Center for Water Resources
Annual Technical Report
FY 2008

Introduction

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

The Water Resources Center funded 8 new projects and continued 14 projects for a total of $425,238.

Research Program Introduction

Data assimilation for shallow water flows using Lagrangian Sensing

Professor Alexandre Bayen, Dr. Olli-Pekka Tossavainen, Qingfang Wu, Andrew Tinka, Issam Strub, Julie Perceley Civil and Environmental Engineering UC Berkeley

The project's main objective is to create a set of hardware and software tools which can be deployed quickly in a flexible manner to perform Lagrangian measurements in the Sacramento San Joaquin Delta. Our group is working on the development of a hardware platform (drifters), which can measure velocity, using GPS, transmit it in real time to a base station using GSM modules, and perform onboard computing (using a Linux gumstix). Additional sensors can easily be added to the hardware platform developed for the project. The floaters have an underwater sail in case we are interested in capturing subsurface currents. Based on the measurements provided by the drifters, we are interested in developing inverse modeling algorithms used to reconstruct currents (and other features in water such as salinity) in real time. This relies on an accurate modeling of the deployment areas (using Shallow Water Equations), on which we can add additional one way coupled models for salt for example. The inverse modeling algorithms we develop for the project rely on a proper discretization of the flow equations, and the formulation of an optimization program in which we try to minimize the discrepancy between the measured quantities and the estimated quantities. In the case of the full nonlinear problem, we solve the data assimilation problem using Ensemble Kalman Filtering, a technique capable of handling the nonlinearity of the equation. Under specific assumptions relevant for the Sacramento Delta, we are able to simplify the equations and use either spectral methods (directly applicable to data reconciliation) and quadratic programming.

Investigation of Groundwater Flow in Foothill and Mountain regions using Heat Flow measurements

Fogg, Graham E. Hydrologic Sciences Program, Dept. of Land, Air, and Water Resources UC Davis

The purpose of this investigation is to improve understanding of groundwater flow patterns in the Sierra Nevada and adjacent foothills, including bedrock infiltration and the role of upland bedrock areas in recharge of adjacent valley basin-fill aquifers. As human population and use of groundwater in the Sierra Nevada area continues to increase, protection of groundwater resources from contamination and general management of water resources can benefit from improved knowledge of groundwater flow patterns.

Assessment of seawater intrusion potential from sea level rise in coastal aquifers of California

Hugo A. Loáiciga & Thomas J. Pingel, Department of Geography, University of California Santa Barbara

One of the likely impacts of modern-age climate change in California identified by the California Department of Water Resources increased potential for salinity intrusion into coastal aquifers, where plausible estimates of sea level rise range from 0.10 to 0.90 meters. One effect of such an increase in sea-level rise is to induce seawater intrusion into the coastal aquifer. This project examines quantitatively the threat of sea-level rise in two of California's most productive coastal aquifers: the Oxnard Plain aquifer in Ventura County and the Salinas Valley coastal aquifer in Monterey County. The project was begun in June 2007 and is scheduled for completion in July 2009.

The objectives of the project are threefold. The first objective is to develop a method to rapidly assess the intrusion potential by utilizing the flow-net geometry of coastal groundwater flow. The second objective is to create numerical simulations of seawater intrusion for each aquifer using state of the art finite element modeling software. The third objective is to use these models to make recommendations to counter the

probable impacts of sea-level rise.

Enforcement-Driven Financing of Water Quality in California: The Case of Supplemental Environmental Projects

Daniel Press, Environmental Studies Department, University of California Santa Cruz

Since the early 1990s, US Environmental Protection Agency guidelines allow states to direct some enforcement fines to Supplemental Environmental Projects (SEPs) in lieu of paying these sums into state general funds or cleanup and abatement accounts. The US EPA established guidelines governing SEPs in 1998. These require that 1) there is a nexus between the discharge violation and environmental benefits arising from a SEP, 2) the SEP must improve protection or reduce risks to public health of the environment, and 3) the SEP must consist of a project that violators would otherwise not have performed.

