California Institute for Water Resources
Annual Technical Report
FY 2012

Introduction

The California Institute for Water Resources (CIWR) is a special program within the University of California's Division of Agriculture and Natural Resources (UCANR), enabled by the federal Water Resources Research Act (WRRA), with the mission of supporting research and extension activities that contribute to the efficient management of California's water resources, in water quality, quantity, and reliability.

CIWR brings together federal, state, and local stakeholders to identify issues and sources of political and financial support for water-related research. The CIWR mission is to provide leadership to engage with state entities to help identify water priorities in California and engage existing UC campus-based Water Centers to implement statewide water planning, research, and outreach. The University of California system supports nine additional water-related research centers and two water-related programs with the sustained efforts of approximately 271 UC faculty members on eight of UC's 10 campuses. The CIWR also engages with non-UC Water Centers and academics interested in California water (e.g., several CSUs, Stanford University, and others).

Given the WRRA statutory mission of education and outreach, CIWR is best suited to linking water research to the needs of water managers and users throughout California. The CIWR serves an important linkage niche: science to public policy, science to education and outreach, researchers to State agencies and the public, UCANR initiatives to each other, UC Water Centers to each other, and UC Water Centers to other academic institutions.

CIWR allows individual campus water Centers to continue their research work and focus, as well as provide opportunities to those Centers for greater collaboration. The Institute serves a coordinating function, not competing with existing UC Water Centers for research resources.

The Institute's Director is housed within UCANR to facilitate a statewide focus. During the past year the Director has networked with other University of California (UC) and California State University (CSU) Water Centers and individual academics who are engaged in research, education, and extension activities related to California water.

The CIWR Director now serves as a key spokesperson on California water issues - working with federal, state, regional, nonprofit, and campus stakeholders to improve the understanding of water issues through advocacy and outreach programs. CIWR conducts and sponsors conferences, symposia, and other events to increase public awareness of water issues and resource management strategies (see Information Transfer Program).

The Director of CIWR also serves as Leader for UCANR's Strategic Initiative on Water Quality, Quantity, and Security. Thus, part of CIWRs mission is to assist UCANR in the management of this Strategic Initiative. As part of that Initiative, CIWR helps to manage UCANR's competitive grants portfolio. Through this partnership, CIWR is developing such strategic themes of importance as nitrogen use efficiency in agriculture, irrigation efficiency, ecosystem services, water policy, drinking water protection, food safety, and water quality (see additional projects funded and cost shared in this proposal).

Rosenberg International Forum on Water Policy: The overarching theme of the Rosenberg Forum is to reduce conflict in the management of water resources. Specific sub-themes are chosen by the Advisory Committee for each individual Forum. The primary objective is to facilitate the exchange of information and experience in the management of water resources. The problems of managing water are surprisingly common around the world. However approaches and solutions may differ depending upon the available financial resources as well

as social and cultural norms. Discussion of alternative approaches and identification of what works and what does not work are intended to aid in devising more effective and efficient water management schemes.

There are two sub-objectives which provide specificity and support in achieving the main objective and in addressing the overarching theme. The first is to emphasize the role of science in making of water policy and in the management of water resources. The second is to promote exchange and interaction between scientists and policy-makers for the purpose of facilitating the use of science as a basis for the making of water policy. Participants at each Forum are a mix of scientists and policy makers. The presentations and discussion focus equally on illumination of the pertinent science for policy making and on the experience with different policies in different settings around the world. In the past year the CIWR has supported the planning and development of the 8th Rosenberg Forum. The Forum was initially planned for fall 2012 in Aqaba, Jordan. Due to security concerns the Forum was postponed to late March 2013.

Research Program Introduction

CIWR assists ANR in the water aspects of its competitive grants program and its extension collaborations throughout California.

ANR Grants Programs:

ANR Competitive Grants Program: ANR invests in research, education and outreach projects that meet the goals of its mission by conducting an internal competitive grants program aimed to support high priority issues, encourage collaboration among ANR representatives and key players from throughout the state, support short-term high-impact projects, continue to strengthen the research-extension continuum, yield policy relevant outcomes, and achieve significant statewide economic, environmental and social impacts in California. To address some of these challenges, ANR developed the Strategic Vision 2025 to identify and meet the statewide scientific, technological, social, and economic demands facing California. As an initial implementation strategy, ANR identified five Strategic Initiatives that are favorably positioned within the Division to achieve maximum results. To attest to the importance of California water research, one of the five grant categories is specifically dedicated to “Water Quality, Quantity, and Security.”

Joseph G. Prosser Trust: The Irrigation Management Program, funded by the Joseph G. Prosser Trust, supports a broad spectrum of research related to crop irrigation management, focusing on conserving water, improving irrigation efficiency, and optimizing yields. Emphasis is placed on research outputs that improve current practices, and on dissemination of information. Recent projects fully funded by this program include “Creek carbon – Dynamics of carbon and nitrogen in restored Mediterranean riparian zones (Davis Lewis, UCCE Marin County).”

M. Theo Kearney Endowment: This fund is currently directed to support research in the relations of soil and water to plants through basic physical, chemical, biological, and hydrological research. Studies are targeted at understanding the balancing of multiple ecosystem services and biotic diversity in California’s working landscapes. One project is currently fully supported by this fund: "Effect of forest management on water yields and other ecosystem services in Sierra Nevada forests" (Kevin O’Hara, Environmental Science, Policy, and Management Department, UC Berkeley).

Improving aquifer storage recovery operation to reduce nutrient load and benefit water supply

Basic Information

Title:	Improving aquifer storage recovery operation to reduce nutrient load and benefit water supply
Project Number:	2007CA195G
Start Date:	7/1/2008
End Date:	6/30/2012
Funding Source:	104G
Congressional District:	17th
Research Category:	Ground-water Flow and Transport
Focus Category:	Water Supply, Water Quality, Nitrate Contamination
Descriptors:	
Principal Investigators:	Andrew Fisher, Marc Los Huertos, Charles Geoffrey Wheat

Publications

1. Papers Presented at Professional Meetings (*student co-authors) *Schmidt, C., A. T. Fisher, M. Los Huertos, B. Lockwood, 2008. Processes, controls, and potential for in-situ nutrient removal during managed aquifer recharge to a shallow aquifer, Am. Geophys. Union, Fall Meet. Suppl., Abstracts on CD-ROM.
2. *Racz, A., A. T. Fisher, B. Lockwood, M. Los Huertos, C. Schmidt*, J. Lear, 2008. Quantifying the distribution and dynamics of managed aquifer recharge using mass-balance and time-series thermal methods, Am. Geophys. Union, Fall Meet. Suppl., Abstracts on CD-ROM.
3. Papers Presented at Professional Meetings (*student co-authors) *Schmidt, C., A. T. Fisher, M. Los Huertos, B. Lockwood, 2008. Processes, controls, and potential for in-situ nutrient removal during managed aquifer recharge to a shallow aquifer, Am. Geophys. Union, Fall Meet. Suppl., Abstracts on CD-ROM.
4. *Racz, A., A. T. Fisher, B. Lockwood, M. Los Huertos, C. Schmidt*, J. Lear, 2008. Quantifying the distribution and dynamics of managed aquifer recharge using mass-balance and time-series thermal methods, Am. Geophys. Union, Fall Meet. Suppl., Abstracts on CD-ROM.
5. *Schmidt, C., A. T. Fisher, M. Los Huertos, B. Lockwood, The magnitude and controls on denitrification during managed aquifer recharge into a shallow, unconfined aquifer in a coastal groundwater basin, Am. Geophys. Union, Fall Meet. Suppl., Abstracts on CD-ROM, 14-18 December 2009.
6. *Racz, A., A. T. Fisher, B. Lockwood, M. Los Huertos, C. Schmidt*, J. Lear, Spatial and temporal variations in seepage during managed aquifer recharge, Am. Geophys. Union, Fall Meet. Suppl., Abstracts on CD-ROM, 14-18 December 2009.
7. *Schmidt, C., A. T. Fisher, A. Racz, C. G. Wheat, J. Sharkey, B. Lockwood, Processes and controls on rapid nutrient removal during managed aquifer recharge, 27th Biennial Groundwater Conference, Abstracts with programs, Sacramento, CA, October 6-7 2009.
8. Papers Presented at Professional Meetings (*student co-authors) *Schmidt, C., A. T. Fisher, M. Los Huertos, B. Lockwood, 2008. Processes, controls, and potential for in-situ nutrient removal during managed aquifer recharge to a shallow aquifer, Am. Geophys. Union, Fall Meet. Suppl., Abstracts on

