California Water Resources Center

Annual Report 1999-2000

July 1, 1999 September 30, 2000

Dr. John Letey, Director
UC Center for Water Resources

University of California
Water Resources Center Report No. 100
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Copies of Center publications may be examined at the Water Resources Center Archives, 410 O'Brien Hall, University of California, Berkeley, CA 94720 (510)642-2666.

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

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

Cover photo: UC Center for Water Resources (then the California Water Resources Center), 1989. Photo courtesy of James Woods, USDA Salinity Laboratory.

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From the Director

Dr. John Letey
Director
UC Center for Water Resources

The Water Resources Center (WRC) was administratively combined with the Wildland Resources Center, the U.C. Salinity/Drainage Program, and the Cooperative Extension Water Quality Program into a unit known as the Centers for Water and Wildland Resources on July 1, 1993. The Wildland Resources Center was reassigned to another administrative unit during 1999-2000 and the three remaining programs are presently in the U.C. Center for Water Resources. Transition of the main administrative office from Davis to Riverside occurred during the year, and as of July 1, 2000 the complete program is now operational at Riverside. Rex J. Woods, Interim Associate Director of the Centers, was a major contributor to the transition activities.


Dr. John Letey

A revision of the Water Resources Center by-laws approved at the April 6, 2000 Coordinating Board/ Advisory Council meeting expanded the role of the Advisory Council. The Advisory Council consists of representatives of the Department of Water Resources, State Water Resources Control Board, California Department of Fish and Game, the U.S. Geological Survey, as well as at-large membership from the water community.

The Coordinating Board is comprised of academic senate members from the U.C. Campuses and serves as the governing body of the Center. The Advisory Council participates with the Coordinating Board members in reviewing research proposals, serving on committees, and discussing business matters at the semi-annual meetings.

The largest proportion of the WRC budget goes to supporting research projects on a broad range of water-related issues. The projects serve the dual role of developing knowledge and training students.

The WRC provides the major support budget for the Water Resources Center Archives located on the Berkeley campus. However, the financial and other support services by various donors and the Advisory Board to the Water Resources Center Archives are acknowledged and greatly appreciated. A more detailed report on the Archives is presented on page 13 in this annual report.

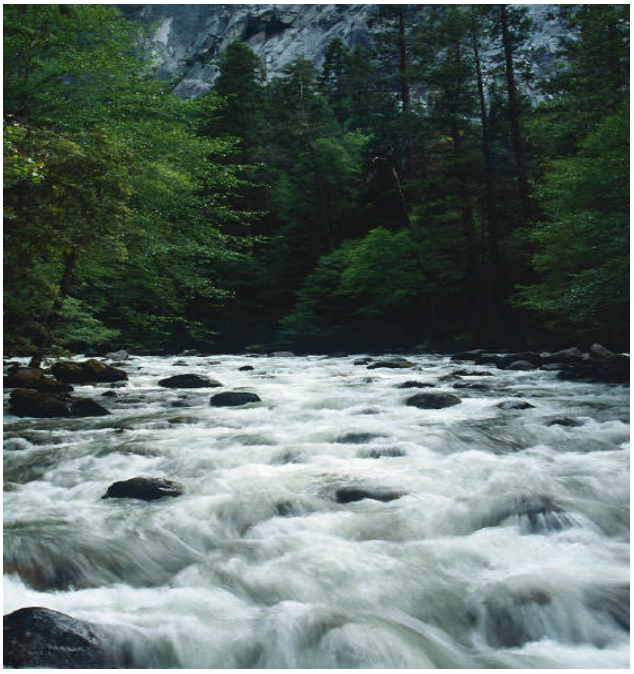
The WRC Archives has also been awarded grants in the amounts of $8,860 and $15,000. *Survey of California and Irrigation Districts* will create a comprehensive list of water districts and irrigation districts in California through surveying these agencies' significant historical documents. The information will be compiled and organized in a searchable database that will be available at the Water Resources Center Archives. *San Francisco Bay Fund Inventory of Projects* will develop an inventory and interactive information system for all San Francisco Bay Fund projects, with links to other systems. The inventory will be hosted by the Information Center for the Environment (ICE) and will reside as one of the Water Projects Inventory files.

I take this opportunity to express appreciation and thanks to members of the Coordinating Board and Advisory Council for their contribution to the success of the WRC. They will be called upon for even greater service as we work together to increase the effectiveness and contributions of the WRC to addressing water issues in California.

About the Center

California
Water Resources Center

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



In 1964, the Center became part of a national network of university water research institutes when it was designated the California Water Resources Research Institute by the Governor and the President of the University under the terms of the federal Water Resources Research Act of 1964. As the state's designated federal research institute, the Center is responsible for water research coordination and administration activities that extend beyond the University of California to all state and private universities in California. Since 1964, the Center has received federal funds and is subject to various federal policies and regulations.

The Center is organized with an Office of the Director on the Riverside campus, and an archive library on the Berkeley campus. The Director's Office also administers the Salinity/Drainage Program and the Water Quality Program. The Center does not undertake research directly, but supports an annual portfolio of between thirty and thirty-five projects on all phases of water research through its competitive grants program. This research is conducted by faculty and students within the departmental structure of each U.C. campus and those at other universities who successfully compete in the awards process.

OBJECTIVES

The basic goal of the Center is to stimulate and support water and water-related research both within and among the various academic department and research organizations of the University. The broad research focus includes the conservation, development, management, distribution and utilization of water resources with a view to their optimum present and future use. In order to achieve this goal, the Center operates according to the following long-standing functional objectives:

- *Extend and intensify the water resources research program on all campuses of the University by widening the participation of individual researchers and disciplinary fields involved in water-related research and, to the extent feasible, by stimulating research in conjunction with academic programs;*

- *Identify substantive research agendas which when pursued, will assist in solving California's most urgent water problems anddevelop for the University major short-and long-term research priorities which are responsive to these problems;*

- *Maintain an inventory of water and water-related research within the University and assemble information on such undertaken throughout the United States and in other nations. Information on the current state of water and water-related research will be disseminated to University personnel, water managers, public interest organizations, and t h e interested public;*

- *Support and foster research which cuts across disciplinary boundaries and focuses on the interrelatedness of water*

with other natural resources such as energy and timber;

• *Maintain close relationships with government agencies, quasi public organizations, and other research organizations for the purpose of keeping both the University and outside organizations aware of each other's activities and problems.*

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The Coordinating Board

California
Water Resources Center

The Coordinating Board establishes policy for the Center and makes final decisions regarding the allocation of available funds. It is chaired by the Vice President of Agriculture and Natural Resources through whom it reports directly to the President of the University. The Board, appointed by the President of the University, is composed of at least thirteen faculty members from diverse disciplines and various administrative, teaching and research responsibilities. All members have a strong interest in water-related research. Eight of the nine campuses of the University are represented on the Board. The Board normally meets twice yearly, although special committees of the Board may meet from time to time throughout the year and individual members attend Center-sponsored meetings and conferences. Members serve as liaison or as a contact on their own campuses as well as to agencies, citizens, faculty, and students in water-related research. These liaison interactions contribute valuable insights in establishing policy for the Water Resources Center. Members of the Coordinating Board during 1999-2000 were:

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RESEARCH ACTIVITY BY CAMPUS

	1999-2000			2000-2001	
Location	**Projects Funded**	**Graduate Students Supported**	**Undergraduate Students Supported**	**New Projects**	**Total Projects**
UC Berkeley	5	13	9	7	12
UC Davis	7	22	19	3	10
UC Irvine	1	1	0	3	4
UC Los Angeles	2	2	0	2	4
UC Riverside	2	3	0	3	5
UC San Diego	0	0	0	0	0
UC Santa Barbara	5	10	4	1	6
UC Santa Cruz	1	3	0	0	1
TOTAL	23	54	32	19	42

Total research funds allocated during the 1999-2000 fiscal year:

Approximately $600,000

Total amount of funding WRC projects received from other sources:

Approximately $1.5 million

THE WATER RESOURCES CENTER ARCHIVES

Mission and Scope

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

WRCA is a research library with more than 139,000 cataloged items. The scope of the collection includes fresh water supply and quality, groundwater, municipal and industrial water uses, flood control, water reuse, sewerage and waste disposal, river mechanics, coastal engineering, estuaries, water pollution, and water law. WRCA collects a variety of types of materials including printed reports, government documents, books, manuscripts, maps, videos, photographs, and electronic resources. The collection concentrates on materials relating to California and the West, although there are national and international materials in the collection as well.

Access to the Collection

WRCA is a member of the Online Computer Library Center (OCLC), an international database that currently contains more than 43 million records in the Library of Congress' Machine Readable Catalog (MARC) format. The system indicates which member library holds a given title, and is both a shared cataloging resource and interlibrary borrowing mechanism. Since 1983, all new WRCA material has been cataloged onto the OCLC database.

OCLC regularly uploads all of the recent cataloging records from all nine UC campuses. This cumulative tape is then uploaded to the Melvyl® Catalog, the University of California's online catalog database. Melvyl® is searchable on the World Wide Web (http://www.melvyl.ucop.edu), on the campuses by dedicated terminals and via modem. This makes the WRCA's collection available both nationally and internationally.

In October 1998, the WRCA became a participant in the California Digital Library's Online Archive of California (OAC), a union database of encoded archival finding aids. Finding aids provide detailed descriptions and outlines of archival collections and are essential tools for understanding the true content of a particular collection. The OAC is searchable at the collection, repository, and institutional levels, or the entire database can be searched for documents or photographs on particular subjects. At this writing, the Water Resources Center Archives has over 90 finding aids on the OAC, which will expand the use of the archival collections. Recently the finding aid for the Mono Lake Committee Collection was added to the OAC. WRCA's collections on the OAC can be found at http://www.oac.cdlib.org/dynaweb/ead/berkeley/wrca/.

Use of the Collection

Use of the collection in 1999-2000 included 12,371 transactions (titles used on the premises and borrowed). Users, by category, were as follows: graduate students—27%, undergraduate students—13%, faculty and staff—9%, interlibrary loans—11%, general public—40%.

Publications

WRCA produces two publications—*Selected Recent Accessions*, a bi-monthly list of new publications, and *WRCA News*, a newsletter that is published three times per year. These publications are distributed free-of-charge in paper format to approximately 300 subscribers. They are also available in electronic format on the WRCA web site (http://lib.berkeley.edu/WRCA/).

Stream measurements were made to determine the Owens River flow (Lipp 141:84). Photo courtesy WRC Archives.

The Water Resources Center Archives and the Harmer E. Davis Transportation Library collaborated on the publication of a calendar for the year 2000 that featured historic photographs of Bay Area bridges under construction. All of the photographs are from the Archives' Charles Derleth manuscript collection. Publication of the calendar was generously underwritten by T.Y. Lin International/Moffatt & Nichol Engineers, a joint venture. One thousand calendars were distributed to donors of the two libraries, sold in local bookstores, or sold via mail-order. The two libraries have recently completed compiling a calendar for the year 2001. The 2001 calendar features images of the Golden Gate Bridge and the San Francisco-Oakland Bay Bridge. The images are from the Derleth, J.D. Galloway and Walter Huber collections, held by the WRCA.

Web Site and Online Resources

The Water Resources Center Archives continues to develop and expand its web site. The web site, which is now searchable, includes an introduction to the library's print and electronic resources, lists of archival and video collections, specialized research guides, and all library publications. It also provides links to the California Digital Library (which includes Melvyl® and the Online Archive of California, electronic reference resources, article indexes, electronic journals, and other online resources. In July 2000, the Internet Resources section of the WRCA web site was selected as a "Key Resource" by Links2Go (http://links2go.com/topic/Hydrology), an extensive Internet search and directory service.

The online resources provided by the Water Resources Center Archives help researchers get up-to-date information. Different systems provide information in bibliographic, full-text, or data forms. *Water Resources Abstracts* contains bibliographic citations to journals, books, documents, and reports on hydrology and other areas of water-related research. This system is now accessible to UC Berkeley students, faculty and staff via the WRCA web site. WRCA also maintains subscriptions to two key CD-ROM databases: *USGS Peak Values* and *USGS Daily Values*, both published by Hydrosphere, Inc. WRCA staff members are experts at locating and retrieving data and information from all of these electronic resources.

Fundraising and Fee-For-Service

WRCA continues its fundraising activities. In 2000, approximately five hundred letters were sent to California Water or Irrigation Districts asking them to become members of the Archives. The memberships are currently being received. The Advisory Board to the Water Resources Center Archives continues to meet semiannually and to assist with outreach and fundraising strategies.

The Water Resources Center Archives and the Mono Lake Committee (MLC) jointly sponsored a benefit concert on Sunday, November 7, 1999, 3:00 p.m. at St. John's Presbyterian Church, 2727 College Avenue, in Berkeley. The concert featured violinist David Abel and pianist Julie Steinberg performing works of Beethoven, Debussy and Dresher. Pacific Gas and Electric Co. in San Francisco generously underwrote $5,000.00 of the cost of the concert. A wine and dessert reception for sponsors and donors followed the performance. Dr. G. Mathias Kondolf, Associate Professor in the Departments of Landscape Architecture/Environmental Design and Geography at UC Berkeley, and Dave Shuford, a biologist with the Point Reyes Bird Observatory, spoke about the activities of each organization. The concert was a huge success, generating approximately $7,500.00 in revenue for each organization.

WRCA continues to expand the use of the collection and increase outside revenues by providing fee-based document delivery services to non-UC requestors. Requests are received via OCLC, telephone, fax or email.

Conferences and Exhibits

On March 1, 2000, the WRCA held a reception in the Morrison Room of Doe Library to celebrate the installation of *Bridging the Bay: Bridging the Campus*, an exhibit which contained a wide selection of historical and contemporary materials showcasing the building of the Bay Area's bridges. The exhibit was a collaborative effort featuring materials from eight libraries on the UC Berkeley campus, including extensive materials from WRCA's archival collections. Exhibit curators were Linda Vida, WRCA, and Waverly Lowell, UCB Environmental Design Archives. Randal Brandt, WRCA, was the curator of the virtual exhibit which is still available at http://www.lib.berkeley.edu/Exhibits/Bridge/.

The reception for sponsors, exhibitors and their guests featured a presentation by Rafael Manzanarez, Vice President of T.Y. Lin International and Marwan Nader, Associate and Lin. The presentation was entitled: *Design of the New San Francisco-Oakland Bay Bridge East Span*. T.Y. Lin International/Moffatt & Nichol Engineers were

awarded the design/build contract for the new East Span of the San Francisco-Oakland Bay Bridge.

In May 2000, WRCA staff exhibited at the Association of California Water Agencies (ACWA) Conference that was held in Monterey, California.

Bay Bridge, January 1936 (Derleth 102, H-349). Photo courtesy WRC Archives.

Grants

The Water Resources Center Archives has been awarded a $15,000.00 grant from the San Francisco Foundation to create an online inventory of projects that received grants from the Foundation's San Francisco Bay Fund. The award was one of the first 15 grants from the fund approved by foundation trustees in March 2000. WRCA will us its grant to develop an inventory and interactive information system for all San Francisco Bay Fund projects and link that inventory with other related systems.

The inventory will be housed on the Information Center for the Environment's (ICE) web-based system at UC Davis (http://ice/ucdavis.edu/). ICE hosts a variety of inventories offering information about restoration, mitigation and conservation projects in, or bordering California. The new inventory will become a file in the Natural Resources Project Inventory (NRPI). An important component of the grant is the design and implementation of a community outreach effort to contact schools, libraries, local organizations and businesses to increase awareness of the inventory and encourage its use.

The Water Resources Center Archives was also awarded a grant for $7,500.00 from the Librarians Association of the University of California (LAUC). Today there are approximately 1,200 water and irrigation districts in California. However, no comprehensive directory of these districts exists, nor has there been a survey performed to identify what, if any, historical research materials have been created and maintained by these districts. The grant allows the Archives to survey California water and irrigation districts in order to create a comprehensive list of water districts and irrigation districts and to include basic information about each district. At the same time, a survey of these agencies' significant historical documents will be conducted. This information will be compiled and organized in a searchable database that will be available at the Water Resources Center Archives web site.

PUBLICATIONS

The publication and distribution of the results of sponsored research projects are important functions of the Center's program. The various publication categories produced by the Center are:

Contribution Series. Published refereed technical monographs which are generated from Center sponsored research projects;

Report Series. Publications which are less technical and appeal to a wide audience. Examples of the Report Series include the Annual Report, Proceedings of Center-sponsored conferences and symposia, and interpretive summaries of research projects;

Miscellaneous. An unnumbered series of non-technical publications on topics relating to California's water resources development, use and management;

Technical Completion Reports. All Center sponsored projects file a Technical Completion Report (TCR) which is the formal professional summary that covers all elements of the project. Such reports may be reviewed in the Director's Office and in the Water Resources Center Archives on the Berkeley campus. Although unpublished TCR's are not for general distribution, copies will be provided upon request.