This project evaluates California's experience with SEPs, primarily as they are implemented by the nine regional water quality control boards. The central inquiries include 1) the extent and variation of SEP activity throughout the state (i.e., do the regional boards vary in their elective use of SEPs; has SEP use increased or decreased in recent years), 2) the proportion of enforcement fines being re-directed to SEPs, 3) the parties involved (e.g., are violators primarily implementing their own SEPs or are third parties doing so? If third parties are taking the lead, how are they getting involved?), and 4) what are the environmental outcomes of SEPs; do they generally and reliably improve water quality?

The transport of current-use, sediment-bound pesticides into a coastal marine system.

Donald P. Weston Department of Integrative Biology University of California, Berkeley

The purpose of the investigation is to assess whether current-use, sediment-associated pesticides are being transported via rivers into the shelf sediments of the Monterey Bay, if they are entering the Monterey Canyon (a deep ocean environment), and whether pesticide contributions from the individual rivers can be differentiated. In conjunction with the questions about transport, it was important to determine the effects of the pesticides on biota.

Mechanisms of Boron Toxicity in Crop Plants

Patrick Brown and Hening Hu, Department of Plant Sciences, University of California, Davis

Boron toxicity is a problem threatening significant areas of agricultural production in California and limiting the reuse of drainage waters. Research into the management of B has been plagued by results that are inconsistent, contradictory and difficult to interpret primarily because we do not know why B is toxic to plants and we do not know how to measure crop B and its relationship to the occurrence and impact of B toxicity. Based upon recent findings of the role of B in plants, we hypothesized that root and shoot extension (meristematic) growth would be the most sensitive indicator of boron toxicity. This project aims to identify the mechanism of B toxicity, and to develop the sampling strategies and standards necessary for field research and crop management.

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

Basic Information

Title:	Model Development for Conjunctive Use Planning and Aquifer Protection in Semi-arid Regions
Project Number:	2005CA137G
Start Date:	9/1/2005
End Date:	8/31/2009
Funding Source:	104G
Congressional District:	30
Research Category:	Ground-water Flow and Transport
Focus Category:	Nitrate Contamination, Management and Planning, Models
Descriptors:	
Principal Investigators:	William W-G. Yeh

Publication

1. Tu, M-Y, F. T-C. Tsai and W. W-G. Yeh, 2005, "Optimization of Water Distribution and Water Quality by Hybrid Genetic Algorithm," Journal of Water Resources Planning and Management, ASCE, 131 (6): 431-440.
2. McPhee, J. and W. W-G. Yeh, 2007, Groundwater Management using Model Reduction via Empirical Orthogonal Functions, to appear in Journal of Water Resources Planning and Management.
3. McPhee, J., Yeh, W. W-G., Groundwater Management using Model Reduction via Empirical Orthogonal Functions, Journal of Water Resources Planning and Management, ASCE, 134(2): 161-170, March 2008.

The Department of Geography at UCSB has 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 techniques for monitoring the physical variables governing crop growth, such as the timing and amount of precipitation, evapotranspiration and temperature, along with human-related factors such as cropped area, agricultural inputs, and economic indicators. We combine university-based research in the modeling, monitoring and analysis of remotely sensed estimates of environmental variables with science advisory, training, and development activities in Africa and Central America. This project brings together field scientists from Africa and Central America with research scientists at the University of California, Santa Barbara, in a single team of the UC Center for Water Resources, assembled to take on the activities needed to deal with threats to food security in the developing world.

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. In addition to the impacts of these disasters on food supply is the effect these extremes have on the entire economy of developing countries (Kreimer and Arnold, 2000). The economic effects of hydro-climatic extremes in developing countries can easily be equivalent in cost to war (Kates, 2000).

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.