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9. *Racz, A., A. T. Fisher, B. Lockwood, M. Los Huertos, C. Schmidt*, J. Lear, 2008. Quantifying the distribution and dynamics of managed aquifer recharge using mass-balance and time-series thermal methods, Am. Geophys. Union, Fall Meet. Suppl., Abstracts on CD-ROM.
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13. *Racz, A. J., A. T. Fisher, C. I. Schmidt*, B. Lockwood, and M. Los Huertos, 2011, The spatial and temporal dynamics of infiltration during managed aquifer recharge, as quantified using mass balance and thermal methods, Ground Water, accepted for publication (pending minor revision).
14. *Schmidt, C. I., A. T. Fisher, A. J. Racz*, M. Los Huertos, and B. Lockwood, 2011, Rapid nutrient load reduction during infiltration as part of managed aquifer recharge in an agricultural groundwater basin, Hydrol. Proc., accepted for publication (pending minor revision).
15. *Schmidt, C., A. T. Fisher, M. Los Huertos, B. Lockwood, Managed aquifer recharge as tool for sustainable management of ground water quantity and quality in agricultural basins, in Towards Sustainable Groundwater in Agriculture, Groundwater Resources Association of California, June 15-17, 2010 San Francisco, CA, p. 154.
16. Langridge, R. and Fisher, A. T., Climate Change, Agriculture and Sustainable Groundwater Management: Groundwater Reserves as a Hedge Against Climate Change and Drought, Eos Trans Am. Geophys. Union, Fall Meet. Suppl., San Francisco CA, H51G-03 (invited), Abstracts on CD-ROM.
17. *Schmidt, C. M.., *Russo, T. A., Fisher, A. T., *Racz, R. J., Wheat, C. G., Los Huertos, M., Lockwood, B. S., Mitigating agricultural impacts on groundwater using distributed managed aquifer recharge ponds, Eos Trans Am. Geophys. Union, Fall Meet. Suppl., San Francisco CA, H53A-0984, Abstracts on CD-ROM.
18. Papers Presented at Professional Meetings (*student co-authors) *Schmidt, C., A. T. Fisher, M. Los Huertos, B. Lockwood, 2008. Processes, controls, and potential for in-situ nutrient removal during managed aquifer recharge to a shallow aquifer, Am. Geophys. Union, Fall Meet. Suppl., Abstracts on CD-ROM.
19. *Racz, A., A. T. Fisher, B. Lockwood, M. Los Huertos, C. Schmidt*, J. Lear, 2008. Quantifying the distribution and dynamics of managed aquifer recharge using mass-balance and time-series thermal methods, Am. Geophys. Union, Fall Meet. Suppl., Abstracts on CD-ROM.
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25. *Schmidt, C., A. T. Fisher, M. Los Huertos, B. Lockwood, Managed aquifer recharge as tool for sustainable management of ground water quantity and quality in agricultural basins, in Towards Sustainable Groundwater in Agriculture, Groundwater Resources Association of California, June 15-17, 2010 San Francisco, CA, p. 154.
26. Langridge, R. and Fisher, A. T., Climate Change, Agriculture and Sustainable Groundwater Management: Groundwater Reserves as a Hedge Against Climate Change and Drought, Eos Trans Am. Geophys. Union, Fall Meet. Suppl., San Francisco CA, H51G-03 (invited), Abstracts on CD-ROM.
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28. *Racz, A. J., A. T. Fisher, C. I. Schmidt*, B. Lockwood, and M. Los Huertos, 2011, The spatial and temporal dynamics of infiltration during managed aquifer recharge, as quantified using mass balance and thermal methods, Ground Water, doi: 10.1111/j.1745-6584.2011.00875.x.
29. *Schmidt, C. M., A. T. Fisher, A. J. Racz*, C. G. Wheat, M. Los Huertos, and B. Lockwood (2011), Rapid nutrient load reduction during infiltration as part of managed aquifer recharge in an agricultural groundwater basin: Pajaro Valley, California, Hydrol. Proc. , 10.1002/hyp.8320.
30. *Schmidt, C. M., A. T. Fisher, A. J. Racz*, B. Lockwood, and M. Los Huertos (2011), Linking denitrification and infiltration rates during managed groundwater recharge, Env. Sci. Tech., dx.doi.org/10.1021, es2023626.
31. *Racz, A. J., Fisher, A. T., *Schmidt, C. M., Lockwood, B. S., Los Huertos, M., Modeling the spatial and temporal dynamics of infiltration during managed aquifer recharge, Eos Trans Am. Geophys. Union, Fall Meet. Suppl., San Francisco CA, H41E-1077, Abstracts on CD-ROM. (Awarded Outstanding Student Presentation Award)
32. *Russo, T. A., Fisher, A. T., Hanson, R. T. and Lockwood, B. S., Spatial Analysis of Suitability for Managed Aquifer Recharge in a Groundwater Basin in Central Coastal California, Eos Trans Am. Geophys. Union, Fall Meet. Suppl., San Francisco CA, H13E-1259, Abstracts on CD-ROM. (Awarded Outstanding Student Presentation Award)
33. Fisher, A. T., *Schmidt, C., *Racz, A., Los Huertos, M. Lockwood, B., Dynamic Variations and Improvement to Water Supply and Quality during Managed Recharge, 28th Biennial California Groundwater Conference, Groundwater Resources Association of California, Sacramento, CA (invited), Abstracts with Programs.
34. *Russo, T. A., Fisher, A. T., Los Huertos, M., *Jacuzzi, N., Spatial Analysis of Suitability for Managed Aquifer Recharge in Central Coastal California, 28th Biennial California Groundwater Conference, Groundwater Resources Association of California, Sacramento, CA, Abstracts with Programs.
35. Fisher, A. T., *Schmidt, C., *Racz, A., Los Huertos, M. Lockwood, B., Dynamic Variations and Improvement to Water Supply and Quality during Managed Recharge, a presentation to the Pajaro River Watershed Council, 10/13/12.
36. Fisher, A. T., *Schmidt, C., *Racz, A., Los Huertos, M. Lockwood, B., Dynamic Variations and Improvement to Water Supply and Quality during Managed Recharge, a presentation to the South Bay Region of the Groundwater Resources Association of California, 11/11/12.
37. Papers Presented at Professional Meetings (*student co-authors) *Schmidt, C., A. T. Fisher, M. Los Huertos, B. Lockwood, 2008. Processes, controls, and potential for in-situ nutrient removal during managed aquifer recharge to a shallow aquifer, Am. Geophys. Union, Fall Meet. Suppl., Abstracts on CD-ROM.

38. *Racz, A., A. T. Fisher, B. Lockwood, M. Los Huertos, C. Schmidt*, J. Lear, 2008. Quantifying the distribution and dynamics of managed aquifer recharge using mass-balance and time-series thermal methods, Am. Geophys. Union, Fall Meet. Suppl., Abstracts on CD-ROM.
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46. *Racz, A. J., A. T. Fisher, C. I. Schmidt*, B. Lockwood, and M. Los Huertos, 2011, The spatial and temporal dynamics of infiltration during managed aquifer recharge, as quantified using mass balance and thermal methods, Ground Water, doi: 10.1111/j.1745-6584.2011.00875.x.
47. *Racz, A. J., Fisher, A. T., *Schmidt, C. M., Lockwood, B. S., Los Huertos, M., Modeling the spatial and temporal dynamics of infiltration during managed aquifer recharge, Eos Trans Am. Geophys. Union, Fall Meet. Suppl., San Francisco CA, H41E-1077, Abstracts on CD-ROM. (Awarded Outstanding Student Presentation Award)
48. *Russo, T. A., Fisher, A. T., Hanson, R. T. and Lockwood, B. S., Spatial Analysis of Suitability for Managed Aquifer Recharge in a Groundwater Basin in Central Coastal California, Eos Trans Am. Geophys. Union, Fall Meet. Suppl., San Francisco CA, H13E-1259, Abstracts on CD-ROM. (Awarded Outstanding Student Presentation Award)
49. Fisher, A. T., *Schmidt, C., *Racz, A., Los Huertos, M. Lockwood, B., Dynamic Variations and Improvement to Water Supply and Quality during Managed Recharge, 28th Biennial California Groundwater Conference, Groundwater Resources Association of California, Sacramento, CA (invited), Abstracts with Programs.
50. *Russo, T. A., Fisher, A. T., Los Huertos, M., *Jacuzzi, N., Spatial Analysis of Suitability for Managed Aquifer Recharge in Central Coastal California, 28th Biennial California Groundwater Conference, Groundwater Resources Association of California, Sacramento, CA, Abstracts with Programs.
51. Fisher, A. T., *Schmidt, C., *Racz, A., Los Huertos, M. Lockwood, B., Dynamic Variations and Improvement to Water Supply and Quality during Managed Recharge, a presentation to the Pajaro River Watershed Council, 10/13/12.