Through the office, the Center for Water Resources has filled approximately 80 requests for publications. A total of 1,400 publications (volumes) were distributed worldwide to interested parties both in the public and private sectors. Most of the

Center's publications are available at no charge, and a listing of available publications can be found on the Center's web site (http://www.waterresources.ucr.edu). When the Center's supply of a publication is depleted, the publication can often be obtained from the National Technical Information Service (NTIS) for a fee. Recent Center publications are downloadable from the Center's web site. A complete set of Center publications is available at the Water Resources Center Archives at 410 O'Brien Hall on the UC Berkeley campus. In addition to Technical Completion Reports from sponsored research, the Center produced the following publications during 1999-2000:

- 1999. Water Resources Center Annual Report, July 1, 1998-September 30, 1999. Water Resources Center Report No. 97. 73 p.

- 2000. *Western Watersheds: Proceedings of the Seventh Biennial Watershed Management Council Conference*. Water Resources Center Report No. 98. 160 p.

- 2000. *Distribution, Ecology and Potential Impacts of the Chinese Mitten Crab* (Eriocheir sinensis) *in San Francisco Bay*. Water Resources Center Contribution No. 206. 74 p.

OTHER PUBLIC SERVICE AND INFORMATION ACTIVITIES

The Director of the Center continues to participate in the National Institute for Water Resources (NIWR). The Water Resources Research Institute Program (WRRIP) was established by Congress in 1964 and consists of fifty-four institutes at the nation's Land Grant institutions. The National Institute for Water Resources is a coalition of these institutes organized to collaborate, communicate and network with each other on important water resources issues. The URL for NIWR's web site is http://wrri.nmsu.edu/niwr/. It lists all fifty-four institutes, the programs, events and publications within each institute, and summaries of each institute's research projects.

The institutes have established themselves as a primary link between the academic community and water resources personnel in government and private sectors. Training future water professionals is one of the primary missions of WRRIP. Each year WRRIP-supported projects provide training for more than 100 students nationally. WRRIP also provides the framework for a national network of water researchers, promotes innovative solutions to water-related problems, and encourages a bottom-up approach to water resources problem identification and solution.

Each year the Center submits a report to WRRIP which contains the annual report for each WRRIP-supported project at the Center, all publications and presentations, total students trained by academic level/discipline, and significant accomplishments of the Center.

Direct contact with principal investigators is an important source of information concerning research work. Campus addresses, phone numbers and email addresses of investigators are provided in the Principal Investigator Index section of this report on page 83. Interested readers are directed to individual principal investigators to obtain reprints of journal articles as well as additional information on their research projects.

Many of the research narratives summarized in this report include a list of publications which reflect the principal investigator's research in detail as published in professional and technical journals.

SRA Cindy DeChaine, AAII Melanie Carlson and Student Assistant Marlynn Wauran prepare the first issue of Currents *for mailing.*

Libraries throughout the United States and in foreign countries receive copies of all Water Resources Center publications.

The Center for Water Resources, in collaboration with the Water Education Foundation has developed a quarterly newsletter titled *Currents*. The first,

Summer 2000, edition was mailed to over 3,000 recipients and is available on-line at www.waterresources.ucr.edu. The premier edition was developed to re-introduce the UC, Center for Water Resources' mission and recent achievements. Future editions will focus on research highlights as well as the Water Resources Center, Salinity/ Drainage program and Water Quality program accomplishments.

For instance, a large portion of the Fall 2000 newsletter is dedicated to the many successes achieved by the Archives this past year., including the award of two grants, web site recognition and special acknowledgements in a recently published book.

The Center for Water Resources' has developed a new web site that has garnered approximately 200 visits to date and has enabled visitors to view and download the recent Water Resources Center Call for Proposals 2000, all funded research executive summaries and information on upcoming water-related events, workshops, meetings and water-related funding opportunities.

Research Project Index

California Water Resources Center 1999-2000

Research Category I -- Hydrology, Climatology and Hydraulics

Research Category II -- Aquatic Ecosystems

Research Category III -- Water Quality

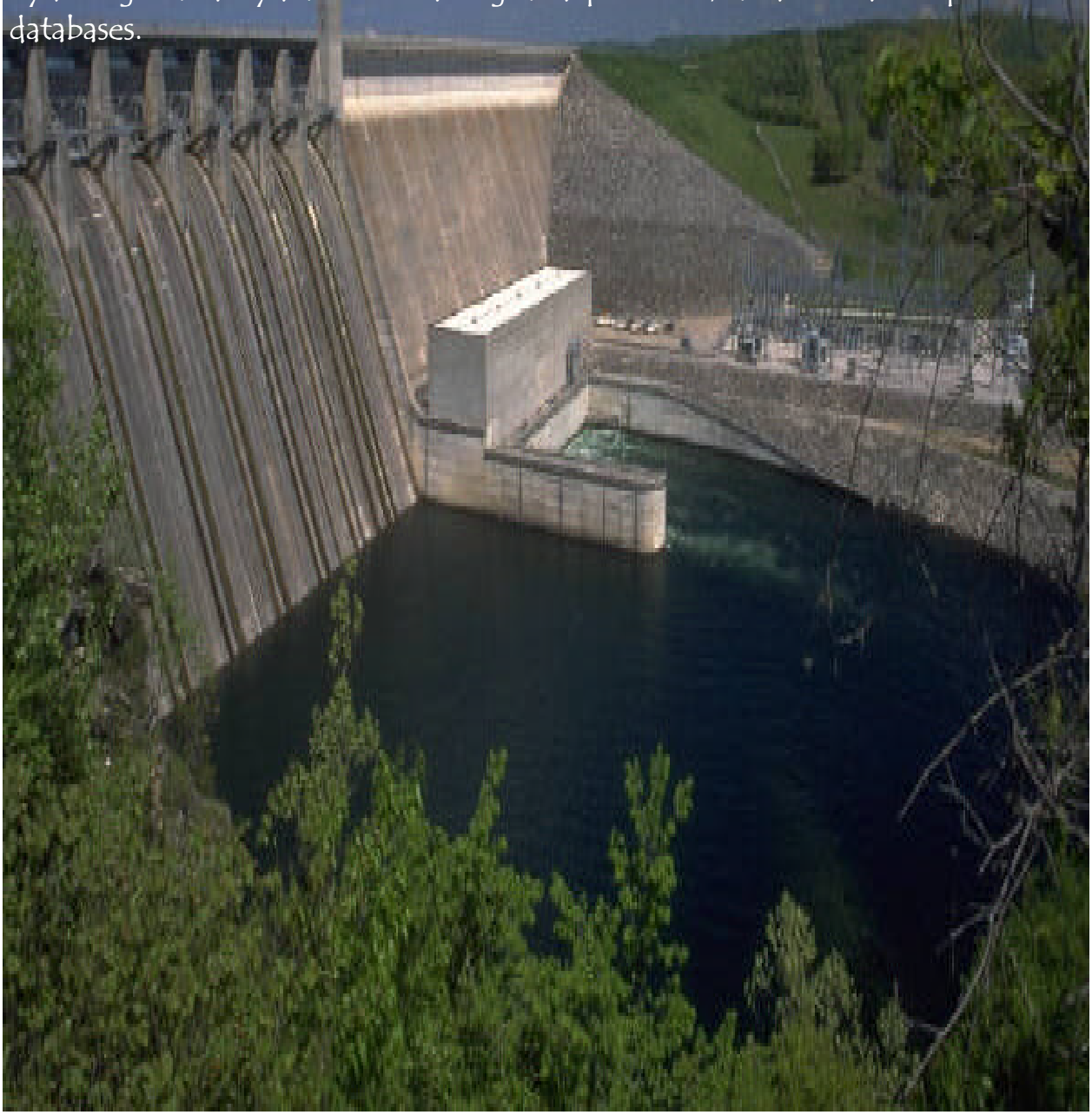
Research Category III -- Water Quality, continued

There are no projects to report this year for Research Category IV--Water Development and Management Alternatives.

Research Category V--Water Law, Institutions and Policy

Research Category I Hydrology, Climatology & Hydraulics

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



Assessment of Intraseasonal Variations in California Rainfall and the Roll of the Madden and Julian Oscillation

Charles Jones
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UC Santa Barbara

Project W-905
July 1998-June 2000

California receives most of its annual precipitation during the winter season, with large spatial contrasts and temporal variations being observed in the total rainfall amounts. Currently there is widespread understanding of the implications of large atmospheric and oceanic anomalies to the economy and society of the state of California. Typical of this awareness, is the high level of public and government concern at the onset of El Niño conditions in 1997. Therefore, thorough documentation and understanding of the spatial and temporal variability of precipitation in California is a key element in developing efficient and successful programs of water resources management and emergency awareness.

Observational evidence of California rainfall shows important variations on interannual and intraseasonal time scales. While the relationships between El Niño events and California rainfall have been investigated in previous studies and is indeed the present focus of several research activities, the mechanisms associated with intraseasonal changes have received much less attention. In the tropical region, the Madden and Julian Oscillation (MJO) (30-60 day variations) is the primary mode of intraseasonal variability. During this research project, we have investigated the occurrence of extreme precipitation events in California and a possible modulation by the MJO. The research accomplishments have been reported in a refereed journal article and several professional meetings.

During the second year of this project, it became clear that a better understanding of local circulations (i.e., mesoscale circulations) are necessary in order to understand the problem of heavy precipitation events in southern California. Local circulations and their interaction with the complex topography play a key role in generating heavy rainfall.

The terrain of southern and central California is one of extremes. For example, Los Angeles County alone is arguably the most terrain diverse county in the Nation. It encompasses the islands of Santa Catalina and San Clemente—20 to 50 miles offshore in the Pacific Ocean, the broad expanses of the L.A. Basin and the San Fernando Valley, the Santa Monica Mountains that reach over 3,000 feet, the San Gabriel Mountains that exceed over 10,000 feet, and the dry and sparsely populated Antelope Valley of the Mojave Desert. Like the terrain, the weather of central and southern California is one of extremes. The complex coastal topography, for example, can induce mesoscale circulations responsible for heavy precipitation. For instance, some of the heaviest 24-hour precipitation totals ever reported in the entire state of California were recorded in southern California. Goodridge (1992) reports 26.12 inches of rain fell in just 24 hours in the San Gabriel Mountains of Los Angeles County in 1943. In fact, the U.S. Department of Commerce (1998) estimates the probable 24-hour precipitation is 38 inches for the mountains in Santa Barbara County, 42 inches for Ventura County and over 48 inches for the mountain ranges of Los Angeles and San Bernardino Counties. Current operational models from the National Centers for Environmental Prediction (NCEP) are of insufficient resolution (30 to 40 km or greater) to accurately capture both the complex weather/terrain interactions and the intense gradients

Key Words

Atmosphere
Models and processes
Rain and rainfall
Climate and climate change
El Nino/La Nina
Floods and flood control
Storms
Water runoff
Weather prediction

of temperature and humidity which are so important in providing daily, critical forecasts for the millions of central and southern Californians.

The P.I. (C. Jones) is currently using high-resolution forecasts produced with the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model 5 Version 3 (MM5-V3). Figure 1 shows the topography resolution for the finest nested grid. The open circles denote the locations of weather stations used to assess the skill of the MM5-V3 precipitation forecasts. The P.I. is currently investigating the mechanisms of extreme rainfall during the El Niño of 1997-1998, which was the strongest El Niño/Southern Oscillation (ENSO) event in the instrumental record. It caused significant climatic anomalies worldwide, especially over North America. Four major storms during that winter season produced individually over ten inches of rain in Southern California—along with extensive flooding. We specifically analyzed the events of 5-6 December, 2-3 February, 6-7 February and 23-24 Feburary 1998. Special consideration is being given to further understand local circulations that are topographically forced and are responsible for extreme rainfall. Figure 2 is an example during 23-24 February 1998. Note the coincident location of maximum precipitation with the highest elevations.

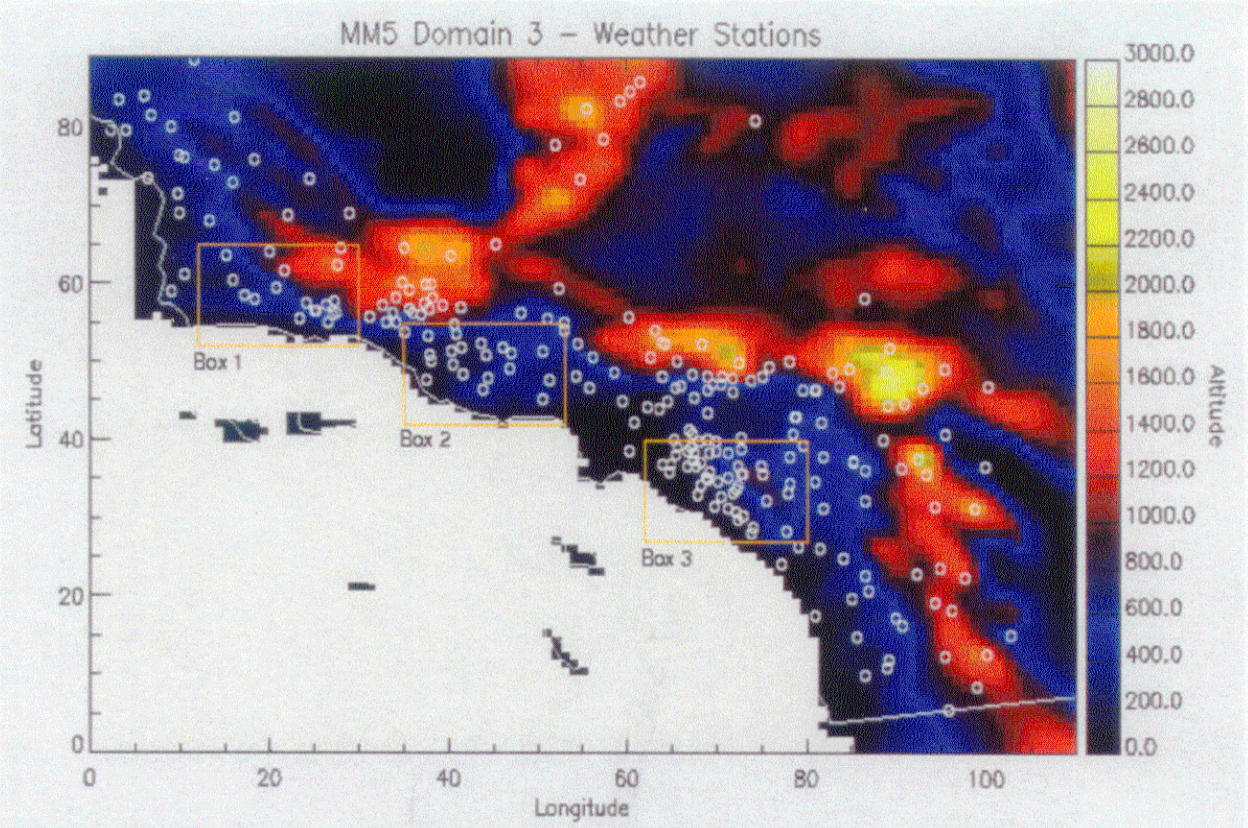

Figure 1. MM5-V3 Domain 3 (4km) and terrain height (m). Open circles donate locations of weather stations used to assess the skill of precipitation forecasts. Boxes 1, 2 and 3 are key regions used to determine the time evolution forecast of synoptic systems moving over Southern California.

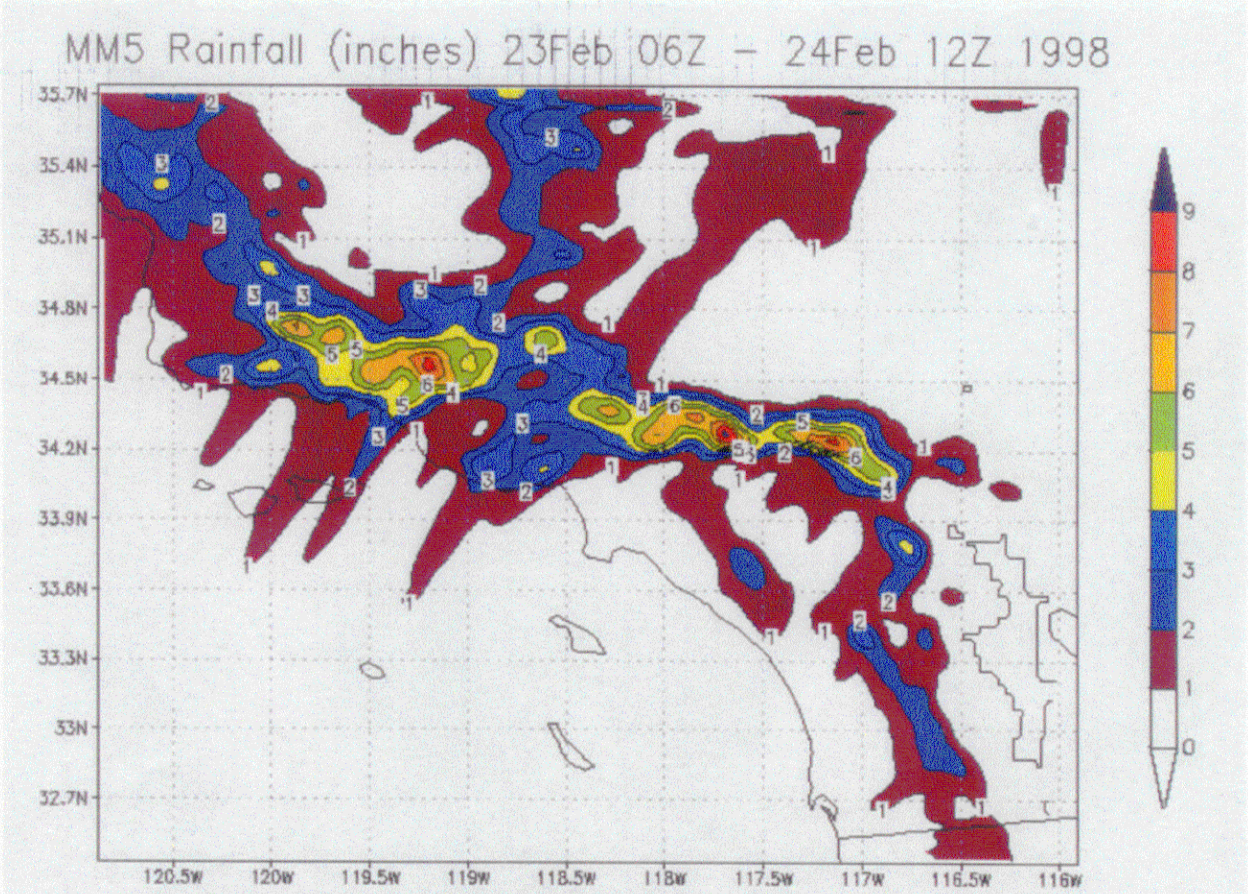

Figure 2. Accumulated 30-hour forecast produced with the MM5-V3 mesoscale model.