The University's strengths in statistical climatology, hydrology, GIS, remote sensing, and geostatistics match up well with the goals and priorities of FEWS NET. The university can use these strengths to improve the scientific research, capacity building, and applications of the USGS component of FEWS NET. Both on-campus and off-campus activities (in FEWS NET countries) are proposed.

The university's scientific focus will be on estimating food production, with emphasis on monitoring and forecasting the natural and human inputs to food production. Basic research will address improved monitoring of rainfall, crop modeling, and cropped area estimates in FEWS NET countries. Better techniques, algorithms, and modeling applications, involving exploitation of remote sensing and other geospatial data, will emerge. Uncertainty associated with monitoring products and seasonal forecasts will be made clear to users, and the spatial data infrastructure underpinning the analyses will strengthened.

1. GeoWRSI

The GeoWRSI tool is a program developed by our southern Africa field scientist. This multi-faceted program was originally designed to allow users to run their own WRSI estimates. Based on initial positive response and some feedback the scope is developing into a end-to-end program which will take satellite based rainfall fields, allow users to input their own station data, update fields of evapotranspiration or crop coefficient, and run scenarios for the remainder of the season. This work will require extensive programming and debugging efforts, but the end result is a valuable stand-alone program allowing various agencies to create products that best simulate their local conditions based on additional inputs. Products that allow users to input their own data (station or field measurements), manipulate model drivers (start-of-season, crop coefficient, length of growing period, etc.), or run simulations (i.e. mean rainfall for remainder of season, 20th percentile rainfall for remainder of season, etc.) are the type of integrated approach that much of the research in this proposal seeks to produce.

2. Temperature and photoperiod inputs to yield estimation

The previous section shows how yield modeling is principally based on simulating the crop water balance through the growing season, as moisture deficits in many crops explain more of the observed inter- and intra- seasonal variability in yield than does temperature. But 21st century climate forecasts simulate temperature change much more reliably than precipitation variability, and the relationship between the two is likely to become more important in terms of crop yields.

The effort described here will improve the WRSI model for monitoring seasonal crop development and yield by incorporating temperature and photoperiod as climate inputs, which will increase model accuracy, as these are also important factors in certain crop development. For example, Thompson (1968) found the single best weather variable for estimating corn yields in the Midwest U.S. to be an accumulation of the daily maximum temperatures above 32 degrees C in July and August. In general, he found that state average corn yields decreased about 63 kg/ha for each 5.5 degrees C accumulated above 32 degrees C. This period usually covers the time of corn silkening, an especially critical period for determining the number of kernels on the ear. (*Crop Reactions to Water and Temperature Stresses in Humid, Temperate Climates, 1983*). Likewise, yield for Africa's second most important crop after maize, sorghum, is not simply a function of total seasonal rainfall, even where rainfall is the main limiting factor. The most important physiological adaptation mechanism of sorghum to climate variability, the triggering of flowering by day length signals (photoperiodism), synchronizes the final development stages of the plant with the end of the rainy season. *(Kouressy et al. 2007).* By adding crop-specific temperature thresholds and photoperiod characteristics to the current moisture-deficit simulation, the WRSI model will be an even more effective tool for monitoring crop yields throughout the season.

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

Basic Information

Title:	Award No. 04HQAG0001 Spatially Explicit Modeling and Monitoring of Hydroclimatic Extremes: Reducing the Threat to Food Security in the Developing World
Project Number:	2005CA187S
Start Date:	10/1/2003
End Date:	6/30/2009
Funding Source:	Supplemental
Congressional District:	
Research Category:	Climate and Hydrologic Processes
Focus Category:	Drought, Management and Planning, None
Descriptors:	
Principal Investigators:	Andrew Chang, Katheryn Ivanetich