52. Fisher, A. T., *Schmidt, C., *Racz, A., Los Huertos, M. Lockwood, B., Dynamic Variations and Improvement to Water Supply and Quality during Managed Recharge, a presentation to the South Bay Region of the Groundwater Resources Association of California, 11/11/12.
53. Russo, T. A., Fisher, A. T., *Winslow, D. M, 2013, Regional and local increases in storm intensity in the San Francisco Bay Area, USA, between 1890 and 2010, J. Geophys. Res., Atmospheres, 118: 1–10, doi:10.1002/jgrd.502252013.
54. Fisher, A. T., *Racz, A., *Schmidt, C., Los Huertos, M. Lockwood, B., Russo, T., Dynamic Variations and Improvement to Water Supply and Quality during Managed Recharge, Seminar presented at the weekly department seminar, Geological Sciences Department, San Francisco State University, 10 April 2012.
55. Fisher, A. T., *Schmidt, C., *Racz, A., Los Huertos, M. Lockwood, B., Russo, T., Achieving Simultaneous Benefits during Managed Recharge: Improvements to Water Quality and Water Supply, Salt and Nitrate in Groundwater, 26th Groundwater Resources Association of California Symposium on Contaminants, Fresno, CA, 13 June 2012.
56. Fisher, A. T., *Racz, A., *Schmidt, C., Los Huertos, M. Lockwood, B., Russo, T., Spatial and Temporal Variability During Managed Recharge: Impacts on Water Supply and Quality in the Pajaro Valley, Seminar presented at the weekly department seminar, Science and Environmental Policy, California State University, Monterey Bay, 12 September 2012.
57. Fisher, A. T., *Racz, A., *Schmidt, C., Los Huertos, M. Lockwood, B., Russo, T., Spatial and Temporal Variability During Managed Recharge: Impacts on Water Supply and Quality in the Pajaro Valley, Seminar presented during lunch hour to engineering and water quality staff, Santa Clara Valley Water District, 20 September 2012.
58. Fisher, A. T., Enhanced groundwater storage to augment fresh water supplies, Public Forum on Water, Louden Nelson Community Center, Santa Cruz CA, 11 October 2012.
59. Fisher, A. T., *Racz, A., *Schmidt, C., Los Huertos, M. Lockwood, B., Russo, T., Dynamics of Infiltration, Soil Properties, and Water Quality During Managed Aquifer Recharge, Seminar presented at the department seminar, Environmental Fluid Dynamics and Hydrology colloquium, Stanford University, 5 November 2012.
60. Fisher, A. T., Managed recharge to enhance groundwater resources: opportunities and challenges, UCSC Lecture and Lunch series, Santa Cruz Museum of Art and History, Santa Cruz, CA, 15 November 2012.
61. Russo, T. A., Fisher, A. T., Winslow, D. M., Regional and Local Increases in Storm Intensity in the San Francisco Bay Area between 1890 and 2010, Eos Trans Am. Geophys. Union, Fall Meet. Suppl., San Francisco CA, GC11E-05, Abstracts on CD-ROM.

Research Program:

Our research project focused on how improvements can be made to water supply and water quality during managed aquifer recharge (MAR). We collaborated on this research with a local water agency, researchers at other academic institutions and the U.S. Geological Survey, the Resource Conservation District of Santa Cruz County, the Community Water Dialog (a grassroots community group involved in water issues) and numerous landowners, growers, and other regional stakeholders. The review period included in this summary of results includes the second half of the 2012 water year and the first half of the 2013 water year. The first several years of this project focused on a MAR project that is operated by the Pajaro Valley Water Management Agency (PVWMA). This project includes an infiltration pond that is used to recharge fresh water into a shallow, perched aquifer (Figure 1). This water is used by local growers in lieu of pumping groundwater from a regional aquifer that is impacted by overdraft and resulting seawater intrusion. The water put into the pond is diverted from a nearby wetland system during the wet (rainy) season, when flows are sufficient high and water quality is good.

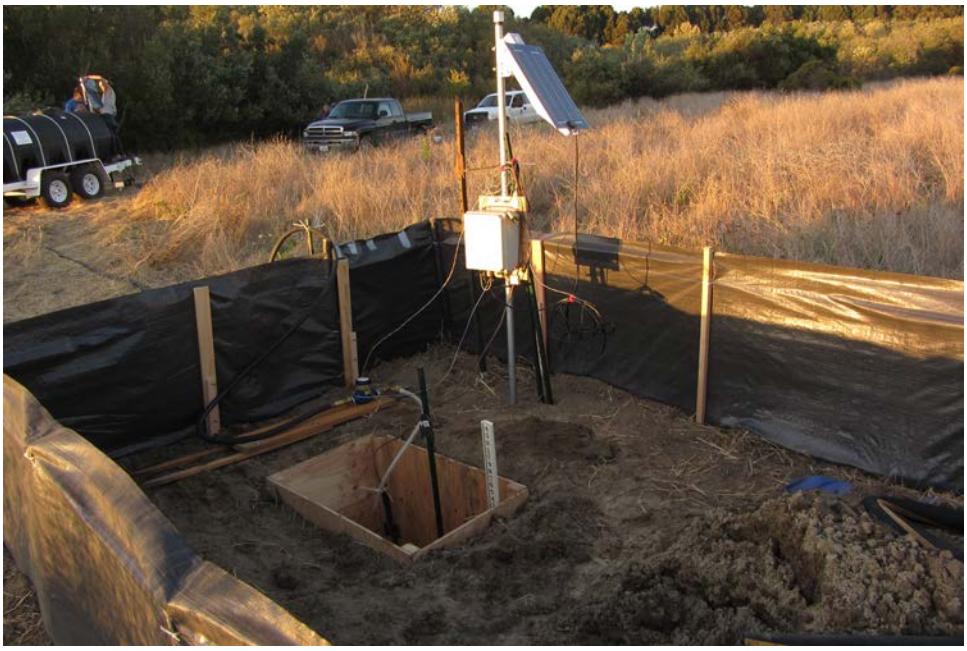

Figure 1. Site configured for infiltration testing, Monterey County.

The first three years of this effort focused on this MAR system, but in the last two years, we have extended these results by transitioning the project to two additional settings: a recharge basin established by a local grower to capture stormwater, and a field site owned by the State of California being considered for managed recharge using recycled waste water. We also extended this work regionally through use of a Geographic Information System (GIS) and a sophisticated regional groundwater model. All of these developments have helped to bring research results into a phase of water supply project implementation.

At field sites, our work involves monitoring the rates of shallow infiltration using mass balance techniques, and determining rates of infiltration at specific locations using heat as a tracer. This last technique involves innovative use of time-series analysis to resolve changes in diurnal temperature changes in shallow soils below the pond, developed in the first three years of our research program. We monitor groundwater levels and quality using local monitoring wells. We deployed water

content, pressure, and thermal sensors in the infiltration pond, allowing us to assess rates of infiltration at different locations. We sampled shallow soils before each recharge season, and again at the end of each recharge season to evaluate the influence of recharge on soil grain size, soil carbon content, and hydraulic properties. This also helps us to assess the influence that sediment transport and deposition may have for project maintenance, a topic of considerable concern to growers and land owners who are considering putting projects like these on their property.

In past two years, we focused on write up and publication of several papers in top-tier journals resulting from work at our initial field site. Full pond infiltration rates were typically 1–5 m/day during the initial 2–3 weeks after the MAR pond was filled, but decreased rapidly to 0.2–0.4 m/day and remained at this rate for the next 6–8 weeks. In addition, we documented large spatial and temporal variations in infiltration rates that shifted during a 6–8 week period. The greatest rates of infiltration were initially at the northwestern end, but the center of the highest rate of infiltration swept across the pond to the southeast, as the magnitude of infiltration rates decreased with time. Grain size analyses of samples collected before and after each recharge season suggest that initial periods of infiltration caused the loss of fine grained material from the upper 50 cm of the subsurface. Later in the season, a thin layer of fine sediment accumulated at the base of the pond, causing a reduction in hydraulic conductivity. The net result is that the overall rate of infiltration slowed, and the extent of saturation decreased in the shallow subsurface because the rate of inflow could not keep up with the rate of drainage from below.

Evaluation of fluid chemistry showed that there was a 30-60% load reduction during the passage of water from the pond through the upper 1 m of subsurface soils, and low nitrate water arrived at the monitoring wells surrounding the recharge pond at different times as a function of distance and direction. Nitrate isotopic analyses showed that the primary mechanism of nitrate removal was denitrification. Comparison of denitrification rates apparent from our data, based on combined chemical and thermal results, are at the high end of denitrification rates detected in soil and groundwater systems in other settings. It may be that this system is especially efficient at denitrification because of the high availability of organic carbon in the diverted fluids, and the availability of particulate carbon in subsurface soils. We have also found that high rates of denitrification were maintained even at some of the greatest infiltration rates, but that eventually (at the highest infiltration rates), we see the expected decrease in denitrification efficiency.