Publications and Presentations

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• Jones, C. 1999. Occurrence of extreme precipitation events in California and relationships with the Madden-Julian Oscillation. Proceedings of the *24th Annual Climate Diagnostic and Prediction Workshop*. Tuscon, AZ, 5-9 November, 1999. pp. 363-366.

• Jones, C., M.V. de Carvalho, D. Danielson, B. Bower and D. Gomberg. 2000. Forecast skill of the Penn State/NCAR MM5 mesoscale model during the heavy precipitation event of 23-24 February 1998 in Southern California. In preparation for *Weather and Forecasting*.

Collaborative Efforts

Local circulations and their interaction with complex topography play a key role in generating heavy rainfall. In this context, the funding support from the Water Resources Center has truly served as "seed money" to enlarge the current project. Collaboration with the National Weather Service Office in Los Angeles/Oxnard has been established in order to investigate local circulations and extreme events. A project supported by the Cooperative Program for Operational Meteorology, Education and Training (COMET) has been awarded: *Investigation of Mesoscale Wind Patterns in the California Bight: Influence on Extreme Precipitation Events*. Agency: COMET/UCAR. Period: 12/01/1999-11/30/2000. Amount: $8,088.00. Among other activities, real-time forecasts based on the Pennsylvania State University/ National Center for Atmospheric Research (PSU/ NCAR) Mesoscale Model (MM5-V3) has been fully operational at the Institute for Computational Earth System Science (ICESS), University of California, Santa Barbara. The real-time forecasts proved quite helpful for the forecasters at the NWS Los Angeles/ Oxnard Office during the last winter, given the much finer resolution of the PSU/NCAR MM5-V3 forecasts compared to other operational weather forecast models. MM5 forecasts can be seen at www.icess.ucsb.edu/asr/mm5_forecasts.htm.

Research Staff

Ph.D. Student
Ms. Valerie Olson
(was originally involved with the project, but has since left the graduate program for personal reasons.)

Mitigation of Extreme Flooding Events by Optimal Control of Flood Plain Storage using the Adjoint Sensitivity Method

Brett F. Sanders
Civil & Environmental Engineering
UC Irvine

Project W-908
July 1998-June 2000

Inland flooding resulting from excessive precipitation and subsequent surface runoff has caused millions of dollars in damage to the State in recent years. Historical land management practices, notably the development of flood plains, have magnified the financial risk associated with flooding particularly in the Central Valley of California where urbanization continues at a rapid pace.

Flood control strategies have historically been to design facilities, including reservoirs and levee systems, to convey a design flood such as the 100-year flood and to prevent the inundation of the flood plains. For floods with peak discharges less than design capacity of a system, performance has been good. However, mitigation efforts for larger floods have failed. Flooding damage that occurred in the Sacramento and San Joaquin Valleys during the winter of 1997 is evidence of inherent physical limitations.

This research project seeks a control procedure to mitigate extreme flooding events. The control procedure includes a control action to create depression waves in open channels, an adjoint sensitivity algorithm to seek control actions that minimize the peak stage of a flood wave at a target location.

Relationship between river stage, flood discharge, channel size, flood plain storage capacity and flood water diversion rates have been characterized and optimal strategies to mitigate floods using deliberate levee breaches have been identified.

Using a non-oscillatory, high-resolution, two-dimensional finite-volume algorithm in generalized coordinates that was developed by the PI to solve the shallow-water equations and to subsequently describe the wave action resulting from the control action, design attributes of the optimal levee breach have been identified. Design attributes include the levee breach size, flood plain area necessary for storage, and breach timing. These can now be predicted based on the discharge of the flood, period of the flood, and dimensions of the channel.

By carrying out simulations of levee breaches and performing suitable scaling transformations, universal properties of a breach design have been identified that lead to a simple, straightforward approach to design levee breaches for flood mitigation.

Publications and Presentations

• Sanders, B.F. and N.D. Katopodes. 1999. Active Flood Hazard Mitigation Part II: Bidirectional Wave Control, *ASCE Journal of Hydraulic Engineering*, 125(10), pp. 1071-1083.

• Sanders, B.F. and D. Jaffe. 1999. Mitigation of Extreme Flooding Events by Tactical Depression Wave Control, Proceedings of the 1999 International Water Resources Engineering Conference, Seattle, WA. (CD ROM)

• Sanders, B.F. (to appear). High Resolution and Non-Oscillatory Solution of the St. Venant Equations in Non-Rectangular and Non-Prismatic Channels. *Journal of Hydraulic Research.*

Key Words

Floods and flood control
Fluid flow and mechanics
Mathematical models
Optimization

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• Sanders, B.F. and S.F. Bradford (to appear). High Resolution, Monotone Solution of the Adjoint Shallow-Water Equations, *International Journal of Numerical Methods in Fluids*.

• Jaffe, D. and B.F. Sanders (in review). Engineered Levee Breaches for Flood Mitigation, *ASCE Journal of Hydraulic Engineering.*

• Bradford, S.F. and B.F. Sanders (in review). Finite Volume Model for Shallow Water Flooding and Drying of Arbitrary Topography, *ASCE Journal of Hydraulic Engineering.*

• Sanders, B.F. and D. Jaffe (presented). 1999. Mitigation of Extreme Flooding Events by Tactical Depression Wave Control. Presentation given at the International Water Resources Engineering Conference, August 8-12, Seattle, WA.

Collaborative Efforts

The WRC grant has been instrumental in generating additional support for research. In the past year, I received a grant $895,234 over three years) from the NSF/EPA/USDA Water and Watersheds program to carry out a multi-disciplinary research project aimed at characterizing, controlling, and managing the impact of urban runoff on coastal water quality. With the support of the WRC, I was able to develop the theoretical basis necessary to propose the use of adjoint methods for optimal mitigation of hazards posed by contaminants in urban runoff. I also received a CAREER award from NSF ($200,000 over four years) in the past year to research the extension of adjoint methods, developed for hydrodynamic sensitivity analyses, to transport problems.

Research Staff

David Jaffe has earned an M.S. degree in Environmental Engineering (2000) and is now pursuing a Ph.D. degree with the support of this grant.

Study of Groundwater Dynamics in the Kern Alluvial Fan, California

Project W-915
July 1999-June 2001

Jordan Clark
Geological Sciences
UC Santa Barbara

The primary objective of this study is to evaluate groundwater flow near the Kern Water Bank (KWB) using an interdisciplinary approach which combines geochemical tracers and numerical model simulations. The KWB is located in the Kern River Alluvial Fan at the southern end of the San Joaquin Valley, Kern County, California. Since the end of the late 1980s—early 1990s drought, approximately one million acre-feet of surface water has been recharged into the shallow aquifers at the KWB. This water will be stored in the ground and will be used in the future during periods of water shortages. Understanding how fast and where this water migrates is fundamental to managing the recharge operation and designing future pumping plans. These issues concerning groundwater flow and groundwater management will be addressed in this study.

In January 2000 we collected our first set of groundwater samples from ten locations in the KWB. At each location, samples were collected from two monitoring wells that had different screen depths. The samples were analyzed for general chemical characteristics (anions, cations, pH, alkalinity, dissolved oxygen), for stable isotopes of water ($\delta^{18}O$ and δD), and for chlorofluorocarbons (CFC-11 and CFC-12). The initial results indicate that relatively young groundwater (15 years old or younger) is found in the northern and central areas and older water(most of it is greater than 50 years old and has CFC concentrations less than 0.02 pmol/l) occupies the southern portion of the Water Bank. (The groundwater age is defined as the amount of time the water parcel has been isolated from the atmosphere or soil air. Hence, this represents the amount of time since recharge.) At the same location, the deeper groundwater is always older. These findings are consistent with the recent recharge history at the KWB which indicates that most of the groundwater banking has occurred in the northern spreading basins. We also found a weak ($R^2 = 0.45$) but significant correlation between nitrate concentration and groundwater age. The younger waters had more nitrate than the older. Although this interesting finding might be linked to denitrification processes in the aquifer, most likely the correlation exists because the groundwater bank is recharging higher nitrate surface water. We will look at historical data to determine if there is a temporal trend in nitrate concentrations at most wells.

A hydrogeological model of the KWB is being constructed using Visual MODFLOW. The model is composed of three layers, representing the aquifer structure and permeability. Each layer is built on a 58 columns, 41 rows system consisting of 2051 active cells ranging in size from 40-140 acres. The model is currently built with hydraulic conductivity, porosity, monitoring wells location and boundary conditions. We are in the process of entering the initial groundwater surface (Jan. 1994), recharge history at KWB, and pumping rates at both public supply and irrigation wells. We anticipate having a working model by the end of the summer 2000. We will perform a second sampling phase at the Kern Water Bank in August 2000 at which time we will share our chemical data set with the KWB and local water agencies.

Collaborative Efforts

As a result of the funded work, Dr. Clark was funded by the Littlerock Creek Irrigation District to study the dynamics of groundwater flow associated with their recharge program on Little Rock Creek. The award totaled $37,000.00.

Key Words

Groundwater banking
Tracers
Chloroflourocarbons
Groundwater modeling
Kern Water Bank

Research Staff

Master's Student
Laurent Meillier, Geology

Undergraduate Student
Jeff Gamlin, Geology

A Stochastic Sediment Supply Model for a Mountainous, Semi-Arid Landscape

Thomas Dunne
Geological Sciences
UC Santa Barbara

Project W-917
July 1999-June 2001

We are investigating the delivery of sediment from hillslopes into channels by directly linking climatic events (including fires) with sediment transport processes. Watersheds in semi-arid regions are subject to a variety of disturbances, including grazing fires, and vegetation cover changes and our goal is to determine how these disturbances affect the magnitude, frequency and spatial distribution of sediment delivery processes. Sediment loading from hillslopes can have an impact on a range of concerns in Southern California and other sub-humid, mountainous environments around the U.S. and the world. First of all, as the urban fringe continues to climb higher into the surrounding foothills and mountains, the potential loss of life and property from geological hazards such as runoff and debris flows will escalate. Secondly, the delivery of fine-grained sediment from hillslopes is a major contributor to nonpoint source pollution. As population centers expand, the issue of water quality for both human consumption and riverine ecosystems will only increase through time. Finally, since many dams in sub-humid mountainous areas around the world would have their storage capacity reduced by sedimentation, efforts are being made to estimate their useful lifespan as well as to increase their useful lifespan. Because hillslopes are the main source of sediment to rivers in sub-humid, mountainous landscapes, the ability to forecast this sediment loading is critical.

Sediment transport processes can be broadly divided into two categories: catastrophic and chronic. Catastrophic processes are those rare but large events, such as **landslides**. During the 1998 El Niño, our fieldsite was hit with record rainfall and over 100 landslides were triggered, delivering large pulses of sediment to the fluvial system. We have mapped all of the landslides and surveyed a subset of them to estimate volumes of sediment evacuated. An important initial result from this work is that there were nearly twice as many failures on hillslopes that had been converted to grassland than on hillslopes with coastal sage.

During the past year of fieldwork, we have identified and quantified several chronic (i.e., high frequency, low magnitude) sediment transport processes. First of all, we have built a portable rainfall simulator capable of sprinkling a 15 m^2 plot to study sediment transport by surface runoff (**sheetwash**). Numerous rainfall experiments on different plots and under different vegetation covers have allowed us to calibrate an equation for predicting sediment concentration in sheetwash. Second, over time, sediment mobilized by various processes accumulates behind vegetation and ground litter on steep slopes. When these burn during a fire, the sediment is released and moves downslope as **dry ravel**. Following a single fire, this process has been observed to fill entire stream channels with sediment. In anticipation of a prescribed burn adjacent to our field site, we installed a series of sediment traps to measure rates of post-fire dry ravel and to relate them to hillslope gradient. Finally, we have also measured the rate of sediment transport by animals (e.g., burrowing), an important but often overlooked process. Rates of this process, **bioturbation**, are approximately 1,000 times higher on grassland slopes than on coastal sage scrub. In fact, initial results suggest that bioturbation by gophers may be the most dominant sediment transport process.

Key Words

Stochastic climate
Sediment delivery
Landslide
Sheetwash

The sediment transport equations from the fieldwork are being incorporated into a computer model. This model is driven by randomly chosen rainstorms and fires and predicts the delivery of sediment from the processes mentioned above. The model also performs a slope-stability analysis to determine whether a landslide would be triggered and, if so, delivers a large pulse of sediment. The output of the model is the amount of sediment that enters the channel network from each hillslope process.

Publications and Presentations

• Gabet, E.J. Gopher bioturbation: Field evidence for nonlinear hillslope diffusion. *Earth Surface Processes and Landforms*. In review.

• Gabet, E.J. Surface coarsening and nonlinear hillslope diffusion by dry ravel. *Catena.* In review.

• Gabet, E.J. and T. Dunne. 1999. Sediment transport by overland flow: Field experiments and modeling results. *EOS Transactions AGU,* 80(48), Fall Meeting Supplement F301.

Collaborative Efforts

We have joined forces with an ecologist who is interested in nutrient fluxes through overland flow. Together, we have submitted a proposal to the USDA to extend the research that we have begun with the California Water Resources grant.

Research Staff

Ph.D. Student
Emmanuel Gabet

Three graduate students

Understanding and Predicting Seasonal-to-Interannual Fluctuations in California Precipitation Using an Atmospheric General Circulation Model

John D. Farrara and Jin-Yi Yu
Atmospheric Sciences
UC Los Angeles

Project W-918
July 1999-June 2001

The water supply in California is subject to large variations on a variety of timescales ranging from intraseasonal to decadal. This variability has been clearly evident during recent years with extremes that include both the abundant supplies during 1983, 1986, 1993, 1997-98 and the multi-year drought of the 1987-1992. The primary sources of water in California have their origins in precipitations associated with winter storms originating over the North Pacific Ocean. Thus, the variability in the frequency and intensity of winter storms is a major cause of variations in water supplies. It is known that a significant amount of the interannual variability in the Pacific storm track is related to variations in sea surface temperatures in the tropical eastern Pacific Ocean—El Niño and La Niña events. However, the response in California precipitation varies from event to event and extreme events such as the flood of January 1997 can occur even when tropical Pacific sea surface temperature anomalies are weak, suggesting that other mechanisms may be important. The natural variability of the Pacific storm track is one such possible mechanism. Our research uses numerical models of the global atmosphere to better understand the relative importance of these different mechanisms in producing variations in California precipitation.

The research completed in the first year suggests that tropical Indian Ocean sea surface temperature anomalies, which have previously been considered unimportant, can in some cases have a significant impact on the Pacific storm track. This suggests the potential usefulness of sea surface temperature forecasts for the tropical Indian Ocean. We have also put our evolving understanding to the test in a modest precipitation prediction exercise for winter 1999-2000 (for details see *www.unilab.atmos.ucla.edu/~vwk206/fest00.html*). For this exercise, we had available predictions of sea surface temperature for the tropical Pacific Ocean only. For future exercises, we hope to include predictions for the tropical Indian Ocean as well. The research being performed is advancing our understanding of the physical mechanisms at work for the observed intraseasonal and interannual variations in California precipitation. The advances in potential prediction skill developed as part of this research will make a significant contribution to California water resource and emergency planning.

Publications and Presentations

• Farrara, J.D., A.W. Robertson and C.R. Mechoso. 2000. Ensembles of two-tier simulations and predictions of the circulation anomalies during winter 1997-98. *Mon. Wea. Rev.*, in press.

• Farrara, J.D., A.W. Robertson, C.R. Mechoso and N. Hall. 1999. Understanding the influences of tropical SST [sea surface temperature] anomalies on precipitation in the western United States. Presentation at the 24th Climate Diagnostics and Prediction Workshop, November 1-5, 1999. Tuscon, AZ.

Key Words

California water supply
Rain
Snow
Drought
Flood
El Nino
Numerical modeling of the atmosphere
Seasonal-to-interannual prediction

Collaborative Efforts

The research enabled by this grant was a factor in the success of our recent proposal to the National Oceanographic and Atmospheric Administration's Pan-American Climate Studies/GCIP Program on warm season precipitation. The three-year proposal, entitled *Interannual Variability of the North American Monsoon and Its Impact on Summer Precipitation Throughout the United States* was funded in the amount of $244,600.

