophic estuaries. It is clear that patterns of fixation are not simply explained by seasonal or long-tern site characteristics. We expect to see that nitrogen fixation rates will correlate with shorter-term sediment, water, and biotic factors. Rates are hypothesized to be higher in areas of decreased nitrogen supply from the water and surrounding sediments, as well as in areas with high organic material. Denitrification rates are not yet available, though they are expected to be highest in areas with higher nitrate concentrations and in more oxygen depleted conditions.

In July 2005 we executed a nutrient experiment in the laboratory using sediment cores from the field to test the response of nitrogen fixation and denitrification rates after exposure to

nutrient enriched water treatments, including enhanced nitrate and phosphorus levels. Replicate sediment cores were exposed to one of four seawater treatments (NO_3^- and PO_4^{3-}, NO_3^- only, PO_4^{3-}only, and ambient). This simulates estuary conditions as nutrient loading into the system continues to increase. Preliminary results of the nutrient experiment suggest nitrogen fixation rates were lower in the presence of increased nitrate and not affected by the addition of phosphorus.

In July – August 2005 we performed a sediment transplant experiment to investigate how sediment characteristics that co-vary with eutrophication affect nitrogen fixation and denitrification rates using a common garden design. Large sediment cores from three areas of the estuary with contrasting sediment types were relocated and left to acclimate to the environmental conditions at this new location (i.e. same tidal flushing and exposure to water nutrients). Initial (Day 0) and final (Day 25) measurements of fixation and denitrification rates and a suite of abiotic characteristics (see field survey) were measured. Preliminary analysis of data shows an increase in fixation rates for all cores transplanted from sites with smaller sediment grain size, which suggests an effect of sediment type.

In June – July 2006, a 40-day long field experiment studied the effects of the prolific green macroalgal mats that dominate upper Newport Bay. We investigated how the presence and density of these mats, often a product of nutrient enrichment, affect nitrogen fixation and denitrification rates and other sediment and water characteristics beneath the algal mats. We used a caging experiment to investigate the effect of high, low and zero density macroalgal treatments on the benthos after 10, 25 and 40 days exposure. We expect presence of macroalgae will decease oxygen and increase nutrient flux to the sediment, especially as decomposition begins. This could decrease fixation and increase denitrification rates over time.

This research will determine: spatial and temporal patterns of nitrogen fixation and denitrification rates, correlations of biotic/abiotic factors with rates, and quantitative relationships between factors and rates. It will contribute to our basic understanding of how nitrogen cycles through Upper Newport Bay Estuary and will provide insight into southern California estuary systems and other unique Mediterranean and heavily impacted ecosystems. It is imperative to understand these processes in California estuaries, since approximately 90% of estuarine and salt marsh systems have already been lost along California's coast. The remaining estuaries are critical habitat and our work will aid in ensuring survival of this vital remaining habitat. Understanding nitrogen cycling in these systems could allow policy makers to make more informed decisions regarding the regulation of nutrient inputs into these systems. These processes that add and remove nitrogen from estuarine ecosystems are especially important as nutrient loading and subsequent eutrophication will only increase in the future.

INFORMATION TRANSFER PROGRAM:

Initial results of nitrogen fixation rates for the field surveys was presented at the California Estuarine Research Society (CAERS) Annual Meeting in Bodega, California in March 2007, and at the UCLA Ecology and Evolutionary Biology Annual Research Symposium in May 2007. Additionally, one undergraduate student involved in the project presented portions of the data which he assisted on at the UCLA Undergraduate Science Poster Day in 2007.

An abstract has been submitted to present the nutrient and algae experiment data at the Estuarine Research Federation Bi-Annual Meeting in Providence, Rhode Island in November of 2007. Portions of this research will also be presented at the Western Society of Naturalists Annual

Meeting in November 2007. As data analysis is being completed, we expect a minimum of four manuscripts will be prepared for publication.

This project has also fostered new collaborations. As determination of nitrogen fixation and denitrification rates requires a Gas Chromatograph in order to measure gas concentrations obtained during assays, Dr. Doug Capone at the University of Southern California has allowed us to use his equipment for these measurements. He and members of his laboratory have been very helpful in teaching us the techniques to measure these characteristics. In addition, we have begun a collaboration with the Southern California Coastal Water Research Project (SCCWRP) to incorporate some of the questions we have been asking in Upper Newport Bay Estuary to a more integrative project in San Diego Lagoon.

STUDENT SUPPORT:

This project has been the main funding source for one PhD student (Tonya Kane). Several additional PhD students contributed to the research and many undergraduates have assisted on this project, as volunteers, for educational credit, and/or for financial support.