In the last two project years, we instrumented a new field site in the southern Pajaro Valley, a three-acre infiltration basin designed to capture stormwater runoff from a 122 acre area. We deployed sediment collection systems, pressure gauges, a rain gauge, and thermal probes. Unfortunately, the last two rainy seasons were both relatively dry, with only 60-70% of "normal" precipitation falling, and much of this falling during a small number of precipitation events. In the 2011-12 water year, we documented only about 5-10 acre-feet of water entering the infiltration basin. In the 2012-13 water year, most of the rain fell during a one-month period (December 2012), and it appears that considerably more recharge benefit was achieved. The field site was instrumented with thermal probes, pressure gauges (for water) level and discharge, and sediment collection systems. Two week ago, we recovered all of our instruments and samples collection devices that were deployed for the 2012-13 rainy season. All instruments returned usable samples/data, and we are currently processing these results and samples; this work will comprise part of a PhD thesis for a UCSC graduate student. We also have two new undergraduate students working on thesis projects as part of this work.

We completed a GIS and modeling study of regional MAR opportunities, and are have a draft manuscript that is almost ready for submission to a peer-reviewed journal. The GIS analyses used

topographic, land use, surficial geology, soil infiltration capacity, aquifer and associated confining layer locations, properties, thicknesses, and historical changes in water levels. A map of MAR site suitability and comparison with an existing project suggests that about 8% of the basin may be highly suitable for MAR (Figure 2). Model results show simulated MAR projects in locations identified as "highly suitable" for MAR reduce seawater intrusion more than projects simulated in "unsuitable" locations, supporting the GIS analysis results. Results from the model also illustrate the variability in seawater intrusion reduction and head level changes throughout the basin and over time, as simulated MAR project locations vary. Collectively, these studies help to evaluate management options for improving long-term groundwater conditions, both supply and quality.

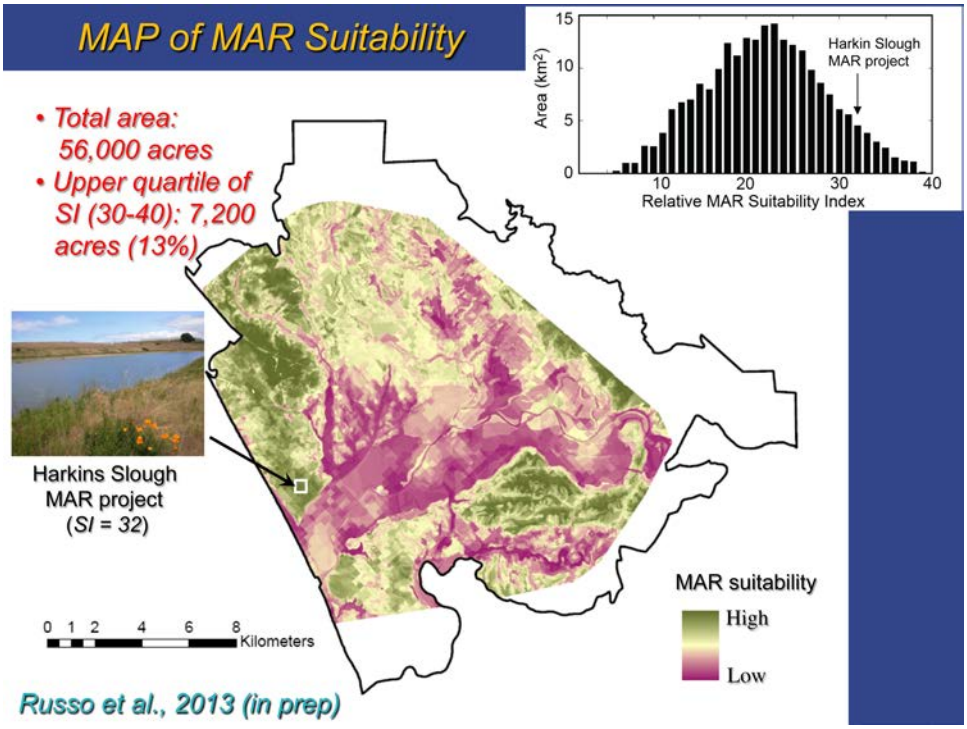

Figure 2. MAR suitability map for the Pajaro Valley

We completed a statistical analysis of historic data from over 600 precipitation stations in the San Francisco Bay Area (SFBA), California, to assess whether there have been statistically significant changes in extreme precipitation between 1890 and 2010. This issue is important for assessing groundwater recharge because there is expected to be less recharge if more precipitation falls during a smaller number of intense events. An annual exceedance probability analysis of extreme precipitation events in the SFBA, coupled with a Markov chain Monte Carlo algorithm, reveals an increase in the occurrence of large events. The depth-duration-frequency characteristics of maximum annual precipitation events having durations of 1 h to 60 days indicate on average an increase in storm intensity in the last 120 years, with the intensity of the largest (least frequent) events increasing the most. Mean annual precipitation (MAP) also increased during the study period, but the relative increase in extreme event intensity exceeds that of MAP, indicating that a greater fraction of precipitation fell during large events. Analysis of data from subareas within the SFBA region indicates considerable heterogeneity in the observed Q2 nonstationarity; for example, the 5 day, 25 year event exceedance depth changed by +26%, +16%, and –1% in San Francisco, Santa Rosa, and San Jose, respectively. These results emphasize the importance of analyzing local data for accurate risk assessment, emergency planning, resource management, and climate model calibration.

Information Transfer:

We have presented results of this work at numerous public meetings and, as a result, there is growing interest regionally in applying what we have learned to other settings.

Invited presentations were made during the reporting period to the following groups, including scientific and engineering personnel and the public at large:

- Program in Environmental Fluid Dynamics and Hydrology, Stanford University (invited department seminar).
- Department of Geological Sciences, SF State University (invited department seminar)
- Two meetings of the Pajaro Valley Water Dialogue
- Salinity Management conference of the Groundwater Resources Association of CA (invited presentation)
- Santa Clara Valley Water District (lunchtime seminar for engineering and water quality staff)
- Science and Environmental Policy seminar, California State University, Monterey Bay (invited department seminar)
- Santa Cruz Water Forum (public presentation on groundwater recharge)
- American Geophysical Union Fall Meeting (one poster, one talk presented)
- American Geophysical Union Hydrology Days (one poster)
- Webcast on Application of Tracer Studies to Managed Recharge, part of an online series developed by the Groundwater Resources Association of California, focusing on recharge (invited webinar).

We were interviewed by the following media groups, generating stories that were published in regional newspapers:

- Santa Cruz Sentinel (newspaper), Santa Cruz, CA

Students supported with NIWR and associated funds, in part, during the project:

- Calla Schmidt, Ph.D., Fall 2011 (CA SeaGrant Postdoc, now tenure track faculty in Environmental Science at the University of San Francisco)
- Tess Russo, Ph.D., Fall 2012 (Postdoc with the Earth Institute at Columbia University)
- Andrew Racz, Graduate Student (anticipated graduation in Summer 2013)
- Sarah Beganskas, Ph.D. student, began Fall 2012
- Katie Earp, B.S., Spring 2011
- Susanna Bird, B.S., Spring 2011 (Env. Chemistry)
- Devon Stewart, B.S. Spring, 2011
- Christina Richardson, B.S., Spring 2012
- Barbara Montgomery, B.S., Winter 2013
- Emily Edwards, B.S., expected Spring 2013
- Eric Lujan, B.S., expected Winter 2014
- Anna Weisenberger, B.S., expected Spring 2014

Award No. G09AC0001 Monitoring and Forecasting Climate, Water and Land Use for Food Production in the Developing World

Basic Information

Title:	Award No. G09AC0001 Monitoring and Forecasting Climate, Water and Land Use for Food Production in the Developing World
Project Number:	2008CA262S
Start Date:	10/1/2008
End Date:	9/30/2013
Funding Source:	Supplemental
Congressional District:	
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	

Publications

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Research Program:

This work builds upon both the first four years of this agreement as well as previous agreements which identified and built relationships with individuals and institutions in food insecure regions to facilitate the passage of information between at-risk populations, decision-makers and domestic and international government agencies. Research collaborations with USGS EROS have covered a wide range of projects including modeling and mapping precipitation and precipitation-related fields to support drought and flood mitigation, analyzing the impacts of sea-surface temperatures on global atmospheric circulation and rainfall, and estimating crop area in African countries. These activities are carried out by a team of researchers, graduate students and technicians at UCSB as well as field scientists stationed in Africa and Central America.

Core activities for Year 5 of the cooperative agreement include many of the fundamental efforts from the field scientists that were performed in Year 4. These include the core activities of training individuals at key institutions, monitoring and presenting timely data describing the impacts of meteorological events on crop production, and the collection and dissemination of data and information. While the essential link of getting this information distributed to the right people will continue to be performed by field scientists, significant resources in backstopping their efforts will be the responsibility of personnel at UCSB and USGS.

Effect of forest management on water yields and other ecosystem services in Sierra Nevada forests

Basic Information

Title:	Effect of forest management on water yields and other ecosystem services in Sierra Nevada forests
Project Number:	2012CA292B
Start Date:	1/1/2012
End Date:	12/31/2015
Funding Source:	104B
Congressional District:	44
Research Category:	Climate and Hydrologic Processes
Focus Category:	Ecology, Water Supply, None
Descriptors:	None
Principal Investigators:	Kevin O'Hara

Publications

There are no publications.