Research Staff

M.S. Student
Ying-Teng

Evaluation of the Effects of Surface Water and Groundwater Interactions on Regional Climate and Local Water Resources

Xu Liang
Civil & Environmental Engineering
UC Berkeley

Project W-922
July 1999-June 2001

The study of interactions between groundwater and surface water over large scales and their effects on regional climate and local water resources has received notably less attention than the studies of the land-atmosphere interactions and the groundwater-surface water interactions over small scales (e.g., hill-slope scale). However, the groundwater and surface water interactions over large scales play a significant role in the hydrological system, water quality, and land-atmosphere interaction studies. For example, the interactions are closely related to the state of soil moisture which plays an important role not only in the energy and water balances in the land-atmosphere system, but also in the drought and flooding, the water resources management, ecological system, and water quality studies.

The goals of this study are to improve our understanding of the interactions between surface water and groundwater hydrology over large scales for moist, semi-arid and arid regions within the context of regional and local climate systems; to understand the two-way effects of the groundwater-surface water interactions on the regional climate and local water resources; to improve the performance of land surface schemes over arid and semi-arid regions; and ultimately, to improve the water quality assessment and water resources management with the considerations of the influence of the local and mesoscale circulations, and the groundwater-surface water interactions.

To achieve our goals, we developed, in the first year, a method that can represent the position of the water table dynamically (i.e., water table position as a function of time) for large spatial scales so that the process of groundwater-surface water interactions can be effectively described. Our new methodology includes newly formatted partial differential equations for the problem that facilitates the solution of a dynamic movement of the water table, a mass-lumped finite element method that can avoid the oscillations in soil moisture, and a new strategy that computes soil moisture distribution first and then the water table position iteratively at each time step. The oscillations in soil moisture can cause negative soil moisture values if the traditional finite element method is used [Xie, et al., 1998] instead of the mass-lumped method employed in this study. In addition, the literature has shown that the dynamic solution of the water table position with numerical methods remains a challenge because of large oscillations associated with the solution of water table in the traditional finite element method unless the time step is very small and the number of soil layers is very large. However, our newly developed method allows, from the numerical point of view, a reasonably small number of soil layers (e.g., ten layers for a 5m deep soil layer). Also, the requirement of time step is much less rigid. We used a time step of one hour in our current studies. At present stage, the method only applies to one-dimensional cases which will be relaxed to the case for large spatial scales in the second year. To deal with the subgrid variability which occurred at large spatial scales, the general approach of nesting a high resolution of hill-slope scale groundwater processes into a land-atmosphere system will not be used. Instead, we will deal with the spatial subgrid variability associated with the coarse resolution of the land-atmosphere system by

Key Words

Dynamic interactions between surface water and groundwater
Large spatial scales
Water resources management
Water quality assessment

parameterizing relevant processes. The main advantages of developing the groundwater processes at compatible grid resolutions with the land-atmosphere system versus the nesting technique are to facilitate the representation of groundwater-surface water interactions over large scales, to avoid many detail accurate data requirement at finer spatial scales, and to significantly save computer resources. At present, we are compiling data at different locations for groundwater wells, precipitation, air temperature, and streamflow to test our method with observations for I-D case.

It is expected that the research results from the proposed study will shed light on the water resources management for arid and semi-arid areas, the understanding of effects of regional climate on local groundwater and surface water interactions and better assessment of water quality.

Research Staff

Zhenghui Xie

Soil Water Monitoring Using Geophysical Techniques: Development and Applications in Agriculture and Water Resources Management

Yoram Rubin
Civil and Environmental Engineering
UC Berkeley

Project W-929
July 1999-June 2001

Monitoring of soil water content is a vital component for agriculture and ecological programs, and the key component for rational water resources management. The information obtained from monitoring is critical for optimizing crop yields, achieving high irrigation efficiencies, planning irrigation scheduling, and minimizing lost yield due to waterlogging and salinization. Such water content monitoring is also important for addressing issues of water quantity and quality, both relevant for managing the environmental impacts of irrigated agriculture and for protecting functional ecosystems. Leaching of agrochemicals and salts into the groundwater and downstream ecosystems, for example, can be minimized if irrigation water infiltrates only to the bottom of the root zone. High resolution, continuous water content distributions allow one to design optimal irrigation and chemical application programs that make possible such "prevention at the source." No current technique can provide such information quickly, reliably, and at low cost. Our funded proposal focused on investigating the applicability of a surface geophysical method, ground penetrating radar (GPR), for use as a water content estimation tool; development of such a tool could lead to increased water savings and better control on the ecology of natural vegetation.

The first pit experiment suggested that surface GPR is indeed a viable technique for obtaining precision volumetric water content profile estimates and that laboratory-derived petrophysical relationships could be applied to field-scale GPR data at this site. However, there was little error associated with the depth of the reflector, superposition of events prevented us from using the data from the ground surface (zero-time) to the reflectors, and the test pit was quite homogeneous in texture and moisture content compared to natural sites. To extend the testing of the GPR method, field experiments have been performed under both controlled conditions (pit tests) and under natural field conditions (Robert Mondavi site). Although the data collected at both the test pits and the Mondavi site are still under investigation, these experiments are helping to illuminate the potential and limitations of the GPR method under variable saturation and soil texture conditions, under realistic field conditions, and by using different reflectors (artificial and natural) for analysis. Preliminary analysis suggests that the proposed GPR method has the capability of providing much more detailed information about soil water content variations than the previously tested EM

Publications and Presentations

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• Hubbard, S., K. Grote and Y. Rubin. Development of GPR Techniques to Non-Invasively Measure Subsurface Water Content, Earth Science Division LBNL Annual Report, 2000.

• Grote, K., S. Hubbard, A. Lawrence, J. Harvey, M. Riemer, J. Peterson and Y. Rubin. Non-destructive Monitoring of Sub-Asphalt Water Content Using

Key Words

Soil water
Monitoring
GPR
Ground Penetrating Radar
Agriculture
Water resources management

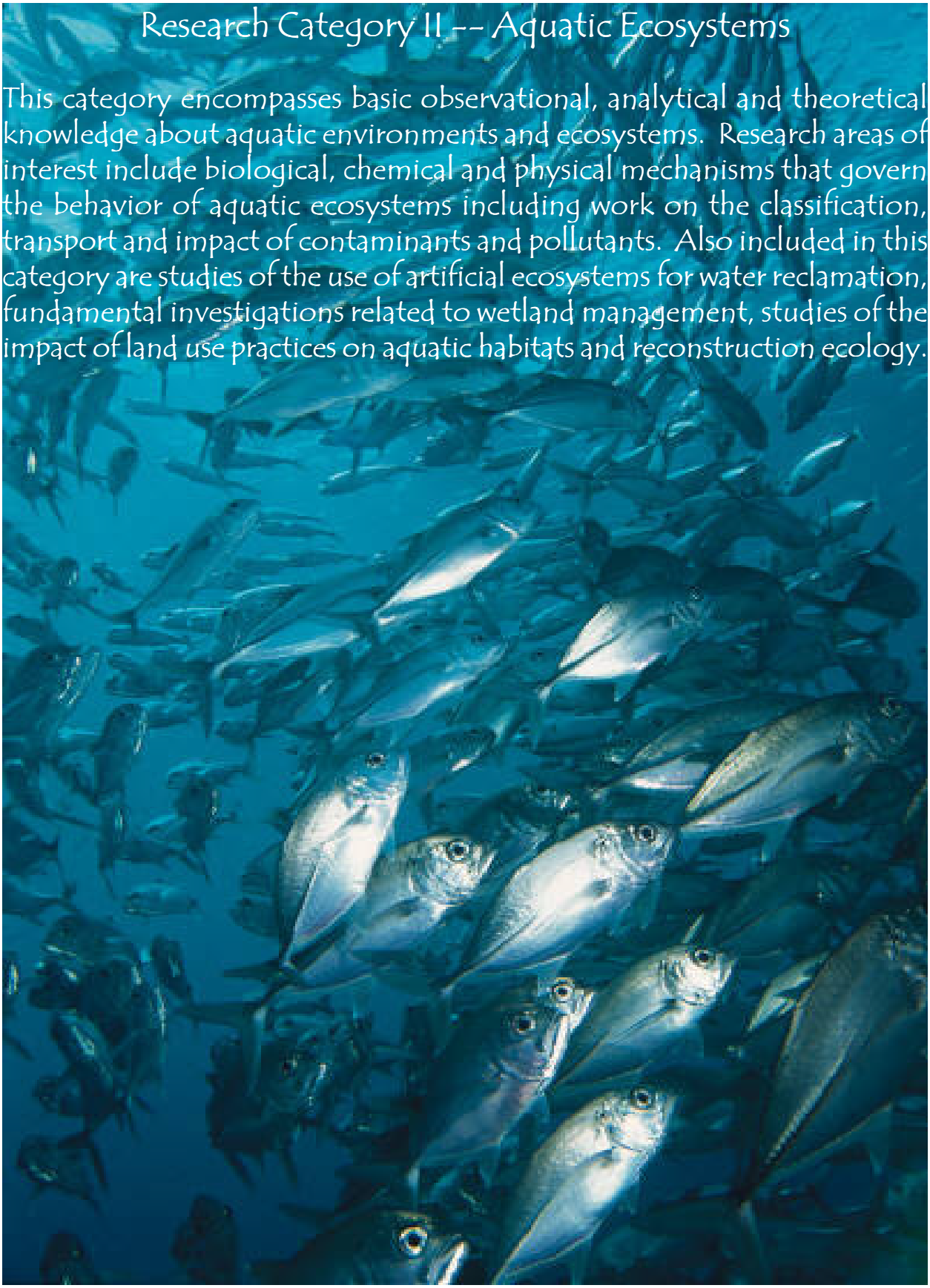
Surface Ground Penetrating Radar Techniques. EOS 80(46), PF291, 1999.

Research Staff

The work described in this report was conducted with the aid of several graduate students: **Katherine Grote, Alison Lawrence and Mike Kowalsky**. Additional help was provided for short periods of time, by graduate students from the Institute of Transportation Studies, which is located at the Richmond Field Station.

Research Category II -- Aquatic Ecosystems

This category encompasses basic observational, analytical and theoretical knowledge about aquatic environments and ecosystems. Research areas of interest include biological, chemical and physical mechanisms that govern the behavior of aquatic ecosystems including work on the classification, transport and impact of contaminants and pollutants. Also included in this category are studies of the use of artificial ecosystems for water reclamation, fundamental investigations related to wetland management, studies of the impact of land use practices on aquatic habitats and reconstruction ecology.



Impacts of Altered Hydrologic Regimes on Carbon Isotope Signatures in Food Webs Supporting Salmonids in Northern California Rivers

Mary E. Power
Integrative Biology
UC Berkeley

Project W-906
July 1998-June 2000

In attempting to reconcile management of California rivers for water and fish production, we need to understand impacts of flow regulation on fish and food webs that support them. Isotopic tracers, specifically $\delta^{13}C$, have been shown to be useful indicators of small scale habitat affinities (riffle versus pool associations) of algae and invertebrates in algal-based food webs supporting fish in certain productive rivers in the Eel River drainage (Finlay et al., 1999 Limnology and Oceanography). We are expanding our study of natural spatial variation in stable carbon isotopes to examine the food web impacts of altered hydrologic regimes. Because algal $\delta^{13}C$ varies with current velocity and inorganic carbonic source, and because this variation in ^{13}C is passed up the food chain so that consumers exploiting food sources from different habitats can be distinguished, we can use ^{13}C as a tracer to indicate the importance of food production in tributary streams, and pool versus riffle habitats of larger rivers for fish and invertebrate consumers. Natural (climate related) or human-caused change in discharge will modify the relative proportions and spatial and temporal distributions of low (pool) and high (riffle) velocity habitats in channels. We are combining field surveys of isotope distributions among food web members with hydrologic habitat mapping to assess how various discharge regimes will influence spatial patterns in energy flow through river food webs.

Publications and Presentations

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Key Words

Isotopic tracers
Salmonids
River food webs
River-watershed exchange

Research Staff

Post-doctoral:
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Adrianna Smyth (partial support)
Camille McNeeley (partial support)
John Sabo (partial support)

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Sapna Khandwala
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Life History Strategies of California Native Wetland Plants: Implications for Wetland Creation and Restoration

Eliska Rejmankova
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UC Davis

Project W-907
July 1998-June 2000

Wetland plants have been recognized as one of the crucial components of wetland ecosystems. The plants not only provide critical habitats for waterfowl and other biota, they have also been shown to perform essential functions in wastewater treatment processes. The flora of marshes of the California Central Valley is quite species rich. Yet most constructed wetlands in this region (as in other parts of the world) are species poor.

Wetland managers are often faced with difficulties in plant species selection. Their goal is to select plant species that would best fit their particular goals whether it is a wastewater treatment, wildlife refuge or a waterfowl habitat. Often, the wrong plant species are selected resulting in a species conversion to one dominant monoculture and loss of biological diversity. More information is necessary about each of these individual species in order to determine their specific role in a wetland community. In order to evaluate the role of plants in different ecosystems, specific traits that determine the functions of plants in their communities need to be identified. One example of a function is primary productivity; a trait responsible for this function is the size of the photosynthetic area. Other traits include dispersal ability, growth plants or functional groups of plants can then be selected for specific projects. Additionally, this information could potentially be applied in simple predictive ecological models.

We have evaluated functional traits for 34 wetland species. Preliminary classification resulted in delineation of four functional groups: (1) Fast growing perennials, (2) Fast growing, mostly non-native annuals, (3) Slow growing native annuals, and (4) Slow growing native perennials. Before the completion of the project, we will add habitat value to each group. A summary of specific traits will be provided for each species/functional group on a species information sheet. This will allow wetland managers easy orientation in which species would be particularly suitable for their goals. For example, if a rapid colonization of a newly created wetland area is a goal, plants from the first functional type would be a proper choice.

The first group consists of primarily perennial species with light seeds, low L (L = the time in days between the sowing of the seeds and the commencement of germination) and high germination percentages (Ex: *Lepidium latifolium, Epilobium ciliatum, Cyperus eragrostis*, etc.). A second group consists of primarily (obiligate) annual introduced species that have light seeds, low L values, and high germination percentages. They also have high RGR (relative growth rate) and SLA (specific leaf area) values (Ex: *Echinochloa crus-galli, Lythrum hyssopifolium, Polypogon monspeliensis*, etc.). A third group consists of native (facultative) annual species that have heavy seeds, high L and t_{50} (time to 50% germination) values, and low germination percentages (Ex: *Polygonum* spp. and *Conium maculatum*). The fourth group consists of native perennial species that have heavy seeds, high L and t_{50} values, and low RGR and SLA values (Ex: *Scirpus* spp.). The PCA (Principal Component Analysis) performed on 34 species showed similar trend with germination percentages, t_{50} and L values the primary axis and annual/perennial the secondary axis.

Key Words

Wetlands
Aquatic plants
Plant growth and productivity
Species distribution
Life history strategies
Wetland construction and restoration

Publications and Presentations

An M.S. thesis is being written.

Research Staff

One M.S. student

One undergraduate assistant

Sources of Inorganic Nitrogen Utilized by Salt Marsh Macroalgae; Identification Using Stable Nitrogen Isotope Ratios

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UC Santa Barbara

Project W-923
July 1999-June 2001

Nutrient availability can control the rate of algal production in estuarine systems. Surface runoff entering estuaries from adjoining watersheds is frequently nutrient-enriched. Identifying the source of nitrogen used by macroalgae during bloom events is critical to determine the extent to which the ecology of coastal wetlands is coupled to land use in the watershed. Data from tracer studies, together with information on nutrient loading and variation in macroalgal biomass, may provide strong evidence for coupling between anthropogenic nitrogen inputs and blooms of macroalgae in coastal wetlands. A tracer may also provide evidence of the extent to which marsh food webs are influenced by anthropogenic nitrogen inputs.

The overall objective of this project is to investigate the potential of stable nitrogen isotope ratios to trace the utilization of fertilizer-derived nitrogen by salt marsh macroalgae. The stable nitrogen isotope ratio is a measure of the relative abundance of the two naturally occurring isotopes of nitrogen (^{14}N and ^{15}N). This study is being conducted in Carpinteria Salt Marsh, a component of the UC Natural Reserve System, and in the drainages entering the marsh.

To determine the stable nitrogen isotope ratios of nutrient sources in the watershed and relate these values to adjacent land use, water samples were collected from all significant sources of runoff entering two channelized creeks through side drains. Nutrient concentration and isotopic data were superimposed on land use maps, constructed as part of this project, to identify point source inputs. Nitrate nitrogen concentrations in the effluent varied with adjacent land use and were highest (up to 20,000 µM) adjacent to greenhouse development. The stable nitrogen isotope ratio ($\delta^{15}N$ value) of nitrate in this effluent was low (-4.7 to 0.5 ‰) and characteristic of fertilizer-derived nitrogen.