Publication

1. Funk, C. and Brown,. M., 2006, A maximum-to-minimum technique for making projections of NDVI in semi-arid Africa for food security early warning, Int. J. of Remote Sensing. 101. 249-256.
2. Verdin J., Funk C., Senay, G., Choularton, R., 2005. Climate Science and Famine Early Warning, Philosophical Transactions of the Royal Meteorological Society, B. 360. 2155-2168.
3. Husak, Gregory. Methods for Statistical Evaluation of African Precipitation. Ph. D. Dissertation, Geography, University of California, Santa Barbara, Santa Barbara, CA.
4. Freund, Jeremy, Aids for Estimating Crop Area and Production in Kenya: A Multi-Temporal Remote Sensing Approach, M.A. Thesis , Geography, University of California, Santa Barbara, Santa Barbara, CA.
5. Funk, Chris, Jeremy Freund, Mike Budde, Elijah Mukhala and Tamuka Magadzire, 2006, Analysis of MODIS -NDVI for 2000 through 2006. FEWS NET Report. ftp://hollywood.geog.ucsb.edu/pub/AnalysisOfMODIS_NDVIforZimbabwe_JTF4.zip. 8 pages.
6. Funk, C. and J. Michaelsen, 2004: A simplified diagnostic model of orographic rainfall for enhancing satellite-based rainfall estimates in data poor regions, Journal of Applied Meteorology, V43. October, 2004
7. Funk, C., J. Michaelsen, J. Verdin, G. Artan, G. Husak, G. Senay, H. Gadain, and T. Magadazire, 2003: The Collaborative Historical African Rainfall Model: Description and Evaluation. International Journal of Climatology, 23, 47-66
8. Brown, M. & Chris Funk, 2008, Early Warning of Food Security Crises in Urban Areas: the Case of Harare, Zimbabwe, 2007. Submitted.
9. Funk, C., Ederer, G., Pedreros, D. (2008) The Tropical Rainfall Monitoring Mission, NIDIS Knowledge Assessment Workshop: Contributions of Satellite Remote Sensing to Drought Monitoring, Feb 6-7, Boulder, CO, Extended Abstract

10. Funk C. & M. Budde, (2007) National MODIS NDVI-based production anomaly estimates for Zimbabwe, Crop and Rangeland Monitoring Workshop, Nairobi, March 2007. Extended Abstract.
11. Funk, C., Husak, G., Michaelsen, J., Love, T. and Pedreros, D. (2007) Third generation rainfall climatologies: satellite rainfall and topography provide a basis for smart interpolation, Crop and Rangeland Monitoring Workshop, Nairobi, March 2007, Extended Abstract.
12. Husak, G.J. and Funk, C., 2007. SPI Forecasting in the Conterminous United States. American Association of Geographers Annual Meeting: San Francisco, California.
13. Husak GJ, MT Marshall, J Michaelsen, D Pedreros, C Funk, G Galu, 2008. Crop Area Estimation Using High and Medium Resolution Satellite Imagery in Areas with Complex Topography. Journal of Geophysical Research. (Accepted, 2008)
14. Funk, C., Brown, M., Choularton, R., Verdin, J., Dettinger, M., (200-), FEWS NET Climate Change Impact Report, Special Report for USAID (accepted)
15. Husak, G., Michaelsen, J., Funk, C., (2007) Use of the Gamma Distribution to Represent Monthly Rainfall in Africa for Drought Monitoring Applications, Int. J. of Clim. 27(7): 935-944.
16. Brown, M.E., Funk, C.C., Galu, G. and Choularton, R. (2007). Earlier Famine Warning Possible Using Remote Sensing and Models. EOS, Trans. Am. Geo. Union, 88(39): 381 382.
17. Funk, C., Budde M., (2008) Phenologically-tuned MODIS NDVI-based production anomaly estimates for Zimbabwe, Rem. Sens. Env. (accepted, 2008)
18. Brown, M and Funk, C., (2008) Food security under climate change, Science, (319): 580-581.