Research Project:

Project Summary

The Sierra Nevada harbors globally distinctive forest resources that deliver a wide variety of benefits to the citizens of California and elsewhere. These benefits derived from natural ecosystems – also called ecosystem services – include recreation, biodiversity, conservation, water, and forest product-related services. These ecosystem services often pose competing aims relative to forest management, but there are few mechanisms to evaluate the tradeoffs and complements related to different strategies.

Water is arguably the highest-value ecosystem service associated with the conifer forests of California's Sierra Nevada. Yet the provision of this essential service is vulnerable to changes in the energy and water balance associated with climate warming. To date, we have observed more precipitation falling as rain versus snow, earlier snowmelt, and greater summer water deficits. Such climate forcing will impact the water balance for the foreseeable future. However there is the potential to manage the water balance in forest ecosystems. The dominant vegetation (i.e., trees) is highly productive, forms dense canopies, and, consequently, uses a great deal of water. There is a strong positive correlation between annual net primary productivity (the ultimate measure of the photosynthetic capacity of the ecosystem) and evapotranspiration (the primary cause of water loss). Any manipulation that reduces the productivity (i.e., removes trees) reduces evapotranspiration, shifts the balance of energy driving snowmelt, and thus may affect soil-water storage and streamflow. Water from the Sierra Nevada provides both hydropower and water supply to downstream users. Reducing and restructuring the forest vegetation density can also mitigate the negative impacts of wildfires as well as accomplishing important forest-restoration.

The objectives of the project are to: 1) determine rates of evapotranspiration in Sierran mixed-conifer/true fir forests; 2) determine the water use efficiency of trees and shrubs in Sierran mixed-conifer/true fir forests; 3) determine the potential for forest management to delay snow melt in Sierran forests; 4) determine the potential economic tradeoffs of forest management treatments to affect water yield and ecosystem services; and 5) involve stakeholders in decision-making regarding forest management and watershed effects.

Summary of Activities/Outcomes to Date

This long-term project is underway with one year of intensive field work complete and the second year about to begin as of this date. However, we are just over one year into the project with no significant findings to report. Our fieldwork involves two general areas: 1) intensive measurement of trees for development of leaf area prediction equations, which equations will then be used with plot-level inventory to estimate leaf area index on selected watersheds; and 2) measurement of water use efficiency on individual trees. Combining 1 and 2 will enable us to look at water use efficiency at the stand- and watershed level. We have also made progress in identifying test watersheds and working with landowner/public land managers to develop potential treatments. We have initiated monitoring in some watersheds in anticipation of using them in future analyses.

We continue to anticipate that this work will provide new insights into the effects of forest structure on snow retention and water yields from Sierra Nevada mixed-conifer forests. The region continues to experience controversy over wildlife management, threats from fire, and water shortages are becoming a greater threat as we understand more about potential climate change in California. This work is as timely as when it was first proposed.

Outreach and Extension Programs for Co-management of Food Safety and Ecosystem Services in Fresh Produce

Basic Information

Title:	Outreach and Extension Programs for Co-management of Food Safety and Ecosystem Services in Fresh Produce
Project Number:	2012CA293B
Start Date:	9/1/2011
End Date:	3/15/2013
Funding Source:	104B
Congressional District:	44
Research Category:	Ground-water Flow and Transport
Focus Category:	Agriculture, Irrigation, Management and Planning
Descriptors:	None
Principal Investigators:	Mary Bianchi

Publications

There are no publications.

Research Program:

Growers and distributors of California's fresh produce have long realized that reliably safe products and responsible use of resources inspire brand trust and consumer loyalty. Balancing food safety and sustainability goals has become a vital element of produce management. On their farms, growers are active stewards of the land, protecting soil and water quality as well as supporting wildlife populations by preserving their habitat. At the same time, growers must ensure that their crops are free from contamination by fecal matter, which may introduce pathogens that can cause food borne illnesses. Balancing these unique management objectives while maintaining a sound bottom line is a central challenge for California's fresh produce producers and distributors.

Co-management offers a solution. Co-management minimizes the risk of fecal contamination and the resulting microbiological hazards associated with produce production while simultaneously conserving soil, water, air, wildlife, and other natural resources.

Information Transfer Program:

Since organizing the seminal co-management research conference in 2007, ANR advisors and specialists have participated in outreach, extension and research efforts. In cooperation with the Farm Food Safety and Conservation Network, ANR academics have organized and participated in biennial Co-management Forums on the Central Coast to bring the latest research information to policy makers, conservation and food safety professionals including FDA, EPA, USDA, DFG, USF&WS, and CA LGMA. ANR academics have received more than $1.5 million dollars in research funds to answer some of the critical research questions regarding microbial contamination in the production environment

Recognizing the need for a widely distributed and science-based description of co-management, ANR produced an Issues Brief in 2012, presented to the Food Science and Technology and the Sustainability Committees at the United Fresh 2012 meetings in Dallas Texas. This Issues Brief, *"Balancing food safety and sustainability: Opportunities for co-management*," has been distributed to federal and state policy makers as well buyers and distributors of fresh produce.

Co-management is widely recognized as a necessary consideration in fresh produce production. Consideration of co-management is included in the California and Arizona Leafy Greens Marketing Agreement and the 2011 Food Safety Modernization Act. By working together, food safety and sustainability managers can build understanding of how food safety practices may affect natural resources and how conservation practices affect food safety. Building understanding of co-management into all levels of management - from farm to fork - will ensure that the fresh produce industry continues to lead the way to successful balance of food safety, sustainability and a sound bottom line.

Regarding the Co-management Forums - Hank Giclas, senior vice president for strategic planning, science and technology at Western Growers said "despite the challenges, growers are committed to providing safe food while ensuring conservation of vital natural resources and these forums are

important settings in which a free flow of ideas and experiences are exchanged to further both objectives".

We are continuing to work with stakeholders to identify and engage appropriate produce buyers and food safety professionals. These audience members have helped us to design appropriate and effective mechanisms of ongoing outreach and actionable training materials for outreach to industry decision makers.

Creek Carbon - Dynamics of Carbon and Nitrogen in Restored Mediterranean Riparian Zones

Basic Information

Title:	Creek Carbon - Dynamics of Carbon and Nitrogen in Restored Mediterranean Riparian Zones
Project Number:	2012CA294B
Start Date:	9/1/2011
End Date:	8/30/2013
Funding Source:	104B
Congressional District:	44
Research Category:	Biological Sciences
Focus Category:	Water Use, Surface Water, Nitrate Contamination
Descriptors:	None
Principal Investigators:	David Lewis

Publications

1. UC Delivers, Sequestering Carbon from Watershed Restoration Conservation Practices 2013
2. Policy Brief, Realistic expectations for C sequestration from conservation practices 2013
3. Temporal vs. spatial and local vs. landscape control of C sequestration dynamics by riparian forests in Ca. coastal watersheds 2013
4. (ANR 8000 Series and/or Cal. Ag.), Watershed conservation practices also improved air quality 2013

Research Program:

Land managers have restored river and stream banks using revegetation technologies with native plant material for over four decades in coastal California, achieving multiple ecosystem functions and natural resource management objectives. The number of river and stream restoration projects in the U.S. has steadily increased since the 1980s with over $2 billion spent on river restoration in California. In Marin County alone, 25 miles of stream has been restored since the 1960s.

Despite the increase in stewardship effort and funds expended, there has been limited documentation of improvements in water quality, watershed functions, and ecosystem services. Though evidence of improved wildlife habitat is abundant, the current knowledge base is lacking an understanding of the biophysical relationships between soil properties, flooding, riparian forests, and the temporal vs. spatial variability controlling how conservation practices have restored watershed functions.

In addition to wildlife habitat and water quality, watershed restoration appears to have also improved air quality. Total and labile carbon increase over time as project age increases. The upperbank locations have consistently higher amounts than floodplains; however, the rate of carbon sequestration appears greater in floodplain soil and correlates to the rapid increase in canopy cover and root density as sites transition from grassland to riparian forest. Multivariate analysis is in progress to ascertain if keystone species or certain functional groups maximize long-term carbon storage. The conservation partnership, including most importantly its farmers and ranchers, have a fuller appreciation for what they have accomplished and are applying our results towards options to improve long-term agricultural viability.

Understanding long term carbon sequestration potential within coastal California streams provides a foundation of knowledge to maximize these ecosystem services. In doing so, the researchers are adding to the growing body of knowledge validating the outcomes from ecological restoration and conservation practices. The information is timely for policies and programs to mitigate greenhouse gas emissions and develop market driven incentives for carbon sequestration. It is also needed by restoration planners for optimizing revegetation project design and setting realistic objectives. Lastly, the funding community will utilize this research to guide the allocation of financial resources and document long term project effectiveness.