$\delta^{15}N$ values of nitrate-N in surface runoff entering the marsh varied among six drainages; low values (~2 ‰) in the two creeks were associated with point source inputs (greenhouses) while high values in smaller artificial drainages (up to 15 ‰) were not associated with point sources and may indicate the seepage of perched groundwater into channels. The similarity between the $\delta^{15}N$ values of nitrate and *Enteromorpha clathrata* from the upper reaches of marsh channels indicate that this macroalga is assimilating fertilizer-derived nitrogen.

To date, stable nitrogen isotope ratios appear useful in tracing the assimilation by marsh macroalgae of fertilizer nitrogen originating from greenhouse development. Stable nitrogen isotope ratios may also be useful in identifying contributions of nitrate from perched groundwater to surface runoff. Stable nitrogen isotope ratios of ammonium-N in marsh pore water are being determined and will be used in a simple mixing model to estimate the relative contribution of regenerated nitrogen versus fertilizer-derived nitrogen to macroalgal growth in restored portions of Carpinteria Salt Marsh that receive runoff from greenhouse agriculture.

Key Words

Nutrients
Nitrogen
Nitrate
Watershed
Macroalgae
Enteromorpha
Salt marsh
Estuary
Nitrogen isotopes

Publications and Presentations

• Data from this study are included in a poster entitled, "Introducing the new Santa Barbara coastal system LTER" presented at the LTER All Scientists Meeting in Snowbird, Utah, August 2-4. Reed, D.S., S. Cooper, S. Gaines, J. Melack and M. Page, authors.

• Data from this study were incorporated into the Carpenteria Valley Greenhouse Program, Final Environmental Impact Report, Santa Barbara County.

• Court, David and Henry M. Page. "Nutrient inputs into a southern California estuary: Links with land use in the coastal plain". *Journal of Environmental Quality*, submitted.

Collaborative Efforts

Data from this study were incorporated into a grant application to the EPA to establish a "Center for Wetlands Studies" at UC Davis and UC Santa Barbara. This proposal has successfully passed technical review and will be reviewed for relevancy in the near future.

Data from this study are also being used in the Santa Barbara Channel LTER program to design long-term monitoring of runoff from the Carpenteria watershed into the marsh and coastal ocean.

Research Staff

Graduate Student
David Court

Undergraduate Students
Michael Henry
Jason Clapper
Mario Mirabello

Habitat Features and Aquatic Health: Evaluating California s Stream Bioassessment Procedure in Natural and Artificial Streams in a Grazed Eastern Sierra Valley

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Agronomy & Range Science
UC Davis-UC Cooperative Extension

Project W-925
July 1999-June 2001

This research explores a central question in the development and use of macroinvertebrate-based stream bioassessment procedures: to what extent do habitat features, particularly those which respond linearly to human activities (e.g., bank and riparian features), correlate with "healthy" aquatic biota? A second, but equally important question, is whether macroinvertebrate-based stream bioassessment procedures designed for citizen monitoring in fact provide any information about water quality and aquatic health beyond what could be obtained using simple chemical parameters and visual stream assessment methods. We approached these questions by examining macroinvertebrate communities in 15 natural and manmade streams flowing through Bridgeport Valley in the eastern Sierra. A total of 30 sites were selected and established, and observers also rated the sites using the Natural Resource Conservation Service (NRCS) Visual Stream Assessment Procedure, the EPA's Rapid Bioassessment Protocol's Habitat Assessment, and the Proper Functioning Condition method initially developed by the Bureau of Land Management. Additionally, temperature loggers were placed upstream and downstream of each site, and staff gauges were installed at strategic flow control points to monitor variations in water depth (and by implication, velocity). Macroinvertebrates were collected at each site in August of 1999, using the methods established by the California Department of Fish and Game's Stream Bioassessment Procedure for Citizen Monitors, and bank surveys for fish were conducted. During the winter and spring of 2000, samples were cleaned, sorted, and identification and cataloguing of macroinvertebrates began. Data analysis will occur after the second season of sampling. During the summer of 2000, collections of macroinvertebrates and assessments of sites will be repeated at 20 of the sites used in 1999 to evaluate inter-annual variability.

Publications and Presentations

• Linda Vance has presented summaries of the research approach and design to the Walker River Basin Authority Committee (July, 1999), to the Walker River Technical Advisory Network (February, 2000) and to the University of California Rangeland Watershed Workgroup (April, 2000).

• Carol Vance gave a demonstration and presentation to a group of Eastern Sierra K-12 teachers during an "Ag in the Classroom" professional development workshop in August, 1999, and to a 7th grade class in Bishop, CA in January, 2000.

Collaborative Efforts

This grant has been instrumental in helping us establish and broaden water quality research in the Eastern Sierra north of Tioga Pass, where little research has been done before. The North Mono County Resource Conservation District and the Bridgeport Ranchers' Association supported a separate assessment program in 1999, focusing on nutrient loading in streams, and the U.S. Forest Service has joined the effort for 2000. These two

Key Words

Bioassessment
Aquatic Biota
Water Quality
Riparian
Macroinvertebrate
Eastern Sierra
Aquatic Health

projects, undertaken by Linda Vance, will give a broad evaluation of water quality parameters and nutrient loading from Tioga Pass to Sonora Pass on the East Side of the Sierras, and will help evaluate impacts of air pollution from the Bay Area. This grant research is also linked to a NASA grant received by Tate, Vance and investigators from UC Berkeley and UC Santa Barbara for 1999-2001 to evaluate impacts of flood irrigation. In the Spring of 2000, a grant proposal was submitted to the Agricultural Research Initiative program at Chico State to hire additional undergraduates to assist on all these projects, and to extend the inquiry into groundwater quality. The grant was approved, although we have deferred funding until 2001 due to the unavailability of Chico State students this summer. The scope of activity occurring in Bridgeport has attracted the attention of the Lahontan Regional Water Quality Control Board, and they are now supporting additional water quality sampling by the USGS. The U.S. EPA has also added this watershed to its regional characterization effort. In short, the WRC grant has allowed us to initiate and participate in significant partnership activities with government and stakeholders, and will have important impacts on our understanding of aquatic health in the Eastern Sierra.

Research Staff

Linda Vance, who is currently working Interim County Director and Farm Advisor in Mono and Inyo Counties, undertook the research design and execution and is using a portion of it for her Ph.D. dissertation. An additional Ph.D. candidate was employed as a field assistant during the summer of 1999, and two undergraduates were employed doing sample sorting and cataloguing. One M.S. student and a recent B.S. graduate were trained in macroinvertebrate collection and habitat assessment. The B.S. student has incorporated the training into the research she is currently conducting as a Post Graduate Researcher, which will be the focus of her M.S. work.

How California Fishes Swim Upstream Past Rapids, Waterfalls and Human-Made Barriers

Malcolm S. Gordon
Organismic Biology, Ecology & Evolution
UC Los Angeles

Project W-928
July 1999-June 2001

Fishes that swim upstream are of great economic and recreational interest to the people of California. Many stream modifications, such as weirs and dams of different sizes, seriously interfere with reproduction and other important aspects of the life histories of fishes like the Pacific salmon species and steelhead trout. These problems are partially addressed by building fishways, such as fish ladders, to assist fishes in overcoming these obstacles. Most fishways are designed by engineers primarily to ease the passage of salmonids. Little attention has been given in these designs to other ecologically important fishes that share the streams and interact with the salmonids. Even less attention has been given to the behaviors of any of these fishes as they travel upstream past natural rapids and waterfalls as well as through fishways. Fishway design has traditionally been approached from engineering perspectives neglecting the biology of the animals that are supposed to use the fishway. One important approach is to experimentally study fishes traveling up artificial rapids and waterfalls in controlled laboratory environments.

Increased understanding of how fishes travel up rapids and waterfalls, and of why they behave as they do when faced with such obstacles, is essential to the continuing survival of many California inland fishes. The results of this study will aid water resource management in protecting the complex fish assemblages of California watersheds.

Two field trips have been completed to describe and quantify the leaping behavior of wild salmonids trying to pass natural (unmodified) waterfalls and to describe the physical stream conditions around these falls. The data obtained provide the naturally evolved "ground truth" that has hitherto been missing from discussions of fishway designs. Two very different locations were analyzed to represent some of the variety that migrating salmonids encounter. The results from these analyses suggest a relatively low leaping success rate up natural waterfalls (approximately 10%).

The kinematic results of the field data were used to construct a theoretical model describing the kinematic parameters required for successful leaps. The measured stream conditions (water velocities, plunge pool depths and fall heights) have been compared to published scientific literature describing suggested fishway specifications. The findings of the field studies loosely coincide with current fishway design suggestions in the scientific literature but more work at other natural waterfalls and in controlled laboratory conditions is needed.

The theoretical "successful leap" model and the measured stream conditions at the leaping locations have been used in drafting the plans for constructing a laboratory rapids and waterfall flume. The construction of this flume will be complete this summer (2000) and experiments using the flume will be carried out during the fall of this year (2000) at the Bodega Marine Laboratory in Sonoma County, California.

Combining the wild fish leap results with the laboratory experiments to be done in the fall will provide a detailed quantitative analysis of how fishes pass rapids and waterfalls. These results will elucidate the fishes' requirements for passable torrent conditions and will allow for a more substantial biological influence in the design of fishways.

Key Words

California inland lakes
Rapids
Waterfalls
Fishway
Behavior
Swim
Leap

Publications and Presentations

Presentations:

• International Congress on the Biology of Fish in Aberdeen, Scotland (July 2000).

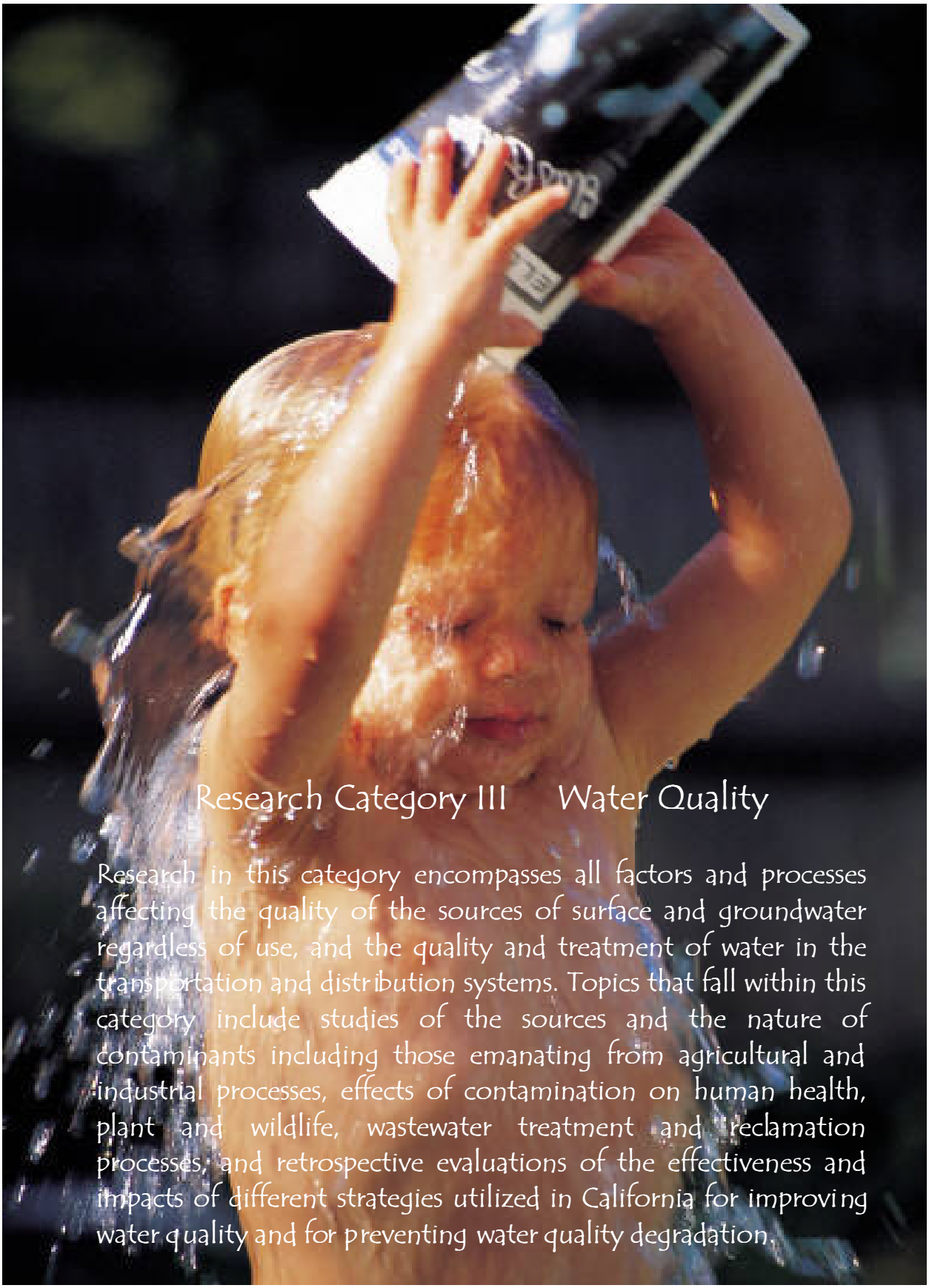
• International Symposium on Aqua Bio-Mechanisms in Honolulu, HI (August 2000).

Collaborative Efforts

The Center for Water Resources grant (project W-928) has led to the acquisition of an award from the University of California Energy Institute, Energy Science and Technology Program Award in the amount of $15,800.00.

Research Staff

Graduate Student
Dean V. Lauritzen



Research Category III Water Quality

Research in this category encompasses all factors and processes affecting the quality of the sources of surface and groundwater regardless of use, and the quality and treatment of water in the transportation and distribution systems. Topics that fall within this category include studies of the sources and the nature of contaminants including those emanating from agricultural and industrial processes, effects of contamination on human health, plant and wildlife, wastewater treatment and reclamation processes, and retrospective evaluations of the effectiveness and impacts of different strategies utilized in California for improving water quality and for preventing water quality degradation.

Predicting Groundwater Nitrogen Removal in Riparian Zones Based on Plot and Landscape Scale Variables

Tracy L. Benning
Environmental Science, Policy & Management
UC Berkeley

Project W-900
July 1998-June 2000

Changes in human land use and increases in atmospheric nitrogen (N) deposition are affecting freshwater N levels throughout the Northern Hemisphere; Lake Tahoe is a regional example of this global trend. Computer simulation models capable of depicting watershed N inputs to rivers and lakes under different management and disturbance scenarios would provide a useful tool for managing or predicting changes in freshwater N inputs. Riparian zones are capable of removing over 90 percent of anthropogenic N from groundwater before it enters the stream; as a result, riparian buffers are often recommended to reduce N inputs to rivers and lakes, such as Lake Tahoe. However, riparian N effects are rarely, if ever, included in watershed models of N input to open waters. Through this research, we are examining ways to incorporate riparian effects into watershed scale models of N dynamics.

In order to determine the variables best suited for watershed scale models of riparian N dynamics, we are examining a carefully selected suite of variables that have been theoretically and/or empirically shown to be associated with riparian N dynamics at the landscape, stream reach and microsite ($1m^2$) scales. We are examining how these variables covary with riparian N processes. Through this research, we will be able to test several methods for modeling variation in riparian N dynamics, based on data collected at the landscape to microsite scales.

Data collection: We used field data collected on 144 riparian sites around the Tahoe Basin to develop an ecosystem type classification and to assess physical and floristic characteristics that account for the greatest degree of variation among riparian sites in this mountain landscape. We have used Ward Creek watershed as a focal area in which to study watershed scale variation in riparian N dynamics. By the end of last year, we had established 20 research sites representative of five of the ecosystem types defined through our Basin-wide survey. To date, we have collected data on watershed scale variables (e.g., valley width, stream gradient, elevation, average annual precipitation, parent material, stream size), stream reach scale variables (e.g. ecosystem type, effluvial surface, stream characteristics), and micro-site variables (e.g., groundwater level and chemistry (NO_3-N, NH_4-N, PO_4-P), surface soil redox and temperature, and soil atmosphere O_2 levels) for the 1998 growing season and for spring and summer of 1999. In each of these study sites, we measured rates of a suite of N processes, including net N mineralization and nitrification for 1998 and N pool sizes for 1999, denitrification potential in saturated zone soils (one sample date) and seasonal and inter-annual variation (1998-1999) and denitrification potential in the surface soil (top 10 cm). During 1998 and 1999, we also measured in situ denitrification rates (static core method) in response to added N fertilizer in three (1998) and four (1999) of these ecosystem types. Finally, we completed a survey of all wells and piezometers established in the watershed and finished lab measurements of saturated hydraulic conductivity for all sites.

Laboratory and Statistical Analysis: Chemical analysis of all ground water and soil extract samples for N and P content was completed during the winter of 1999-2000. Statistical analysis of these N process data in relation to micro and stream reach scale

Key Words

Riparian
Nitrogen
Groundwater
Denitrification
Nutrient
Ecosystem
Landscape

variables was also completed this spring. Correlations between N process rates and the broader, watershed scale variables will be accomplished this fall. We are currently completing development of a groundwater flow model based on well/piezometer location and groundwater level, and site soil hydraulic conductivity. We are integrating groundwater chemistry data into this model to develop measures of change in groundwater N and P levels and groundwater flows through each study site. This will give a direct measure of the overall effect these sites have on groundwater chemistry.