	Total Project Funding		Supplemental Awards	Total
	Federal Funding	State Funding		
Undergrad.	23	23	$5,000	23
Masters	1	1	None	1
PhD.	6	6	$2,000	6
Post-Doc.	None	None	None	None
Total				

NOTABLE ACHIEVEMENTS AND AWARDS:

A poster presentation by Tonya Kane, the PhD student this project supports, at the UCLA Ecology and Evolutionary Biology Annual Research Symposium in May 2007 earned a second place award.

PUBLICATIONS FROM PRIOR PROJECTS:

n/a

PUBLICATIONS AND CITATION FORMAT:

All publications from this project are in progress.

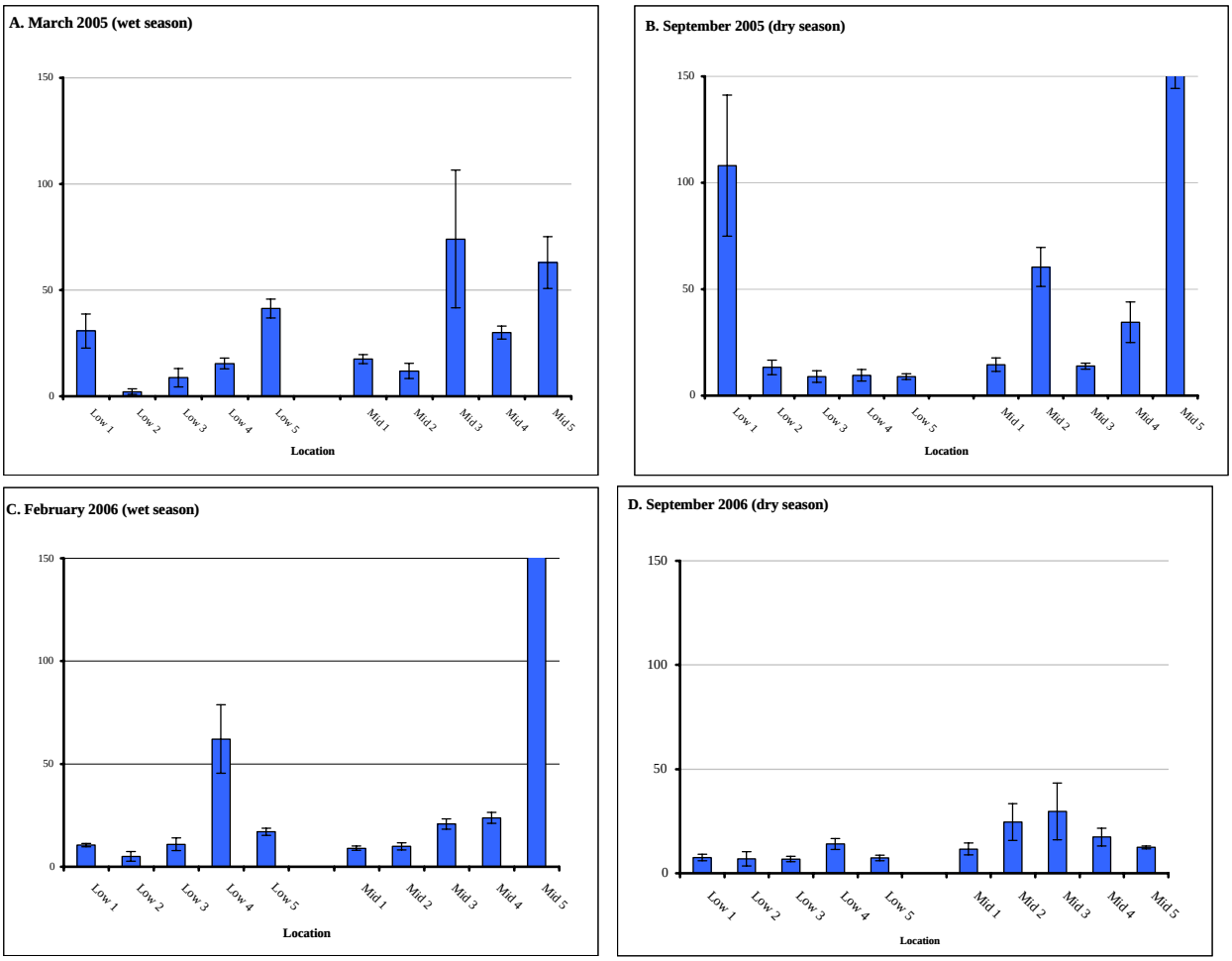

Figure 1. Mean nitrogen fixation rates (nmol N fixed m-2 hr-1) at each location for field surveys over two years. (For September 2005, Mid 5 extends to 180 $\pm$ 36. For February 2006, Mid 5 extends to 378 $\pm$ 101)