The objectives of our project include: 1) documenting the potential to store carbon and nitrogen pools in soil and vegetation across a chrono-sequence of riparian restoration projects; 2) measuring carbon pool fractions within riparian soils to document long term carbon sequestration potential within these systems; 3) understanding the characteristics of riparian restoration (age, biodiversity, stream characteristics) that affect processes of carbon and nitrogen storage in order to maximize these ecosystem services for future efforts; and 4) making the research information available to restoration practitioners, funders, and permitting agencies for integration of carbon sequestration and nitrogen storage into stream restoration objectives.

Figure 1 - 30 year old stream restoration site (left) and aggrading soil in a floodplain plot (left) depicting layers of annual leaf litter and sediment deposition (right).

Information Transfer:

Changes in Knowledge
The above ground component of carbon sequestration has been well understood and justifies revegetation with woody species as a mitigation tool for climate change. However, research into the below ground storage is showing the importance of recalcitrant carbon forms to long-term sequestration. Understanding the recovery processes of riparian forest systems offers pragmatic applications to riparian buffer management and maximizing ecosystem services over multiple decades.

Changes in Skill/Behavior/Practice
The effectiveness of existing conservation practices to impact new societal concerns offers the feedback needed to improve and fine-tune approaches for maximizing environmental returns. Stream restoration can now target watershed locations and soil types that provide the greatest potential for long-term carbon sequestration. Landowners are prioritizing new sites for conservation and restoration projects in addition to organizing old ranch photos that document pre-project conditions of previously restored sites.

Changes in Conditions
The conceptual relationships between vegetation and ecosystem function provides the foundation for impacting communities' approach to stewardship. Local Resource Conservation Districts are implementing water quality trading credits and grant funds are being leveraged to install new stream restoration projects. Policies encouraging ecosystem services have also utilized our results to validate how conservation practices have improved numerous ecological attributes and functions.

Creating or strengthening partnerships with stakeholders
The on-farm conservation partnership working across Marin, Sonoma, Napa, and Mendocino counties has directly benefited by this project in addition to numerous local programs such as the Marin Carbon Project. For example, the Natural Resource Conservation Service, local Resource Conservation Districts, university researchers, and private consultants are incorporating the

concepts and preliminary results from this project into their assessments of conservation practice effectiveness and plans to compensate landowners for providing ecosystem services.

Our research findings are being disseminated on multiple levels to local partners, regional programs, and international disciplines. The interest is very high in our results in part because of the critical reviews watershed restoration has received in recent years after spending over $2 billion dollars across the US. In addition, on-farm conservation practices are existing stewardship systems hungry for evidence supporting or refuting effectiveness to mitigate climate change that are reviewed by applied scientists in economics, agriculture, engineering, and many others with international exposure.

In summary, we documented the variation of carbon trajectories in streamside soil and vegetation from watershed restoration programs and the associated conservation practices. The information provides a data-driven quantification of actual outcomes for potential inclusion in market-based payments for ecosystem services and carbon or water quality credits. The conservation partnership, including most importantly its farmers and ranchers, have a fuller appreciation for what they have accomplished and greater options to improve long-term working landscape viability.

Spatial Analysis of Irrigation Efficiencies for the Sate of California

Basic Information

Title:	Spatial Analysis of Irrigation Efficiencies for the Sate of California
Project Number:	2012CA295B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	44
Research Category:	Climate and Hydrologic Processes
Focus Category:	Irrigation, Water Use, Water Supply
Descriptors:	None
Principal Investigators:	Samuel Sandoval Sandoval Solis

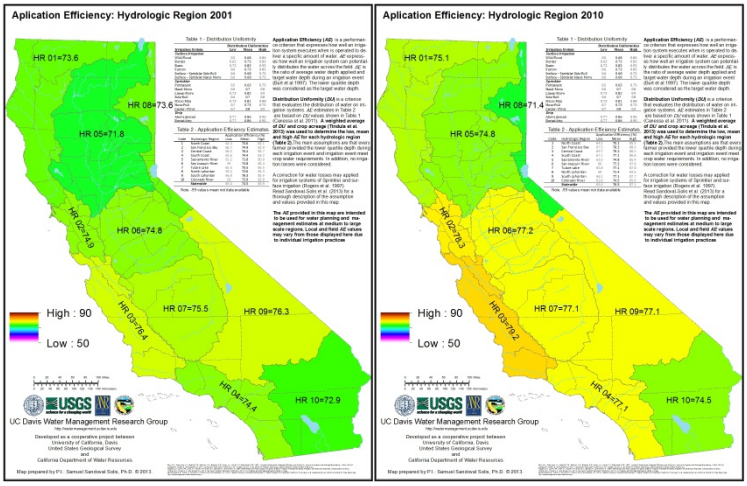
Publications

1. Sandoval-Solis, Samuel; Morrie, Orang: Richard, Snyder; Steve, Orloff; Kayle,Williams; and Jenna, Rodriguez (2013) “Analysis of Application Efficiencies of Irrigation Systems for the State of California,” J. Irrigation and Drainage Engineering. To be submitted
2. California Department of Water Resources (DWR) (2011). “Survey of Irrigation Methods in California: Statewide Irrigation methods Survey” <http://www.water.ca.gov/landwateruse/surveys.cfm> Visited Dec/2013.
3. Hagan, R. M., and Wagner, R. J. (1983). “Irrigation methods in California: An update.” California Dept. of Water Resources Division of Planning and Local Assistance, Sacramento, CA
4. Tindula, G.N., Orang, M.N., and Snyder, R.L. (2013). “Survey of Irrigation Methods in California in 2010” J. of Irrigation and Drainage Engineering, ASCE. In press.
5. Orang, M.N., Matyac, J.S. and Snyder, R.L. (2008) “Survey of Irrigation Methods in California in 2001” J. of Irrigation and Drainage Engineering, ASCE. 134(1):96-100
6. Sandoval-Solis, Samuel; Morrie, Orang: Richard, Snyder; Steve, Orloff; Kayle,Williams; and Jenna, Rodriguez (2013) “Spatial Analysis of Application Efficiencies of Irrigation Systems for the State of California,” Final Report. Water Management Research Group. University of California Davis. Davis, CA.
7. Sandoval-Solis, Samuel (2013) “Map of Application Efficiencies for Hydrologic Regions of the State of California”, plus entire project map library available at: http://watermanagement.ucdavis.edu/research/application-efficiency/maps/

Research Program:

Analyzing the application efficiency of irrigation systems is important to identify enhancements already achieved and potential places where improvements can be made. Application Efficiency (AE) is a performance criterion that expresses how well an irrigation system performs when is operated to deliver a specific amount of water. AE is defined as the ratio of the average water depth applied and the target water depth during an irrigation event. The average water depth is the average height of water applied in a field during an irrigation event. The target water depth is the desired water to be supplied in a field during an irrigation event. For this research, the target water depth is the low quartile depth, which is the average of the depths in the sections of the field that receives less water than the rest of the field (percentile < 0.25).

Five irrigation surveys have been conducted in California: in 1972, 1980, 1991, 2001, and 2010. These surveys have improved the understanding and trends of the irrigations methods used and the types of crops grown in California. The two main goals of this project are to: (1) combine the irrigation surveys of 2001 and 2010 with theoretical AE values to estimate the spatial AE for different crops and hydrologic regions and (2) create the California Irrigation Information System (CALIIS) to store and display this analysis (Figure 1). The target audience for the AE estimated is regional/state water planners as well as large scale water resources modelers.



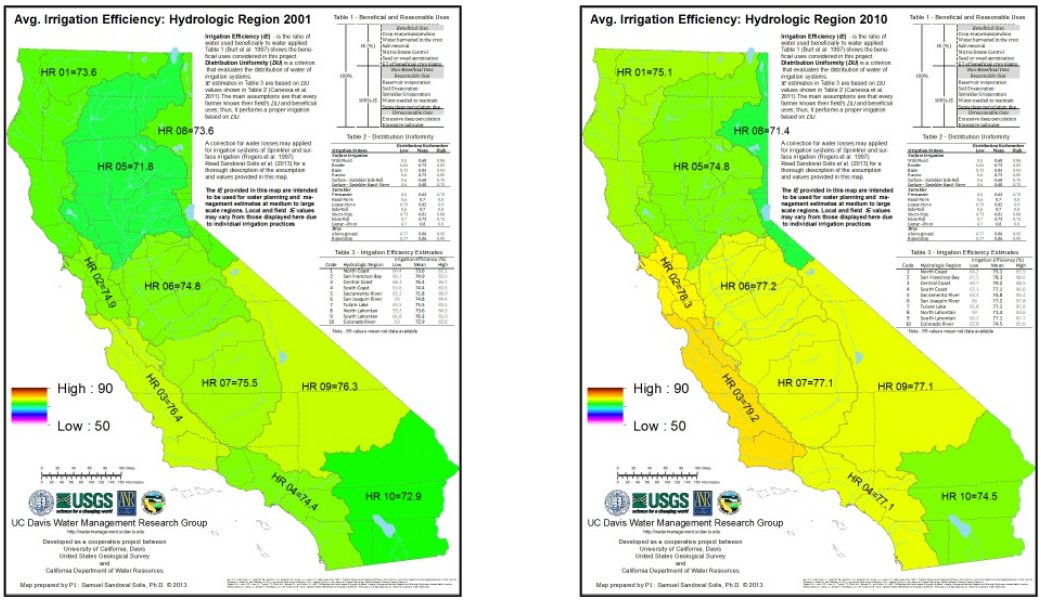
Overall Application Efficiencies by Hydrologic Region.