Publications and Presentations

• Drafts for publication have been completed that describe aspects of this research regarding variation in structure and floristic composition of riparian zones in the Tahoe Basin, background N dynamics (potential denitrification, net mineralization and nitrification rates) and variation correlated to stream reach and micro-site scale controls, and surface soil response to added N, as related to ecosystem type and micro-site controls. We are currently writing a draft on effects of riparian zones under unfertilized and fertilized conditions on ground and surface water quality, based on the groundwater model described above. We anticipate completion of the first draft of this paper by the end of August 2000.

• We presented results of our research at the 1999 annual meeting of the Ecological Society and the annual meeting of the American Geophysical Union. This August, we will be presenting more of our findings at the 2000 annual meetng of the Ecological Society of America. The presentation titles are as follows:

• 1999 annual meeting of the American Geophysical Union. *Landscape scale variation in riparian nitrogen dynamics in the Lake Tahoe Basin.* Merrill, A.G. and T.L. Benning. Department of Environmental Science, Policy and Management, University of California, Berkeley, CA 94720-3110

• 1999 annual meeting of the Ecological Society of America. *Using ecosystem types to identify patterns of variation in riparian zone N dynamics.* Merrill, A.G. and T.L. Benning. Department of Environmental Science, Policy and Management, University of California, Berkeley, CA 94720-3110.

• 2000 annual meeting of the Ecological Society of America. *Landscape patterns in the distribution of riparian plant associations and ecosystems in the California Sierra Nevada.* Merril, A.G. and T.L. Benning, Department of Environmental Science, Policy and Development, University of California, Berkeley, CA 94720-3110.

Research Staff

Two graduate students

Two undergraduate students

Seven high school students

New Approach for Assessing Regional Groundwater Vulnerability to Contamination

Graham E. Fogg
Land, Air and Water Resources
UC Davis

Project W-901
July 1998-June 2000

The second year of study culminated in two important discoveries. First the Kings River alluvial fan has major incised valleys that contain coarse-grained channel deposits and cut through the previously reported paleosol creating pathways for significantly enhanced vertical flow of groundwater and contaminants. Because of the sequence stratigraphic approach, these valleys are predictable in terms of their existence and location. In other words, a scientific basis has been developed for predicting or mapping locations of these zones of significantly greater vulnerability to contamination. Second, our high-resolution characterizations of the system heterogeneity and accurate simulations of transport processes of advection, mechanical dispersion, and molecular diffusion show that natural mixing of groundwater of different ages in a typical alluvial aquifer system like this one results in significant variation in actual ages within a groundwater sample, even if that sample is obtained from a well having a narrow screened interval (e.g., <1 m). The amount of variation in age within a given parcel of water can be decades to centuries, which means that a water sample that has been dated at, say 50 yrs., could easily contain H_2O molecules that range in age from 1 to 100 yrs. This is of profound importance for groundwater vulnerability analysis. For example, this helps explain why seemingly old groundwater often has detectable concentrations of contaminants. Perhaps most important, these findings suggest that if nonpoint sources of contamination do not diminish over time, groundwater contaminant concentrations will steadily worsen in the future. This calls into question the common assumption that groundwater quality is sustainable, particularly in typical alluvial basins containing intensive agricultural and urban land uses.

Using a transition probability geostatistical approach and detailed hydrostratigraphic analysis, we built 30 geostatistical realizations to effectively simulate the multi-scale heterogeneous distribution of hydrofacies within a 94.5 km^2 portion of the Kings River alluvial fan aquifer system. MODFLOW-96 was used to simulate the velocity fields, and an improved random walk particle tracking model (RWHET) was used to simulate solute transport. Backward time transport simulations were used to model the groundwater age distributions for various screened intervals. The multiple realizations provide a means of accounting for uncertainty regarding the heterogeneity.

Spatially connected gravel and sand bodies in the system form a series of aquifers, which are the preferential pathways for groundwater flow and contaminant transport. Paleosols, ancient soils, are laterally continuous, except where eroded out by incised valleys, and represent unconformities as well as semiconfining beds that bound the different depositional sequences. The distribution of these relatively low-permeability paleosols divide the alluvial fan system into different hydraulic units and reduces their connectivity. The simulation results show reduced dispersion and longer travel times for contaminant plumes in the vertical direction due to the existence of these paleosols. Therefore the paleosols tend to reduce the susceptibility of deeper aquifers to pollution, but do not prevent contaminant plumes from eventually migrating into the deeper aquifers. Since this multi-scale heterogeneity results in the slower vertical transport of contaminants, contamination might be expected to reach the deeper zones within several decades after being released at the ground surface. Pumping of water from deeper wells tends to increase the rate of downward solute

Key Words

Groundwater, Contamination, Transport, Water Quality, Groundwater management, Hydrogeology, Subsurface characterization, Groundwater vulnerability, Nonpoint source, Stochastic modeling

movement. In addition, most of the models show that the movement of contaminant plume fronts are faster and lateral dispersion is larger in shallow zones due to the existence of the paleosols.

Also during the past year, the size of the study area was doubled to include the more complex central portion of the alluvial fan where incised valleys are known to exist, expanding greatly the scope of last year's effort out to a regional scale. Incised valleys were formed by ancient river channels. These channels generally cut into earlier paleosols forming breaks in the lateral continuity of the paleosols. The spatial distribution and geometry shape of an incised valley was characterized, based on high quality C-horizon soil mapping, 8 USGS continuous cores, 269 drillers' log data and 3 new cores collected recently. The stratigraphic character of each depositional system was modeled separately using the transition probability approach, in order to avoid the problem of non-stationarity which exists across boundaries formed by unconformities. After combining each sequence, we use the same method, outlined above, to simulate groundwater flow and contaminant transport. The modeling was performed for three scenarios; without paleosols, with continuous paleosols, and with discontinuous paleosols. Model results show that the existence of an incised valley provides an enhanced pathway for groundwater flow and contaminant transport.

The stratigraphic concepts developed during this research are already being applied in several study sites within California and elsewhere in North America. After presenting the results from this work at Lawrence Livermore National Laboratories, geologists began reassessing previous interpretations of the hydrostratigraphy based on these characterization methods. Also, presentations at various meetings have led to inquiries about this hydrostratigraphic approach, possibly leading to improved aquifer characterization by individuals whose work concerns characterizing and modeling contamination in alluvial fan aquifer systems. Finally, a similar approach is being used to understand the hydrostratigraphy at two study sites in Sacramento County and Modesto Irrigation District. As well, other UC Davis investigators are pursuing application of the approach to other aquifer systems in the San Joaquin Valley.

Publications and Presentations

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• Weissman, G.S. and G.E. Fogg. 1999. Multi-scale alluvial fan heterogeneity modeled with transition probability geostatistics in a sequence stratigraphic framework. Journal of Hydrology, v. 226(1-2), p. 48-65.

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• Weissman, G.S., E.M. LaBolle and G.E. Fogg. 2000. Modeling environmental tracer groundwater ages in hetergeneous aquifer systems. Proceedings of the XIII International Conference on Computational Methods in Water Resources, Volume 2, Calgary, Alberta, Canada, June 2000, p. 805-811.

• Weissman, G.S. and G.E. Fogg. 2000. Correlation of sequence boundaries between continental and marine strata, AAPG Annual Convention, New Orleans, April 16-19, 2000.

• Weissman, G.S., Williamson, R.J. and G.E. Fogg. 1999. Modeling heterogeneity of stream dominated alluvial aquifer systems: Implications for contaminant transport, GSA 1999 Annual Meeting, p. A-149.

• Weissman, G.S. 1999. Toward new models of subsurface heterogeneity: an alluvial fan sequence stratigraphic framework with transition probability geostatistics: Ph.D. Dissertation, University of California, Davis, 279p.

Research Staff

One undergraduate student

Two Ph.D. students
(**Gary Weissman** graduated 1999 with a Ph.D. in Hydrologic Sciences. Currently Assistant Professor, Michigan State University).

One Post-doctoral student

Bioremediation of Perchlorate in Groundwater

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Environmental Sciences
UC Riverside

Project W-902
July 1998-June 2000

Perchlorate, often used as a propellant in solid rocket fuel, is a drinking water contaminant that poses a serious problem in California. The health effects are uncertain, with a potential, at high concentrations, to damage the thyroid gland. The State of California has set an action level for drinking water of 18µg L^{-1} and the U.S. Environmental Protection Agency is currently reviewing data in preparation to set a national standard for acceptable levels of perchlorate in drinking water.

In light of these regulations, it has become increasingly important to have treatment options available to remove perchlorate from drinking water so that water companies can avoid well closures. Bioremediation is an attractive option for removing this contaminant because bacterial metabolism will destroy perchlorate and produce chloride, a harmless end product. Our research has focused on one particular bacterium, per 1 ace, which is capable of this transformation at very fast rates. Previous work tested this organism in a bench scale bioreactor and showed that perc 1 ace would remove perchlorate from contaminated groundwater in a flow-through system. During this fiscal year, the bioreactor was scaled-up and tested in a realistic bioremediation setting. A flow-through system was designed with a 1.2 liter, packed bed reactor. Perc 1 ace was immobilized in the reactor on a Celite support. Groundwater containing 0.8 mg L^{-1} perchlorate was obtained from a contaminated site in Los Angeles County. The system was temperature controlled to simulate environmental conditions. The bioreactor performed exceptionally well, removing perchlorate to below detectable levels (4 µg L^{-1}) with column residence times of 0.3 hours. This is a significant improvement over the bench scale trials, which required more than two hours to remove perchlorate. Other applications for this technology were also tested. Current non-biological treatment systems for perchlorate cannot destroy the contaminant. Instead, it is removed from the drinking water and concentrated into a waste system along with other salts present in the water. This high dissolved solids waste still needs to be treated to remove perchlorate. The bioreactor described above was tested for this application. We found that our system was efficient at removing perchlorate from the waste stream, but residence times were slightly longer than for treatment of groundwater (0.8 hours).

These experiments demonstrated the potential for a packed bed reactor to be used for treating perchlorate contaminated water and waste systems. These promising results will be used as a basis for further studies both treating groundwater on a larger scale and for treating other types of perchlorate contaminated water.

Publications and Presentations

• Giblin, T., D. Herman, M. Deschusses and W.T. Frankenberger. 2000. Removal of perchlorate in water with a flow-through bioreactor. J. Environ. Qual. 29:578-583.

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Key Words

Groundwater
Bacteria perchlorate remediation
Environment
California

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• Giblin, T., M. Losi, V. Hosgangadi and W.T. Frankenberger, Jr. 2000. Removal of perchlorate from simulated reverse-osmosis rejectate using the bacterium perc 1 ace. Appl. Microbiol. And Biotechnol. Submitted.

• Losi, M., T. Giblin and W.T. Frankenberger, Jr. 2000. Bioremediation of ClO_4 in contaminated groundwater using perc 1 ace in a biological reactor system. Bioremediation J. Submitted.

Collaborative Efforts

This work has led to collaboration with several local consulting firms including Foster Wheeler Environmental Services and EarthTech Corporation. These collaborations would not have been possible without Water Resources Center funding, which allowed us to perform preliminary experiments to prove the efficacy of our bioremediation system. These collaborations may also allow the system to be scaled-up to a field trial. If the system proves efficient on a large scale, the work will represent a marketable product.

Research Staff

T. Giblin
(FTE Commitment 1.00)
Environmental Sciences
University of California, Riverside

A Microscale Approach to Simulating Seasonal Bioavailability Constraints on Intrinsic Biodegradation

Patricia A. Holden & Arturo A. Keller
Environmental Science & Management
UC Santa Barbara

Project W-904
July 1998-June 2000

The current regulatory trend towards accepting intrinsic bioremediation as a long-term management scheme for residual organic pollutants in the subsurface for fuel spills is based on statistical evaluations of plume behavior for a limited array of pollutants. The effectiveness of intrinsic bioremediation towards protecting water supplies and hence human health, is not known for many pollutants. In addition, the patterns of biodegradation that occur over seasonal time scales and hence the seasonality of intrinsic bioremediation and its intermediate effectiveness is unknown. Residual non-aqueous phase liquids (NAPLs) in the vadose zone, if left in place, have the potential to mobilize with seasonal moisture fluctuations. These seasonal variations in mass transfer along with the intrinsic microbial biodegradative response to moisture variations will determine bioavailability, which is a measure of the potential effectiveness of intrinsic bioremediation.

Our research focuses on determining the effect of seasonal fluctuations in moisture content and soil temperature on abiotic and biotic fate and transport of hydrocarbons in the subsurface. Freshly spilled NAPL pollutants travel through the vadose zone displacing the gas phase, and volatilizing and dissolving to the surrounding fluid phases. The rate at which NAPL travels down through the porous media is controlled by soil characteristics such as soil grain size distribution, which determine the permeability and porosity of the soil. However, the presence of soil moisture (i.e., residual aqueous phase) plays an important role in determining the relative permeability of the soil. Our studies indicate that increases in soil moisture can substantially decrease the NAPL relative permeability, altering the distribution pathway of the NAPL. Subsequent decreases in soil moisture provide more channels for flow, releasing trapped NAPL for additional flow. This is accentuated when the system transitions from two (water and NAPL) - to three (water, air and NAPL) - phase flow at the local scale. The "residual" NAPL saturation is a function of the history of drying and wetting events. Our microbial studies also provide insight into the effect of these soil moisture cycles on the interfacial contact area, which is a major determinant on the overall rate of mass transfer from NAPL to aqueous or gaseous phases where biodegradation occurs. Temperature fluctuations play a major role in increasing or decreasing the rate of mass transfer, and a secondary role in the redistribution of "residual" NAPL. Both temperature and moisture affect the amount of polymers surrounding microbes that are the vehicles for biodegradation and bioremediation. The exopolymers, while protecting microbes from desiccation, also are a mass transfer barrier to pollutants at the scale of the microbes. Our research has been addressing the conditions under which microbes produce more polymers and how these additional polymers affect the rate of hydrocarbon biodegradation. Thus far, we are finding that hydrocarbon pollutants and nitrogen fertilization stimulate the overproduction of exopolymers in laboratory systems. This preliminary result is being studied further as it has implications to how engineers and scientists should model the rates at which pollutants are intrinsically biodegraded.

Key Words

Bioavailability, Natural attenuation, Wetting and drying, NAPLs, Exopolymer matrix, Unsaturated zone, Mass transfer, Porous media, Pollution, Oil, Hydrocarbons, Biodegradation, Vadose zone, Soil

Publications and Presentations

Publications are being prepared for submission. Results have been presented at the Soil Science Society Annual meeting in Salt Lake City (November 2000), the program review meeting for EPA's Bioavailability Program in Chicago (November 2000), and the annual meeting of the American Society for Microbiology, Los Angeles (May 2000). The results of these studies were also presented at the Gordon Conference on Modeling Flow in Permeable Media (August 2000), for the special session on "Chemical-Biological Interactions in Contaminant Fate".

Collaborative Efforts

As a result of this seed funding, the PIs have been successful in obtaining a grant of $425,000 from US EPA to extend this research. PI Holden has also led a successful NSF proposal effort ($450,000) to obtain an environmental scanning electron microscope (ESEM) for the UCSB campus so that, in part, the micro-habitat of soil microbes active in pollutant biodegradation can be directly observed during wetting and drying scenarios.

Research Staff

Ph.D. Students
Sanya Sirivithayapakorn
Rachel Steinberger

M.S. Students
Alok Paranjype
Brandon Steets

Some of these students have been co-funded from the complementary EPA funding that was seeded through this support. Also, Steinberger has received a graduate fellowship through the EPA Star program for three additional years of support to study and research related topics.

Impacts of Seasonal Terminal Electron Accepting Processes on Natural Attenuation of Chlorinated Compounds in Groundwater

Project W-909
July 1998-June 2000

Thomas M. Young
Civil & Environmental Engineering
UC Davis

Chlorinated solvents and their transformation products are among the most common organic contaminants in U.S. groundwater supplies. Successful implementation of natural attenuation and other in situ treatment methods requires a detailed understanding of the subsurface processes affecting transport and degradation depends strongly upon the redox status of the groundwater system. Under anaerobic conditions and in the presence of a suitable electron donor, chlorinated ethenes are subject to sequention reductive dechlorination according to the sequence PCE $\rightarrow$ TCE $\rightarrow$ DCE $\rightarrow$ Vinyl chloride $\rightarrow$ ethene. Highly toxic vinyl chloride can be oxidized under aerobic or iron reducing conditions (Davis and Carpenter, 1990; Bradley and Chapelle, 1996), and can be degraded by various co-metabolic processes. Ethene is a harmless byproduct.

A local landfill site with contaminated groundwater supplies has been selected for a field study. The field study is designed to evaluate seasonal changes in the subsurface redox environment, and to investigate relationships between the redox status and degradation of chlorinated solvents at the site. Column studies are being performed to quantify the biodegradation rates of trichloroethene and vinyl chloride under specific reducing conditions and under fluctuation conditions.