The Famine Early Warning System Network (FEWS NET) efforts at UCSB this past year have focused on monitoring some of the most food insecure regions of the developing world. In addition to research personnel at UCSB critical scientific contributions and have been performed by the team of foreign scientists stationed in Central America, Africa and Afghanistan.

Significant effort under this grant was used to develop cropped area estimates for Ethiopia, Niger Zimbabwe, Northern Nigeria and Afghanistan where questions about the amount of area being planted and harvested creates large uncertainty in food production estimates and ultimately the number of people facing food insecurity. The cropped area assessments were created using manually interpreted high-resolution satellite imagery along with physical variables such as elevation, slope and precipitation which dictate cropping patterns in these countries. Much work has also been done to develop long-term rainfall climatologies for Central America which can be used with real-time satellite estimates to create gridded rainfall estimates which are used to drive hydrologic and crop models.
Work under the FEWS NET umbrella also supported the development of new computational tools such as the GeoWRSI, which utilizes crop-specific parameters and environmental information to estimate crop yield by assessing how well the crop's growing requirements are being met.
Finally, many resources in this project have been used to perform GIS and remote sensing trainings, and other forms of capacity building in our regions of interest. These efforts have resulted in improved understanding and distribution of FEWS NET monitoring products by placing well-qualified people at national agencies. These people have a working understanding of the impacts that the scientific efforts of our team can have, and they are familiar with our foreign staff, resulting in easy communication with stakeholders and decision-makers in the developing world.

The FEWS NET project at UCSB represents a successful system to develop new scientific tools, have them implemented in a meaningful way, and get the results distributed to influential parties in a timely manner. Our team of domestic and international researchers, and the support of agencies such as the US Geological Survey, the US Department of Agriculture and others, create an environment where new science and applications can have an impact on reducing food insecurity, maintaining farmer incentive, and ultimately saving lives.

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:	6/30/2011
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

Publication

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.

The focus of this research is in improvements that can be made to aquifer storage recovery activities so as to improve both the quantity and quality of water made available to stakeholders. We are collaborating on this research with a local water agency, and with researchers at other academic institutions and the U.S. Geological Survey. In Summer and Fall 2008, we instrumented the base of a managed aquifer recharge pond, which is used to recharge fresh water into a shallow, perched aquifer. This water is used by local growers in lieu of pumping ground water from a regional aquifer that is impacted by seawater intrusion. The water put into the pond is diverted from a nearby wetland system during the wet (rainy) season.

We are monitoring the rate of ground water recharge through the full pond using mass balance mass balance techniques, and determining rates of recharge at points along the base of the pond using heat as a tracer. This last technique involves innovative use of time-series analysis to resolve changes in diurnal temperature changes with depth below the pond. We monitor ground water levels and quality using eight shallow and one deeper monitoring well, arranged spatially around the recharge pond. We have deployed water content, pressure, and thermal sensors around the pond, allowing us to assess rates of infiltration and recharge that occur at different locations. We sampled shallow soils before the recharge season and will sample these materials again at the end of the recharge season (Summer 2009) to evaluate the influence of recharge on soil grain size and hydraulic properties.

We are monitoring water quality at multiple locations in the wetland throughout the water year. We monitor water quality in the recharge pond, and in the shallow subsurface using piezometers and lysimeters at 44 locations. Samples are being analyzed for major elements and nutrients, and for nutrient isotopic composition in order to quantify rates of denitrification that may occur during recharge. Work completed thus far suggests that about 50% of the nitrate load to the pond can be removed by denitrification during recharge. We plan to combine physical and chemical hydrology data to assess how denitrification varies with seepage rate below the pond.