An extensive literature analysis was done to understand the relationship between AE and Distribution Uniformity (DU). A set of theoretical DU was used as AE considering the following assumptions: (a) irrigation surveys are representative samples of the population, (b) every farmer knew their irrigation system's DU and water requirements for their crops, (c) all farmers supplied exclusively the low quartile depth as the target water depth, and (d) water losses from the irrigation system were not considered. These assumptions allowed the use of DU as AE values.

Results show that AE improved 2.0% statewide from 2001 to 2010. AE improved in all hydrologic regions of California, except in North Lahontan with a slight decrease of 0.7% region wide. San Francisco Bay, Sacramento River, and Central Coast were the hydrologic regions with highest increase in AE, 3.4%, 3.0% and 2.8% respectively. Similarly, for all crops the AE improved from 2001 to 2010, with highest AE values in vineyards, tomato, subtropical trees, pistachio, and almond. At least 12 crops improved their AE by 2% or more from 2001 to 2010: cotton, other field crops,

cucurbit, onion and garlic, tomato-fresh, tomato process, other truck crops, almonds and pistachio, other deciduous, subtropical trees, turf grass and landscape, and vineyards.

The CALIIS provides a series of maps, by hydrologic region, for an overall irrigation efficiency estimated for the whole region, as well as for 20 different crops for 2 years, 2001 and 2010. These are the first application efficiency estimations for the whole state of California.



Overall Irrigation Efficiency estimated by region

Information Transfer Program:

Four main information transfer activities were undertaken for this project:

1. A report was developed to describe the procedure to estimate application efficiencies for the state of California.
2. A geographic information system was built, named California Irrigation Information System (CALIIS) to store the data and results.
3. A series of 42 maps were developed to present the different application efficiencies across 10 hydrologic regions in California, for 20 different crops for two years, 2001 and 2010.
4. A website was created to make available all the previous information through internet (http://watermanagement.ucdavis.edu/research/application-efficiency)

CIWR Information Transfer - Outreach

Basic Information

Title:	CIWR Information Transfer - Outreach
Project Number:	2012CA296B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	44
Research Category:	Social Sciences
Focus Category:	Education, Management and Planning, None
Descriptors:	None
Principal Investigators:	Doug Parker

Publications

There are no publications.

Information Transfer:

The CIWR's mission includes research, education, and outreach. It is through outreach or information transfer that scientific results become implemented in ways that improve our quality of life. Each of CIWR's projects has some information transfer component. These are listed in the individual projects' reports.

In addition to project information transfer, CIWR engages stakeholders in ways that transfer water based knowledge. This may be through direct presentations or meeting participation, through organizing and sponsoring conference and workshops, or through organizational actions that allow other scientist to engage better with stakeholders. CIWR recently launched its website and Twitter feed. These products will help us become a recognized source of scientific based information concerning California water.

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The Director of CIWR serves as a member of the Rosenberg International Forum's steering committee. The 8th international conference was held in Aqaba, Jordan in March 2013. The theme of this year's conference was water management in semi-arid environments.

The Director of CIWR currently serves as the member at large for the executive board of the National Institutes for Water Resources (NIWR). In that position, he is a member of the Natural Resources Board at the Association for Public and Land-grant Universities (APLU). The CIWR is working with the APLU to draft a Natural Resources Roadmap that will be released in 2014.

USGS Award no. G13AC00013 Innovations for an Integrated Approach to Climate Analysis and Food Security Monitoring

Basic Information

Title:	USGS Award no. G13AC00013 Innovations for an Integrated Approach to Climate Analysis and Food Security Monitoring
Project Number:	2013CA306S
Start Date:	12/12/2012
End Date:	2/11/2014
Funding Source:	Supplemental
Congressional District:	
Research Category:	Climate and Hydrologic Processes
Focus Category:	Climatological Processes, Management and Planning, Water Supply
Descriptors:	
Principal Investigators:	Doug Parker

Publications

There are no publications.

Research Program:

Introduction

The University of California, Santa Barbara, is developing a program of cooperative activities with the U.S. Geological Survey in support of the Famine Early Warning Systems Network (FEWS NET). These activities focus on the application and development of datasets for monitoring weather and climate conditions, use of those estimates as drivers for an instance of NASA's Land Information System (LIS) which incorporates a water balance model to evaluate crop performance, reporting on these analyses in country-level summary documents, and ultimately reaching out to communicate the findings to development officials. Precipitation and temperature are non-stationary in both time and space, necessitating analyses that account for location dependences and variations related to trends in climate variables. We are combining university-based research in the modeling, monitoring, and analysis of remotely sensed estimates of environmental variables with science advisory, training, and outreach to climate change adaptation activities in Africa. We are building on existing relationships with field scientists in Africa to improve outreach and uptake of this research by high-leverage decision makers.

Background

The combination of natural variability, climate change, and the current global food crisis makes the monitoring of climate, water, and land resources for food production especially critical. Each year over 200 million people in sub-Saharan Africa face undernourishment, accounting for nearly 32 percent of the population of this region according to the Food and Agriculture Organization (FAO, 2006). This region is the only part of the world where the percentage of undernourished people has remained steady over the last 30 years. Climate, water, land use, and food supply are inextricably intertwined in the developing world where irrigation is limited and crop health is primarily dependent on the available rainfall. Monitoring of rainfall and runoff provides insight into potential crop yield reduction due to drought, as well as identifying locations which may have seen crop loss due to flood inundation.

The United Nations World Water Development Report (WWD, 2006) has pointed out the increasingly dangerous issues associated with water availability, especially in the developing world. Changing pressures stem from growing populations, movements of people from rural to urban environments and increased competition for limited resources. In addition to growing human demand, climate change is expected to have significant impacts on agricultural production in Africa, leading to warmer and drier conditions. The cumulative effects of potentially worsening physical conditions with an increased demand will be most glaring in regions which already face chronic food shortages. Early detection of climate-related stress or changes in human behavior can forecast and make possible the mitigation of the impacts of below-average food production. Alerting decision-makers at agencies such as the US Agency for International Development, US Department of Agriculture, State Department, World Food Program, the Food and Agriculture Organization, and affected national governments can help mobilize action for relief efforts, management of stocks of food reserves, and other measures to reduce the harm to vulnerable populations.

Development of monitoring tools to track precipitation, soil water, evapotranspiration, crop development, cropped area, and other physical parameters can, individually or collectively, indicate the potential for crisis. The earlier these events can be effectively diagnosed and communicated to decision-makers, the sooner measures can be taken to reduce their impacts, saving lives and livelihoods, and protecting hard-won gains in the economic growth of developing countries.

We are working with an international team of scientists working with USGS in the United States and abroad. This work will be separate, though complementary, to FEWS NET activities already underway at UC Santa Barbara's Climate Hazard Group. Research scientists in the United States, with full access to the latest technology, are well-situated to rapidly develop new theories and tools. Regional scientists, stationed in developing countries, can translate new theories and tools rapidly into practice, and communicate their results to decision makers. This model of science for development has proven effective, in our experience, for the improvement of remotely sensed products for estimation of environmental conditions and human land use that impact food production in developing countries.

Project Description

Our activities fall under four major categories, i) rainfall development, ii) implementation of crop water balance model in LDAS, iii) national climate reports, and iv) outreach and information sharing with adaptation stakeholders. These four activities are described in more detail in the following sections.

Rainfall Development

The single biggest input to identifying food security crises before they occur is reliable rainfall estimates. The current state of the practice dataset is National Oceanic and Atmospheric Administration's (NOAA) satellite rainfall estimate (RFE). This product blends satellite estimated cloud top temperatures, passive microwave reflectance and available station reports. This data has been produced in a consistent manner since March of 2000, giving it a 12-year history. This is a valuable product for many monitoring activities, but a longer history is required for many climate change analysis and other statistical characterization of rainfall.

This work leverages the Tropical Rainfall Measuring Mission (TRMM) multi-satellite product (3B43) from NASA (Huffman, 2007) to train and create a ~30-year time series of pentadal (5-daily) cold cloud duration (CCD) rainfall estimates using geostationary satellite thermal infrared data sets from NOAA (Knapp et al., 2011; Janowiak et al., 2001). These CCD estimates will have bias removed with reference to a global set of climatological mean rainfall grids recently created by FEWS NET (Funk et al., in press), and will be further enhanced by geostatistical post-processing to blend in rainfall station data.