Examination and study of field data from the site show correlation between concentrations of parent compounds and daughter products in the groundwater. These data support the theory that reductive dechlorination is occurring at the field site. A clear correlation between water levels and contaminant concentrations was not indicated in the field data. A negative correlation between vinyl chloride concentrations and oxidation-reduction potential was observed, however. The data show more vinyl chloride to be present under reducing conditions which would suggest that vinyl chloride is being produced via reductive declorination. Lower vinyl chloride concentrations at higher oxidation-reduction potentials could indicate aerobic degradation under oxidizing conditions, or could reflect the fact that vinyl chloride is not produced under these conditions. Accumulation of cis-DCE in the groundwater samples indicates that the reductive dechlorination of cis-DCE to vinyl chloride may be the rate-limiting step for the biodegradation process.

Field data indicate that bioremediation is transforming the chemicals at the Yolo County Landfill site from PCE to TCE to DCE and then to vinyl chloride. The site is a promising candidate for the use of natural attenuation, but more work must be performed in the laboratory to determine biodegradation rates for these compounds.

Publications and Presentations

• Moore, A. and T.M. Young. 1999. Biodegradation of Chlorinated Ethenes in Dynamic Groundwater Systems. Professional talk presented at the West Coast Water Chemistry Workshop Conference, Berkeley, CA.

• Moore, A. and T.M. Young. 1998. Impacts of Seasonal Terminal Electron Accepting Processes (TEAPs) on Natural Attenuation of Chlorinated

Key Words

Biodegradation
Aquifers
Groundwater remediation
Sanitary landfills
Geochemistry
Soil microbiology
Anerobic treatment
Environmental contamination

Contaminants: Work in Progress. Poster presented before the annual meeting, American Geophysical Union, September 1998, San Francisco, CA.

• Moore, A. and T.M. Young. 1998. Impacts of Seasonal TEAPs on Natural Attenuation of Chlorinated Contaminants: Field Methods and Microcosms. Talk presented at Groundwater Resources Association meeting, October 28, Sacramento, CA.

Research Staff

Ph.D. Student
Angela M. Moore
(advanced to candidacy)

Four undergraduate research students

Two undergraduate students
(Mentoring Program)

In-Situ Bioremediation of MTBE Contaminated Groundwater Using Biobarriers

Project W-916
July 1999-June 2001

Marc A. Deshusses
and Mark R. Matsumoto
Chemical & Environmental Engineering
UC Riverside

The 1990 Clean Air Act Amendments require the addition of oxygenates in gasoline to reduce atmospheric concentrations of carbon monoxide and ozone. Methyl tert-butyl ether (MTBE) is the most commonly used oxygenate, and consequently ranked second among all organic chemicals manufactured in the United States. Unfortunately, MTBE is quite persistent in the environment. A 1996 U.S. Geological Survey found that MTBE is the second most frequent detected chemical in shallow urban monitoring wells with concentrations ranging from 0.2 ppb to 20 ppb. It is estimated that there might be as many as 250,000 leaking underground storage tanks in the U.S. Clearly, there is need for cost effective remediation solutions. Bioremediation offers great promise and is widely accepted by the general public.

Hence the overall objective of this study is to develop a low-cost in-situ groundwater treatment technology, hereafter referred to as a biobarrier. Supporting objectives to reach this goal are to gain a comprehensive understanding of the kinetics and microbiology fundamentals for MTBE biodegradation from which laboratory and field-scale biobarrier systems may be designed, and to build and operate laboratory-scale biobarrier systems to test the efficacy of treating MTBE-contaminated groundwater.

In the past year, several laboratory prototype systems for the biodegradation of MTBE have been constructed and the biodegradation of MTBE has been investigated under selected operating conditions. It was found that biodegradation of MTBE by our specially enriched consortium is very sensitive to the concentration of dissolved oxygen. Hence, year 1 investigations have focused on an in-situ trickling behavior (rather than a passive submerged bioreactor). The contaminated groundwater is trickled through a bed of porous material on which MTBE degrading organisms are immobilized and MTBE is degraded to harmless substances.

In summary, we found that the in-situ prototype reactor could degrade 5 ppm MTBE down to below 10 ppb, and that at a constant inlet concentration of 10 ppm, the elimination capacity was in the range of 3-4g of MTBE per cubic meter of packing per hour, with removal percentages of 99+%. The maximum elimination capacity was in excess of 10 g $m^{-3}h^{-1}$. These are very high rates. The performance of the systems was not affected by lowering the temperature down to 5ºC. Experiments with radiolabled MTBE (as a tracer) demonstrated that MTBE was mineralized to CO_2, but the release of labeled CO_2 was slow which remains to be explained. The robustness of the bioreactor was investigated by adding small amounts of gasoline co-contaminants and following their biodegradation as well as the cross-inhibition on MTBE biodegradation. Toluene and xylene had the most inhibitory effect, while ethyl benzene and tert-butanol (TBA) had no effect and were well degraded.

Overall, the results show extremely good promise for field deployment of the in-situ trickling process. A basic cost estimation also shows that the treatment would be very cost effective. Efforts for year 2 will be placed on obtaining funding for a field demonstration of in-situ trickling filters and on operating prototypes fully submerged so that biobarrier operation can be characterized. Further information can be downloaded at *http:www.engr.ucr.edu.~mdeshuss/mtbe.html*.

Key Words

MTBE, Groundwater treatment, Innovative technologies, Biobarrier, Gasoline

Publications and Presentations

• Morales, M. and M.A. Deshusses. 1999. Simulation of an in-situ bioremediation process for MTBE in laboratory soil columns. ACS Pacific Conference on Chemistry and Spectroscopy, Ontario, CA, October 14, 1999.

• M.A. Deshusses. 2000. MTBE biodegradation: Lessons from laboratory experiments. EPA-API workshop on in-situ bioremediation of MTBE (invited contribution). Cincinnati, OH, February 1-3, 2000.

• Morales, M., X. Wang, S. Revah and M.A. Deshusses. 2000. Microcosm and Column Studies on the Biodegradation of Methyl Tert-Butyl Ether (MTBE) in Soil-Water Systems. In: Proc. Annual Meeting and Exhibition of the Air and Waste Management Association, June 19-22, 2000. AWMA, Pittsburgh, PA. 12pp.

Training Accomplishments

The funds have been used to support one graduate student (X. Wang) and a postdoctoral fellow (M. Morales, also partially supported by UC Mexus funds).

This research has been quite visible and has generated genuine interest from water boards and owners of MTBE contaminated sites. Even so, obtaining funding for demonstration of MTBE bioremediation using techniques developed in this project has been difficult. We are confident that our efforts in obtaining funding for field work will be successful in the coming year.

Research Staff

Post-doctoral Fellow
M. Morales

Graduate Student
X.Wang

Transport and Fate of Nitrate-Nitrogen in Heterogeneous, Unsaturated Sediments Below the Root Zone

Thomas Harter, Jan W. Hopmans &
William R. Horwath
Land, Air and Water Resources
UC Davis

Project W-919
July 1999-June 2001

Nitrate is the most widespread contaminant in groundwater causing as much as ten times as many well closures in the State of California as all industrial contaminants combined. Most nitrate contamination originates from agricultural nonpoint sources (fertilizer and confined animal facilities). We have only limited understanding of the fate, transport, distribution and travel time of nitrate in the deep unsaturated zone, and few data to develop monitoring strategies for the deep unsaturated zone or to validate current and future groundwater impact assessment methods. The overall purpose of this research project is to improve our understanding of the link between shallow soil monitoring data and groundwater quality in areas with a deep groundwater table. Specifically, we are pursuing two objectives:

1. Establish a field research site specifically designed for the detailed characterization of a deep alluvial unsaturated zone with cutting-edge geologic, soil physical and soil biogeochemical field measurement and laboratory characterization tools.
2. Utilize the field site characterization for an evaluation of current approaches to modeling and understanding nitrate transport in deep vadose zones; and for developing a conceptual model of nitrate-nitrogen fate and transport in realistically heterogeneous, unsaturated alluvial sediments.

Alluvial sediments are encountered in a majority of California's central and southern agricultural valleys and basins. The proposed field and modeling research will explicitly account for the effects of horizontal and vertical variability of sediment properties on nitrate transport and on nitrate biogeochemistry (denitrification). Such variability and the ensuing uncertainty about fate of nitrate is all ignored in current models of nitrate transport in the vadose zone.

An extensive drilling program was conducted in an orchard at the Kearney Agricultural Center, Fresno County, where a 12-year fertilization experiment with various fertilizer rates had been completed at the time of drilling. Detailed characterization of the sedimentary environment was obtained in a 50 feet deep cross-section through the orchard. Nitrate analysis was completed on over 600 soil samples for profiling nitrate concentration under each of three different fertilization treatments (0, 100 and 235 lbs/acre). The measured nitrate distribution serves as a validation tool for evaluation of the tools to be developed under objective 2. Laboratory analysis of the soil physical and soil biogeochemical properties of each of more than 1,000 core samples is ongoing and will be completed during the next funding year. The laboratory data are the basis for understanding and modeling unsaturated water flow and nitrate transport through the soil profile. Laboratory analyses include development and adaptation of new technologies for defining hydraulic conductivity and soil moisture release curves (multi-step outflow technique) and for determining denitrification rates (isotope analysis). A protocol has been established for applying the multi-step outflow technique on direct-push drilling cores. The multi-step outflow experiments were completed on over 100 undisturbed core samples, representing ten major hydrostratigraphic units within the 50-foot vadose zone. The parameters necessary to mathematically describe these measured hydraulic conductivity and soil moisture retention curves are simultaneously

Key Words

Unsaturated zone
Nonpoint source pollution
Soil hydraulic properties
Alluvial fans
Nitrate-nitrogen
Stochastic modeling
Geostatistics
Denitrification geochemistry

determined through inverse modeling with an optimization algorithm using the Levenberg-Marquardt method.

Once completed, the project provides a thorough database to validate current methods assessing the impact of fertilizer management on groundwater quality and to validate the stochastic nitrate transport and fate model that will be developed as part of this project. The modeling approach is neither site-specific nor pollutant-specific. Once the model has been validated with our field nitrate results, it may be applied to other sites, given sufficient field data, to realistically evaluate and predict the impact of fertilizer practices on nitrate groundwater loading rates at the water table. Field conditions similar to those at the site are found throughout many agricultural areas in Central and Southern California. Hence, field results provide direct insight not only to researchers, but also to growers, regulatory agency personnel, political leadership, and the general public about the time-scale and extent of nitrate leaching and the significance of spatial heterogeneity in the unsaturated zone with respect to nitrate leaching and monitoring of nitrate in the unsaturated zone.

This multi-year project is jointly funded by the Water Resources Center, the Fertilizer Research and Education Program, California Department of Food and Agriculture (FREP), and the California Tree Fruit Agreement (CTFA).

Research Staff

Water Resources Center support is providing funding for a graduate student who will be completing her thesis within the framework of this research. Together with funding from the above mentioned agencies, support from Geoprobe Systems, and from the German Studienstiftung Foundations, this project to date has supported three undergraduate students and one postgraduate student involved in the field drilling and stratigraphic characterizations, two undergraduate students handling the laboratory chemical analyses, and two graduate students implementing the multi-step outflow experiments.

Publications and Presentations

• Harter, T., K. Heeren, G. Weissmann, W.R. Horwath, J. Hopmans. Field Scale Characteristics of a Heterogeneous, Moderately Deep Vadose Zone: The Kearney Research Site, *Proceedings, Characterization and Measurement of the Hydraulic Properties of Unsaturated Porous Media*, United States Salinity Laboratory, Riverside, CA, 621-630, 1999.

• (Presented) “Drinking Water Source Protection through Nutrient Management”, 11/30/99, FREP/ SAREP Joint Annual Conference for growers, ag consultants, fertilizer industry, agriculture industry representatives, state government, Modesto, CA.

Feasibility of Using Bioaugmentation with Bacterial Strain PM1 for Bioremediation of MTBE-Contaminated Vadose and Groundwater Environments

Kate M. Scow
Land, Air and Water Resources
UC Davis

Project W-924
July 1999-June 2001

Port Hueneme field site (Plots A and B).

Our overall goal is to help determine if bioremediation is a feasible way to clean up MTBE pollution in groundwater. Our results this year exceeded our original objectives of conducting lab studies of the potential for MTBE bioremediation with the bacterium, Strain PM1. A field trial was initiated in a shallow, anoxic, MTBE-contaminated groundwater at Port Hueneme Naval Facility in Oxnard, California. Two small pilot test plots (A and B) located down gradient from an MTBE source were injected with pure oxygen at two depths. One plot (B) was also inoculated with Strain PM1. Oxygen delivery began late October of 1999. By early November, high concentrations of dissolved oxygen were measurable in most of the shallower wells and some deep wells. Strain PM1 was added to Plot B on November 8, 1999. Results at this date indicate that MTBE concentrations upstream from Plots A and B range from 1.5 to 6 mg per L. In the downstream wells (and immediately upstream near the oxygen release wells), MTBE concentrations have decreased substantially in the shallow zone of the groundwater in both plots, even in the absence of Strain PM1. In the deeper zone, downstream MTBE concentrations have decreased substantially in Plot A but only slightly in Plot B. Difficulties in delivery of oxygen to the deep zone in Plot B, as evidenced by low dissolved oxygen concentrations, is likely responsible for low rates of MTBE removal at that location. Additional groundwater and dissolved oxygen samples are currently being analyzed and monitoring will continue indefinitely. A tracer test is underway to verify groundwater flow through the injection bed.

A unique aspect of this project is our ability to monitor the survival and movement of Strain PM1, as well as measure changes in the native microbial community

Injection of the PM1 bacterial strain into the Port Hueneme MTBE plume.

Key Words

MTBE
Bioremediation
Biodegradation
Microorganisms
Groundwater

during bioremediation. DNA primer sequences specific to PM1 have been identified and synthesized for use in both denaturing gradient gel electrophoresis (DGGE) and intertranscribed spacer (ITS) analysis. A quantitative PCR method (Taqman PCR) has also been developed to measure the density of PM1. Results of the molecular analysis indicate that PM1 is still present in Plot B at high densities three months after inoculation. Our results indicate that PM1 can survive in a foreign groundwater environment in the presence of MTBE. Our findings also suggest that native microorganisms can remove MTBE as effectively as PM1 if oxygen is supplied.

PM1 bacterial strain injection into the Port Hueneme MTBE plume.

Publications and Presentations

• Deeb, R.A., K.M. Scow and L. Alvarez-Cohen. 2000. Aerobic MTBE biodegradation: An examination of past studies, current challenges and future research directions. Biodegradation (in press).

• Deeb, R.A., H.Y. Hu, J.R. Hanson, K.M. Scow and L. Alvarez-Cohen. 2000. Substrate interactions in BTEX and MTBE mixtures by an MTBE-degrading isolate. Environ. Sci. Technol. (under review).

• El-Farhan, Y., K.M. Scow and D.E. Rolston. 2000. Kinetics of trichloroethylene cometabolism and toluene biodegradation: Model application to soil batch experiments. J. Environ. Qual. (in press).

• Green, C.T. and K.M. Scow. 2000. Analysis of phospholipid fatty acids (PLFA) to characterize microbial communities in aquifers. Hydrogeology J. 8:126-141.

• Scow, K.M., E. Schwartz, M. Johnson and J.L. Macalady. 2000. Measurement of microbial diversity. In: Encyclopedia of Biodiversity (in press).

• Scow, K.M. 1999. Soil microbiology. In: Encyclopedia of Microbiology. Academic Press (in press).

• Song, X.-H., P.K. Hopke, M.A. Bruns, K. Graham and K.M. Scow. 1999. Pattern recognition of soil samples based on microbial fatty acid contents. Environ. Sci. Technol. 33:3524-3530.

• Bruns, M.A. and K.M. Scow. 1999. DNA fingerprinting as a means to identify sources of soil-derived dust: problems and potential, p.193-205. In: Scow et al. (eds) Integrated assessment of ecosystem health. Lewis Publishers, Boca Raton, FL.

• Sudarshana, P., J.R. Hanson and K.M Scow. 1999. Application of random amplified polymorphic DNA (RAPD) method for characterization of soil microbial communities, p. 223-231. In: Scow, et al. (eds) Integrated assessment of ecosystem health. Lewis Publishers, Boca Raton, FL.

• Scow, K.M., G.E. Fogg, D.E. Hinton and M.L. Johnson (editors). 1999. Integrated assessment of ecosystem health. Lewis Publishers, Boca Raton, FL.

• Hanson, J.R., J.L Macalady, D. Harris and K.M. Scow. 1999. Linking toluene degradation with specific microbial populations in soil. Appl. Environ. Microbiol. 65:5403-5408.

• Hanson, J.R.. C.E. Ackerman and K.M. Scow. 1999. Biodegradation of methyl tert-butyl ether by a bacterial pure culture. Appl. Environ. Microbiol. 65:4788-4792.

• Schwartz, E. and K.M. Scow. 1999. Using biodegradation kinetics to measure the availability of aged phenanthrene to bacteria inoculated into soil. Environ. Toxic. Chem. 18: 1742-1746.

• Johnson, C.R. and K.M. Scow. 1999. Effect of nitrogen and phosphorus addition on phenanthrene biodegradation in four soils. Biodegradation 10:43-50.

• El-Farhan, Y.H., D.E. Rolston and K.M. Scow. 1999. Coupling vapor transport and transformation of volatile organic chemicals, p. 235-259. In: Hopmans, J. and M. Parlange (eds.) Vadose zone hydrology; cutting across disciplines. Oxford University Press, New York.