A Bayesian approach to snow water equivalent reconstruction

Basic Information

Title:	A Bayesian approach to snow water equivalent reconstruction
Project Number:	2007CA215G
Start Date:	6/1/2008
End Date:	5/31/2010
Funding Source:	104G
Congressional District:	
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Surface Water, Water Supply
Descriptors:	
Principal Investigators:	Noah Paul Molotch, Steven Margulis

Publication

1. Molotch, N.P., P.D. Brooks, S.P. Burns, M. Litvak, J.R. McConnell, R.K. Monson, and *K. Musselman, Ecohydrological controls on snowmelt partitioning in mixed-conifer sub-alpine forests, Ecohydrology, in press
2. Veatch, W, P.D. Brooks, *J. Gustafson, N. P. Molotch, Quantifying the effects of forest canopy cover on net snow accumulation at a continental, mid-latitude site, Valles Caldera National Preserve, NM, USA, Ecohydrology, Vol. 2, doi: 10.1002/eco.45, 2009.
3. Molotch, N.P., Reconstructing snow water equivalent in the Rio Grande headwaters using remotely sensed snow cover data and a spatially distributed snowmelt model, Hydrological Processes, Vol. 23, doi: 10.1002/hyp.7206, 2009.
4. Molotch, N.P., T. Meixner, and M.W. Williams, Estimating stream chemistry during the snowmelt pulse using a spatially distributed, coupled snowmelt and hydrochemical modeling approach, Water Resources Research, Vol. 44, doi:10.1029/2007WR006587, 2008.
5. Durand, M., N.P. Molotch, and S. Margulis, A bayesian approach to snow water equivalent reconstruction, Journal of Geophysical Research, 113, doi:10.1029/2008JD009894, 2008.

This project is focused on questions related to temporal and spatial variability in snow distribution patterns in the Sierra Nevada Mountains. In year one of our project we have made significant progress toward developing a new method of snowfall estimation. This involves using an Ensemble Kalman Smoother to assimilate new remotely sensed snow measurement capabilities into physically based mass and energy balance models. Densely distributed clusters of ultrasonic snow depth sensors spanning the elevational gradients of the seasonally snow covered portions of the Sierra Nevada will be used to develop this new technique by accounting for both sub-grid variability and the spatial representativeness of the ground observations. The combination of these new modeling and measurement capabilities will enable new understanding of the spatial snow accumulation processes.

The project scope and objectives are driven by recent evidence suggesting that the mountain snowpack is responding to increases in regional air temperature associated with climate change. Sensitivity to climate change varies across gradients of physiography (e.g. elevation, vegetative community structure, and latitude) but the drivers and degree of this sensitivity in different mountainous landscapes are not fully comprehended. Similarly, the impact of these changes on basin-scale snowpack water storage cannot be determined because observations are not distributed across a range of elevations and other physiographic conditions that control snow distribution. As a result, statistical interpolation models of these scarce observations inadequately represent spatial patterns of snow accumulation. For nearly three decades, remotely sensed observations of snow cover depletion have been used to forecast seasonal snowmelt runoff and (indirectly) seasonal snow accumulation integrated over a watershed. The scarcity of ground-based observations needed to evaluate model performance and refine algorithms has restricted detailed snowpack modeling studies to small headwater catchments. To address these inadequacies this research project has made steps toward developing new observing and modeling systems for estimating the spatial distribution of snow accumulation. Year one achievements have been made in two categories. First, we have made significant progress in collecting the in situ snow measurements needed for the model validation. Second, we have developed our modeling framework and we have compiled all of the necessary model forcings. These achievements are described in more detail below.

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

   In the western U.S., mountain river basins sustain the water demand of over 60 million people. Operational water supply outlooks in these supply-limited systems are based, in part, on historical relationships between snow observations and observed runoff. These empirical models perform best near mean conditions but perform poorly during conditions not represented in the historical record. Changes in mountain climate, and associated changes in snow accumulation and melt patterns, suggest that such anomalous conditions may be occurring with increased frequency and intensity with local to regional signatures. To deal with this situation deterministic modeling approaches for characterizing snow distribution are needed to develop robust water supply outlooks. Perhaps the largest source of uncertainty in our current modeling abilities is associated

with distributing precipitation over complex terrain. Furthermore, knowledge of interannual spatial patterns of precipitation is crucial in understanding how spring streamflow magnitude timing will be modulated by a changing Sierra Nevada climate. The techniques which we have developed in year one of this research bridges a critical gap in making spatially distributed runoff forecast models operational.