This offers many improvements over existing products. The biggest asset of this dataset lies in the fact that it extends back to 1982. This longer time series allows for a better characterization of rainfall regimes and also allows for the identification of non-stationarity in the data, highlighting locations where climate may be changing. The additional station input is captured from a newly developed database of daily station records at UC Santa Barbara that captures over 160,000 stations, accounting for over 955,000,000 daily precipitation observations dating back to 1832. This data stream is updating daily with new observations being automatically ingested, and when appropriate, calculating pentad and monthly precipitation accumulations. The result is a data steam that contains the latest and most comprehensive precipitation data available in one location. These stations are an indispensable input to the rainfall estimate process, and assist in tying the satellite-based estimates to actual ground observations.

Implementation of Crop Water Balance Model in LDAS

The creation of a land data assimilation system (LDAS) specifically for the domains, data streams, and monitoring/forecast requirements associated with food security monitoring in data-sparse,

developing country settings represents a major milestone in the assessment of food security. This system is currently under development with help from NASA/GSFC and USGS EROS.

Incorporation of a geospatial crop water balance model that evaluates the availability of moisture to a crop relative to its needs over the course of the growing season is a core feature of this new system. Frère and Popov (1986) originally developed the Water Requirement Satisfaction Index (WRSI) for calculation with rainfall station data. It has been adapted to use on a geospatial basis to facilitate wide area monitoring (Verdin and Klaver, 2002; Senay and Verdin, 2003). The WRSI varies from 0 to 100, and is the ratio of actual crop evapotranspiration to the amount that would occur with a full water supply. This quantity has been shown to be a good indicator of yield reduction due to water limitation (Doorenbos and Kassam, 1986).

Integrating the WRSI calculation within the LDAS framework is not entirely straightforward. The ability to modify a variety of the inputs in a way that facilitates the interaction of all the drivers to create an output in a consistent manner allows for a number of experiments to be conducted. The main input to the WRSI is precipitation, and that is where the outputs from the first activity can provide a critical update to existing WRSI implementations. Additionally, research on how changing inputs such as precipitation, temperature, or potential evapotranspiration may impact the crop water balance, and thus the crop yield, will provide key information about locations which are most vulnerable to changing patterns in climate variables. Assessment of these various outputs can serve as key components of real-time monitoring efforts and how changing conditions may impact crop production in the future.

National Climate Reports

This activity consists of series of climate trend analyses providing a unique climate service, supporting the early detection of climate-related increases in vulnerability in food insecure countries. Our regional analyses seek to provide a strong evidence and process-based understanding across a limited spatial domain. This is in contrast to global climate change efforts, which rely heavily on global climate models that do not necessarily faithfully simulate the local weather for a given location. This series of reports is titled the Informing Climate Change Adaptation (ICCA) series.

The ICCA approach combines up-scaling and down-scaling analyses to provide an integrated and coherent view of recent and near-future climate change. The up-scaling phase begins with rainfall and temperature trend identification using station observations. These trend analyses locate the areas where climate is changing, and include diagnostic analysis of observed climate fields (winds, moisture transports, etc.). Trends linked to known non-anthropogenic patterns of natural decadal climate variability will likely reverse sign in coming decades, as they have in the past. Trends attributed to low frequency changes linked to global warming are likely to persist or intensify.

The ICCA process is an iterative, evidence-based dialog between regional trends analysis in food insecure countries, and climate attribution of these trends at regional and global scales. Climate diagnostics provide a two-way bridge explaining and linking cause and effect. By analyzing drought years, local climate variations can be up-scaled, traced through the atmosphere, and attributed (for example) to climatic forcings over the warm tropical oceans. Similarly, through the use of statistical analyses and climate model simulations, the likely consequences of a large scale climate change, such as warming in the southern Indian Ocean, may be down-scaled to estimate specific local climatic outcomes. Further, these projected changes can be run through the LDAS model to determine how these changes may impact the crop yield.

Outreach and Information Sharing with Adaptation Stakeholders

These results of the ICCA process set the stage for development of a program to put the findings in the hands of those who can use them. The outreach activities expand on existing relationships to deliver technical assistance, data, and analytic tools to the climate change adaptation stakeholder community in food insecure countries. These activities will strengthen national and regional capabilities to understand the challenges of climate change, and to plan adaptation and mitigation efforts to deal with them. Outreach and data sharing will target individual and institutional African climate science stakeholders and their networks in the East African Community, the CILSS countries, SADC countries, and the LAC region.

There are four major components to the outreach and information sharing activities. First is the a) communication of risks associated with reductions in area of favorable crop growing condition, b) expansion of socio-climatic regions associated with high levels of childhood stunting, and c) the emergence of new food insecure regions through the interaction of increased drought frequency and increased population pressure. Second is the characterization of sub-national, drought-related yield and production losses and their associated return frequency for improved management of national grain reserves. Third is an analysis of trends in crop production, yield, cultivated area, population, imports and prices, together with national commitments in agricultural development, to gauge progress towards agricultural self-sufficiency. The fourth, and final, component of outreach is analyses of land degradation and land use/land cover with relevant policy recommendations associated with ecosystem and watershed protection, including farmer-managed natural regeneration. Our field scientist's experience and established relationships with targeted institutions provide an essential component in improving the acceptance of recommendations and ensures that the findings of the analyses included in these ICCA reports wind up in the hands of high leverage personnel with influence to change modes of practice.

A significant component of this work is focused on identifying the relevant climate change adaptation stakeholders, their networks and mechanisms of interaction, and then engaging, joining, and working with them in food insecure countries to inform adaptation. This will be achieved by a broad survey of the relevant institutions and entities and identification of the specific policy-relevant climate adaption groups within these institutions, followed by outreach and workshops targeting these offices and individuals. By joining and integrating with existing climate adaptation networks, it is expected that information needs will flow from the stakeholders to FEWS NET, inspiring tailored information products addressing the specific needs of the stakeholders.

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Information Transfer Program:

This project had only been under way for 2 months in this period, of which most research staff had not come online.

Information Transfer Program Introduction

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The CIWR Director has made several presentations to audiences on California water issues, the Clean Water Act, and nitrate pollution in California's groundwater basins. The Director has participated in discussions on management of the Colorado River Basin, environmental services markets, climate change adaption by California agriculture, and groundwater nitrate pollution.

The Director of CIWR serves as a member of the Rosenberg International Forum's steering committee. The 8th international conference was held in Aqaba, Jordan in March 2013. The theme of this year's conference was water management in semi-arid environments.

The Director of CIWR currently serves as the member at large for the executive board of the National Institutes for Water Resources (NIWR). In that position, he is a member of the Natural Resources Board at the Association for Public and Land-grant Universities (APLU). The CIWR is working with the APLU to draft a Natural Resources Roadmap that will be released in 2014.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	6	0	0	0	6
Masters	1	2	0	0	3
Ph.D.	9	2	0	0	11
Post-Doc.	8	4	0	0	12
Total	24	8	0	0	32

Notable Awards and Achievements

Notable Awards and Achievements:

Project #2007CA195G We have developed multiple spin-off and technology transfer projects in collaboration with the Santa Cruz County Resource Conservation District and several stakeholder groups. The new basin management plan was developed based on a variety of data sets, including our GIS map of MAR suitability. We launched a complementary study in a nearby groundwater basin in Monterey County ($61k in new funding). We contributed comments to the Regional Water Quality Control Board concerning proposed agricultural water quality requirements and their potential impact on MAR. My newest Ph.D. student just secured a three-year graduate research fellowship from the U.S. National Science Foundation (NSF), for continuation of this work (value of $180k). We are currently working on a competitive proposal to be submitted in Summer 2013 for the NSF's Water Sustainability and Climate competition.

Project # G09AC0001 •National Science Foundation and Association of American Geographers International Geographical Union travel award for the International Geographic Union (IGU) Regional Conference in Kyoto, Japan, August 4-9, 2013. $1,250. •American Association for the Advancement of Science (AAAS) Early Career Fellowship, AAAS Annual Meeting in Boston, MA. February 14th -18th 2013. $1,000. •Dissertations Initiative for the Advancement of Climate Change Research (DISCCRS) VII Symposium Scholar, sponsored by the National Science Foundation (NSF) and National Aeronautics and Space Agency (NASA), Colorado Springs, Colorado. October 13th-20th 2012. ~$4,000. •Brown International Advanced Research Institutes (BIARI) Fellow - Climate Change and its Impacts: Regional Coupled Human-Natural Systems and Evidence-Based Policy Making. All living and travel expenses for a 2-week workshop in Providence, RI. June 9th-23rd, 2012. $5,000.

Project # 2012CA294B The Natural Resource Conservation Service, local Resource Conservation Districts, and UC researchers are incorporating the concepts and preliminary results from this project into their assessments of conservation practice effectiveness and efforts to develop market based support for landowner ecosystem service provisioning. Our research findings are being disseminated on multiple levels to local partners, regional programs, and international disciplines. The interest is very high in our results in part because of the critical reviews watershed restoration has received in recent years after spending over $2 billion dollars across the US.

Publications from Prior Years