Information Transfer Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	28	1	0	44	73
Masters	2	2	0	9	13
Ph.D.	12	4	0	45	61
Post-Doc.	1	10	0	8	19
Total	43	17	0	106	166

Notable Awards and Achievements

2003CA57G

Two graduate students in Dr. Lydy's laboratory (Andrew Trimble, doctoral student; Amanda Harwood, Masters student) have received EPA STAR graduate fellowships to continue this research. These fellowships began August 2006 and are the result in part due to USGS/NIWR funding. Due in large part to the urban creek findings from this study, as well as our agricultural findings from prior work, the California Department of Pesticide Regulation (DPR) has announced their intent to put pyrethroid pesticides in to the process known as re-evaluation. It is extremely rare for DPR to put pesticides in re-evaluation based on water quality data, but our studies provided strong evidence of agricultural and urban aquatic toxicity due to the pyrethroids. Under re-evaluation, DPR will require the registrants to provide additional data on sources, potential mitigation practices, and environmental fate and effects of pyrethroids so that the State of California can manage them more effectively. We have received four supplemental awards as a result of this study, three from EPA funding via the Sacramento River Watershed Program. The first award of $23,000 provided for sampling at an additional farm site in connection with our studies on changes in pyrethroid bioavailability over time, as described above. The second award, for $91,000, provided for the development of procedures to identify when pyrethroids are the causative agent for mortality when observed in sediment toxicity tests (i.e., Toxicity Identification Evaluation). The third award, for $28,000, was for continued development of pyrethroid toxicity identification evaluation procedures. A fourth award of $60,000 was just received from the University of California Water Resources Center for research on transport of pyrethroid pesticides in to the coastal waters of Monterey Bay, and their effect on benthic invertebrates of the shelf and deep sea canyon.

2004CA110G

Project staff Anne Taufen Wessells gave a public teaching lecture based on this research at the University of California, Irvine in the Department of Environmental Analysis and Design; May 2, 2006. Ms. Wessells also made presentations based on this research at the Greening XVI conference (environmental policy scholars), April 21, 2007 at the Claremont Colleges, Claremont, CA; and at the Theorizing Ways of Knowing: Beyond Interest conference (public policy scholars), May 18, 2007 at the Virginia Polytechnic

University, National Capital Region, Alexandria, VA. Anne Taufen Wessells will also be presenting portions of this research at three upcoming national conferences: the Council of Educators in Landscape Architecture (CELA) annual conference, August 15-19, 2007, State College, PA; the American Political Science Association (APSA) annual conference, August 30-Sept 2, 2007, Chicago, IL; and the Association of Collegiate Schools of Planning (ACSP) annual conference, October 18-21, 2007, Milwaukee, WI.
2006CA168B

Chris Hammersmark was awarded an Honorable Mention for his presentation Hydrologic Effects of A Pond and Plug Stream Restoration in A Mountain Meadow presented at the 2007 Society of Wetland Scientists International Conference: Water, Wetlands, and Wildlife Resolving Conflicts and Restoring Habitat, held in Sacramento, CA, June 10-15, 2007.

2006CA172B

Symposium sponsored by the American Petroleum Institute entitled Review Of Gasoline Oxygenate Research At The Vandenberg AFB Site, at the Association of Environmental Health and Sciences: Seventeenth Annual AEHS Meeting and West Coast Conference on Soils, Sediments, and Water: Analysis, Fate, Environmental and Public Health Effects, and Remediation. The symposium was a three hour session dedicated to highlighting new findings by our collaborative team at Vandenberg, as part of a whole day session on the environmental impact of fuel oxygenates. API graduate student award to Irina Chakraborty (2006) Superfund Basic Research and Training Program Fellowship to Irina Chakraborty (2005-2007)

2006CA173B Ivanetich, Kathryn, Status of California Watersheds and Novel Methods to Identify Host Sources of Fecal Pollution, California State University at Chico, Department of Chemistry and Biochemistry, April 2006.

2006CA176B

A poster presentation by Tonya Kane, the PhD student this project supports, at the UCLA Ecology and Evolutionary Biology Annual Research Symposium in May 2007 earned a second place award

Publications from Prior Projects