Modeling activities. Our year one modeling methodologies largely flow from our original proposal and our continued efforts in year 2 will be unchanged from our original plan. In this regard, we have compiled model forcings (solar and longwave radiation, wind speed, temperature, pressure, specific humidity, and precipitation) from the North American Land Data Assimilation System (NLDAS). On our Hydro Cluster at UCLA we have compiled 10 years of these hourly model forcings. Using these forcings we have conducted a number of sensitivity tests in our data assimilation scheme which ingests forcings and remotely sensed snow data into the Simplified SiB land surface model. Initially, we have focused our detailed analysis of the model runs over our detailed field site in Sequoia National Park. In this regard, we have run a 25 km box and have performed simulations of SWE at 1-km spatial resolution. Hence, we have aggregated the 500-m MODIS snow cover data to 1km to match the model resolution (Figure 1). Future efforts will transform this modeling scheme to a 500-m model grid to match the MODIS data. To date, we have conducted both synthetic tests (Figure 1) and tests using MODIS snow cover observations 2000 – 2008. Beginning with synthetic tests was needed as we need to test our overall model scheme. This modeling scheme involves several new sub-routines (e.g. forcing dissagregation) and an evaluation of the sensitivity of the model to the number of ensemble replicates. In this regard, we have run the SSiB3 code on 1, 4, 8, 16, 32 nodes using 12, 24, 48, and 96 replicates. Our results of these tests indicate that the model computational demand is quite high, requiring all 32 nodes and the full 96 replicates. Further, our results indicate that dissagregation of solar radiation NLDAS forcings based on topography add significant information for the model.

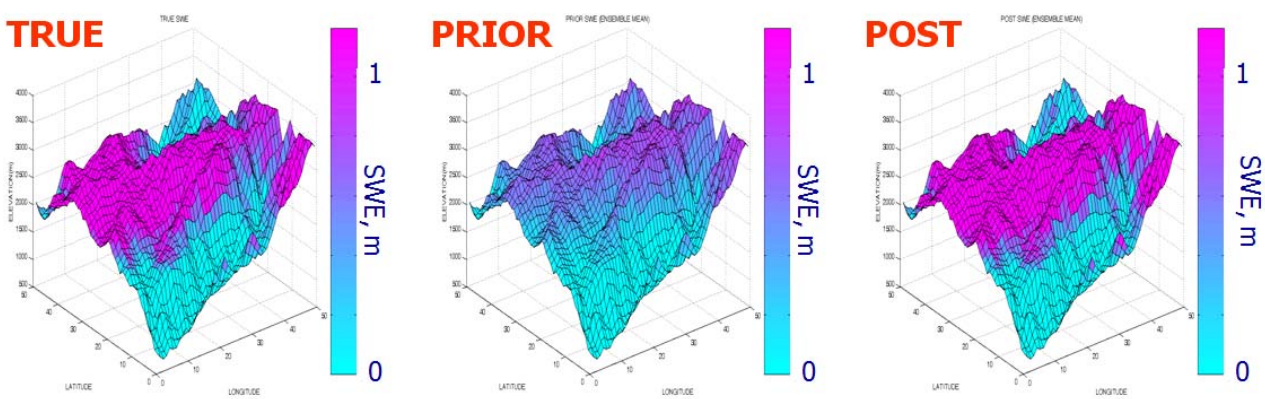

Figure 1. Synthetic truth (left), prior (middle), and posterior snow water equivalent (right) for January 6, 2005 over a 25X25 km area in Sequoia National Park. Note the prior estimates underestimate SWE while the assimilation of the MODIS snow cover depletion data results in a closer match between the posterior SWE and the truth.