• Bioremediation of MTBE. Invited talk at the Association of Women Geoscientists, Sacramento, CA. June 2, 1999.

• Biodegradation of the Fuel Additive, MTBE, in Bioreactors and Groundwater Samples. Invited talk at the University Council on Water Resources/ International Water Resources Association. Kamuela, HI. July 1, 1999.

• Bioremediation of MTBE in Bioreactors and Groundwater. Invited talk at the International Ecosystem Health Congress, Sacramento, CA. August 16, 2000.

• Bioremediation of MTBE. Invited talk at the NIEHS Annual Meeting, Napa, CA. August 30, 1999.

• Microbial Ecology of MTBE Biodegradation. Invited talk at the Ecology Graduate Group Odyssey, Tahoe City, CA. September 13, 1999.

• Bioremediation of MTBE: Can Microorganisms Clean Up Our Messes? Invited talk for the Explorit Cutting Edge Lecture Series, Davis, CA. September 21, 1999.

• Bioremediation of the MTBE at Port Hueneme. Invited talk at the EPA MTBE Workshop, Cincinnati, OH. March 14, 1999.

• Bioremediation of the Fuel Additive, MTBE. Invited talk at the American Chemical Society Annual Meeting, San Francisco, CA. March 30, 1999.

• Bioremediation of MTBE with Strain PM1. Invited Willi Woltz Lecturer. North Carolina State University, Raleigh, NC. April 11, 2000.

Collaborative Efforts

A number of collaborations have been supported or initiated by this project. Based on results of the Port Hueneme trials, we are partnering with the engineering firm, HIS Geotrans, to obtain EPA funding for another bioaugmentation trial in Dixon, CA. My lab continues to collaborate with Doug Mackay from the University of Waterloo, Canada, in a biostimulation study at Vandenburg Air Force Base and Professor Mackay provides advise on hydrological issues at Port Hueneme. We are also initiating a field research study for Chevron in collaboration with Professor Mackay and Murry Einarson of Tetratech. Finally, we are trying to obtain funding for a joint research study with Malcolm Pirnie, Regenesis and Chevron.

Research Staff

One postdoctoral fellow
Hristova

Seven graduate students
Smith (UCD)
Smith (UCD)
Gandhi (UCD)
Green (UCD)
Hohnbaum (UCD)
Aswath (CSU San Jose)
Deeb (UC Berkeley)

Six undergraduate students
Wantanabe
Scott
Smith
DePaoli
Garza
Hernandez

Enhancing the Utility of In-Vitro Digestive Fluid Extraction as a Management Tool for Contaminated Aquatic Sediments

Project W-927
July 1999-June 2001

Donald P. Weston
Integrative Biology
UC Berkeley

Traditional chemical analysis of contaminated sediments relies on a strong organic solvent or strong acid to extract the contaminant, and thus quantification of contaminant levels is biologically meaningless and of little use for assessing the environmental risks posed by those sediments. Traditional extraction methods can far over-estimate the amount of contaminant that would be available to an organism, as much of what is chemically extractable may not be extractable in seawater or the digestive tract of an animal which ingests those sediments. Under the current project we are developing an extraction procedure that provides a more realistic estimate of the fraction of contaminant that an organism would find bioavailable. Briefly, digestive fluid is removed from the gut of a deposit-feeding organism (typically a polychaete worm), and the sediment of concern is incubated in vitro in this digestive fluid. The fraction of contaminant solubilized in the fluid is taken as an upper limit on the amount of contaminant that would be available to the organism during gut passage. The technique holds great promise as a means to assess the ecological risk of contaminated sediments, and should provide a measure of bioavailable contaminant rather than the total contaminant that is presently quantified. Results should be of great interest to state and federal resource management agencies and all parties with a need to evaluate the risks of contaminated sediment.

In the first year of the WRC project we have focused on testing the assumption that in vitro digestive fluid solubilization is a reliable predictor of in vitro absorption by an animal feeding on the sediment. From a variety of contaminated sediments we have measured both the fraction of contaminant solubilized in digestive fluid and the fraction that is absorbed by the whole organism living in and feeding on these sediments. We have found solubilization and absorption to be in good agreement. These experiments were done for two contaminants: a representative hydrophobic organic compound (benzo[a]pyrene) and a representative trace metal (zinc). Parallel experiments were done with two species: the polychaete, Arenicola brasiliensis, and the sea cucumber Parastichopus californicus. These two species make an interesting comparison as Arenicola digestive fluid is an effective solubilizer of both benzo[a]pyrene and zinc, whereas Parastichopus fluid is effective only for benzo[a]pyrene. We have also tested a traditional means of measuring absorption efficiency of a contaminant from ingested sediment using a C-14/ Cr-51 dual radiolabel. We have been able to utilize an alternative approach to absorption efficiency determination by directly measuring contaminant concentrations in subsamples of gut contents along the entire length of the gut, and are currently comparing the results to the widely used dual label method which, we believe, is more error-prone because of the untested assumptions on which it is based.

Collaborative Efforts

WRC funding provided to this project has been critical in attracting a post-doctoral student, Jonas Gunnarsson, to UC Berkeley. Dr. Gunnarsson was previously a post-doctoral scholar at the EPA laboratory in Newport, OR, and has an extensive publication record (11 publications) on the role of

Key Words

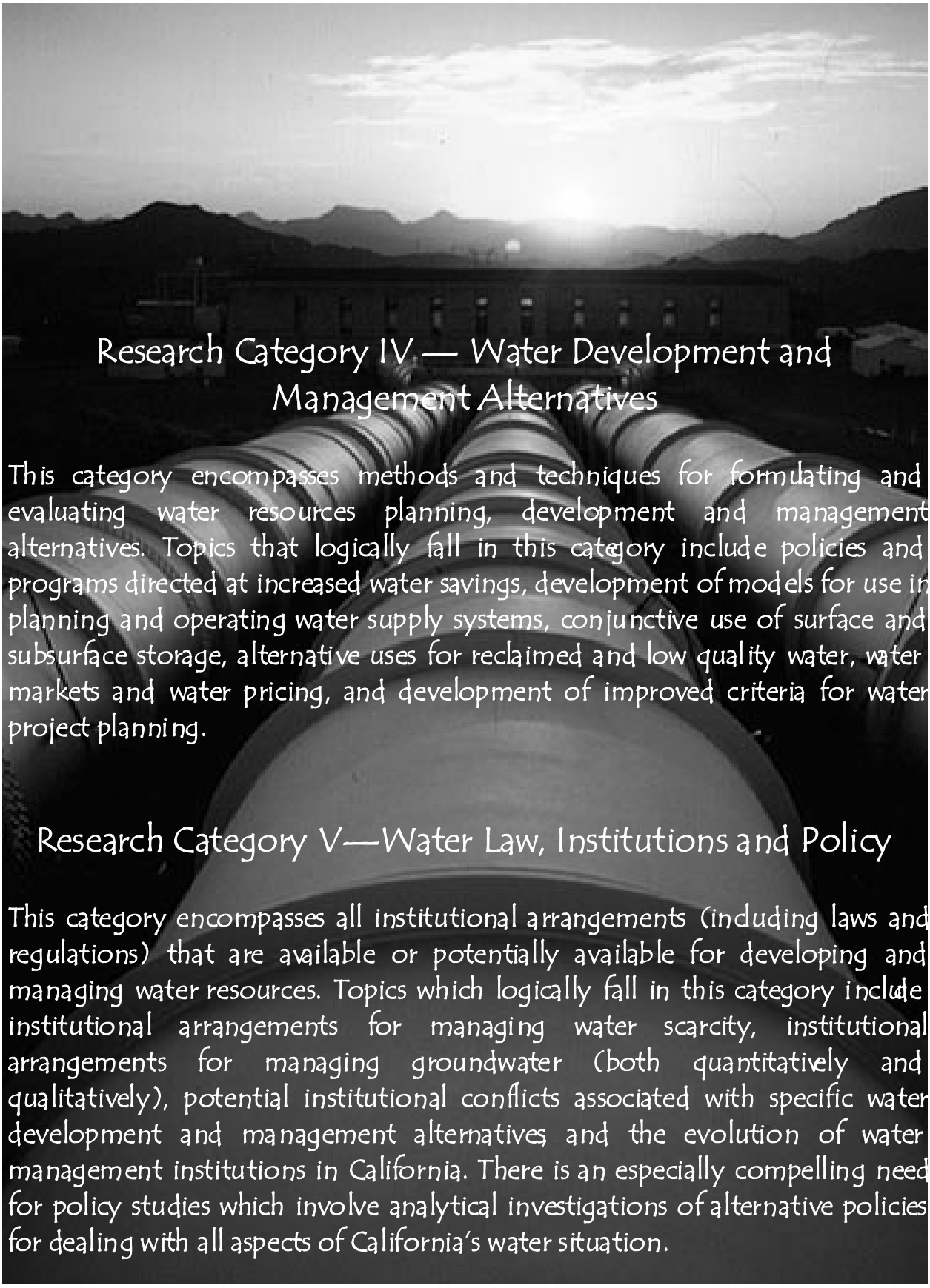
Risk assessment Bioavailability Sediments

organic carbon in controlling contaminant bioavailability. He will be applying this expertise to the WRC project in the remaining year.

Funding for additional work with digestive fluid extraction is currently being developed through a collaborative project with the U.S. Army Corps of Engineers (COE). WRC funding to develop the technique as a management tool for contaminated sediments is of great relevance to COE needs for management of dredged material. COE funding appears highly probable, and will be confirmed in Sept./Oct. 2000.

Research Staff

Graduate Student
Jeff Judd (Integrative Biology, UC Berkeley) has been supported by the project in the past year.



Research Category IV — Water Development and Management Alternatives

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

Research Category V—Water Law, Institutions and Policy

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

An Institutional Analysis of the Application of Urban Reclaimed Water to Agriculture in California

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Environmental Studies
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Project W-903
July 1998-June 2000

Urban recycled water is one potential part of a solution to growing water demand in California. This project is investigating the extent to which California agriculture could become a significant recipient of urban recycled water in the coming years. Already some examples exist of agricultural application of urban recycled water, such as in the Santa Rosa and Castroville areas. Other regions are considering applying urban recycled water to agriculture. But while water planners anticipate expansion of availability of urban recycled water, it is not clear that agriculture will increase its usage from the current tens of thousands of acre feet to hundreds of thousands.

This project is examining the institutional context of decision-making about whether to utilize urban recycled water in the agricultural sector. The objective is to identify both receptive institutional contexts as well as institutional barriers to this practice. To date, most research on agricultural applications of recycled water have focused either on physical/biological impacts of the practice or on the customer attitudes. This research examines the decision-making context of those who would have to approve of the practice for it to move forward.

An emerging story from our interviews with farmers involves the theme of public acceptance of urban recycled water. Several farmers consider this to be the critical impediment to widespread application of recycled water use by agriculture. They have expressed a willingness to use recycled water but currently face contractual obstacles with their wholesalers and public opposition from consumers. They feel that public education on the safety and efficacy of tertiarily treated urban recycled water is a necessary precursor to any significant adoption by farmers. This finding is consistent with public opinion research on this topic going back to the 1980s.

In terms of our analysis of a specific successful recycling project, the Monterey County Water Recycling Project (MCWRP), was established under the cooperation of federal, state, regional and local authorities. Federal sources financed roughly 70% of the initial capital costs, while local authorities own and manage the project. In turn, growers receive urban recycled water and pay acreage fees. Reasons for the success of this project include cost sharing among all beneficiaries, devolution of sufficient authority to regional and local authorities to impose alternative (less desirable) solutions to the region's seawater intrusion problems, federal and state financial support, and development of innovative project-management institutions. Future challenges could arise from increasing competition for all water supplies in the region.

This research is describing in detailed, practical terms what kind of institutions were created and utilized so that the Castroville Seawater Intrusion Project could go forward. This is California's largest urban-to-agriculture water-reuse program, and may serve as a model for other projects around the state in the coming decades. Because the state is facing potential large-scale water shortages, research into how to satisfy growing water demand—in this case through water reuse—is especially important. The research is also investigating the interface of public water management with private water utilization from a perspective of how the institutional structure of

Key Words

Water reuse
Agriculture
Institutional relationships
Irrigation
Wastewater
Reclamation
Water reclamation

cooperation (laws, regulations, ownership) influences the effectiveness of the interaction in terms of implementing water-reclamation and reuse projects.

Publications and Presentations

• In the second year of this project, we published initial findings in the Proceedings of the Annual Meeting of California WaterReuse Association (Haddad, Brunkard and Mueller), finalized revisions (and changed authorship) of our research on the Monterey County Water Recycling Project (Haddad, forthcoming), and advanced our preparation of our paper on liability along agricultural supply chains.

• Haddad, B. 2000. "The Monterey County Recycling Project: An Institutional Analysis," *Journal of Water Resources Planning and Management*, forthcoming.

• Haddad, B., J. Brunkard and K. Mueller. 1999. "Farmer Incentives to Utilize Urban Reclaimed Water in California: Report on a Survey", *Proceedings of the Annual Symposium of the WateReuse Association*, Long Beach, CA, July 1999.

Collaborative Efforts

This research has led to discussions between Professor Haddad and other U.C. faculty on the topic of social-science analysis of efforts to establish indirect potable reuse projects in California. Indirect potable reuse involves the advanced treatment of urban wastewater followed by its introduction to aquifers, reservoirs or streams destined for human use. A proposal for additional funding to study this topic is in preparation.

Research Staff

In the second year, this project provided funding for three graduate (Ph.D.) students. Joan Brunkard and Karsten Mueller participated in survey research and drafting papers relating to urban-to-agricultural transfers of recycled water. Anne Mullan investigated food-chain product-failure liability issues and their relationship to farmer utilization of urban recycled water. This research directly aided Karsten Mueller's dissertation work on water conservation in California. Mueller and Mullan are both doctoral candidates.

An Integrated Modeling Framework for Analyzing Wetlands Policies: Balancing Ecosystem Services and Economic Factors

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U.S. Department of Agriculture
and UC Davis

Project W-926
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Wetlands management is important for water policies in general because (1) they affect water quality by serving as sinks or sources of nutrients and sediments, (2) are important for flood management since they affect the timing and intensity of flood waves, thereby affecting average flood damages in the floodplain, and (3) they have implications for water supplies since healthy wetland systems depend upon adequate water inputs.

The purpose of this project is to construct and operationalize a framework for incorporating considerations of ecosystem services into wetland management. The framework consists of (1) estimating relationships between landscape configuration and the provision of key ecosystem services from wetlands, and (2) incorporating these functions into a spatial optimization model that will allow an analyst to determine the optimal configuration of management decisions in a study area. The model will determine the set of patches in the study area that, if effectively preserved or restored to wetlands, result in the largest gains in ecosystem services for a given management budget.

In this first year of research we have developed a spatial optimization model and applied it to a stylized landscape representative of watersheds in the Central Valley of California. The landscape and the functions describing the provisions of ecosystem services were specified based on general ecological principles. We have applied the model to our hypothetical landscapes in a number of simulation exercises, and we have made important progress towards determining the ultimate applicability of this type of framework.

The results of our simulation exercises demonstrate several important phenomena regarding multi-objective decision-making in a spatially interdependent landscape. First, the only way to guarantee cost-effective management is with a strategy that takes into account all of the important spatial interdependencies regarding the provision of ecosystem services, and considers how management decisions in each location affect the benefits of management at all other locations. Heuristics based on loose indicators of overall levels of ecosystem functions will often result in sub-optimal levels of ecosystem services, even if total wetland area is maximized.

Second, Monte Carlo analyses show that the performance of sub-optimal heuristics—such as simply maximizing total wetland acres—which may be the only feasible means of approaching large problems in the real world, depends in part upon the initial configuration of the landscape. Furthermore, sensitivity analyses demonstrate the importance of the magnitude of the spatial effects on the provision of ecosystem services. For example, even though edge effects may be biologically significant for a particular species of concern in the region, if they are not sufficiently large then optimum habitat conditions may be provided by restoring several, inexpensive unconnected wetland patches as opposed to fewer, more costly continuous patches.

Third, we demonstrate is that effective management depends not only upon the nature of the processes that determine the level of ecosystem services, but also upon the degree to which the costs of

Key Words

Wetlands
Cost-effectiveness
Ecosystem services
Optimization

conservation depend on the location and configuration of managed patches. An integrated analysis that combines considerations of both the relevant ecology and economics is required here, and the framework we are developing will provide this capability.

The next year of research will focus on empirically estimating productions functions for a subset of key indicators of three important ecosystem services: habitat quality, water quality, and flood management benefits.

Publications and Presentations

An abstract was submitted and accepted for a conference presentation, and the subsequent conference paper will be reviewed for inclusion in a handbook to be published by a major publisher. The conference is: Integrated Decision-Making for Watershed Management Symposium, to be held on January 7-9, 2001 in Chevy Chase, MD (http://conted.vt.edu/watershed.htm).

Collaborative Efforts

After receiving Water Resources Center funding this project was selected for funding by EPA under a joint NSF/EPA call for proposals: Decision-making and Valuation for Environmental Policy. EPA will provide supplemental funding for the first two years of the project, and full funding for a third year. The total amount of the award was approximately $125,000.

Research Staff

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Stephen C. Newbold, UC Davis, Department of Environmental Science and Policy. This project will serve as Newbold's dissertation.

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Water Resources Center

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