Field work activities. In an effort to understand inter-storm variability in snow accumulation and to develop a robust ground-truth data set for our modeling activities we have conducted a total of 12 watershed-scale snow surveys in year one of this project. Survey measurements of snow depth, snow density, and physical snow properties were conducted at two sites in the Southern Sierra Nevada (i.e. the Wolverton and Tokopah Basins of Sequoia National Park) (Figure 2). We have also leveraged snow survey data at three sites in the Eastern Sierra (i.e. Mammoth Pass, Virginia Lakes Ridge, and Rock Creek), and at two sites in the Central Sierra Nevada (i.e. at Gin Flat and Ostrander of Yosemite National Park). The sites represent both alpine and sub-alpine environments ranging in elevation from 7,500 to 10,000 feet above sea level and covering one to 19 km2 in aerial extent. Snow surveys were timed to coincide with seasonal accumulation, maximum accumulation, and the snowmelt season. Each survey required a team of five people working for 3 – 5 days, involving undergraduate and graduate students from UCLA, UCSB, and UC Merced. On average, surveyors collected over 400 spatially distributed snow depth measurements and extensive information from three snow pits during each survey, resulting in a seasonal total of over 2000 snow depth measurements and 24 extensive snow pit observations.

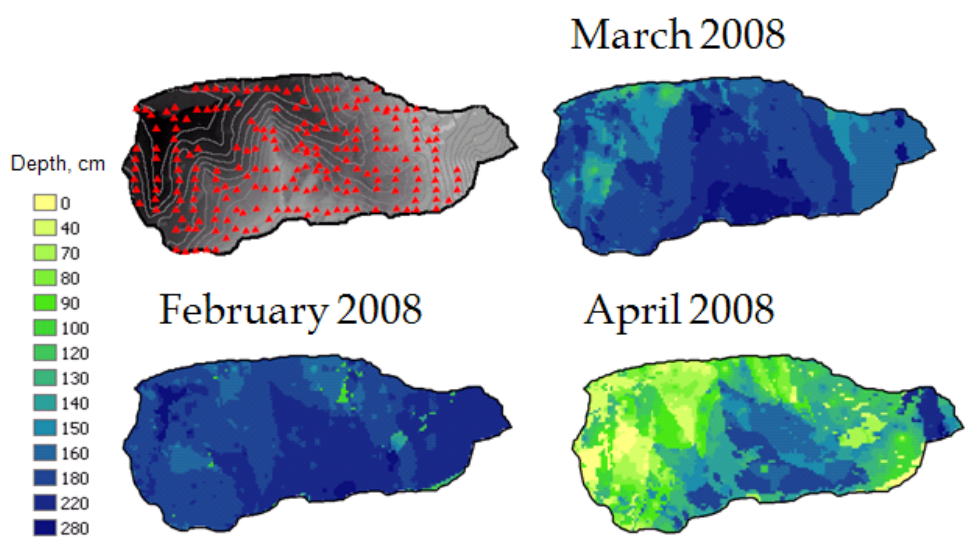

Figure 2. Spatial distribution of snow depth measurements in the Wolverton Basin of Sequoia National Park (Top Left) and resulting snow depth distributions from repeat sampling in February, March, and April of 2008. Note, the red triangles in the top left represent the snow depth measurement locations.

In addition to the manual measurements described above we have also continued maintenance and deployment of the hydrologic instrument clusters we proposed to use in this research. These instruments provide hourly observations of snow depth, soil moisture, sap flow, and atmospheric conditions to be used to validate the extrapolation of our forcing data and model parameters (Figure 3). We have four duplicates of these systems across elevational gradients in Sequoia National Park. In Yosemite National Park our colleagues at UC Merced maintain a transect of three of these clusters. To date,

we have quality controlled and analyzed much of the data we have collected in Sequoia. Future efforts will analyze the data collected in Yosemite.

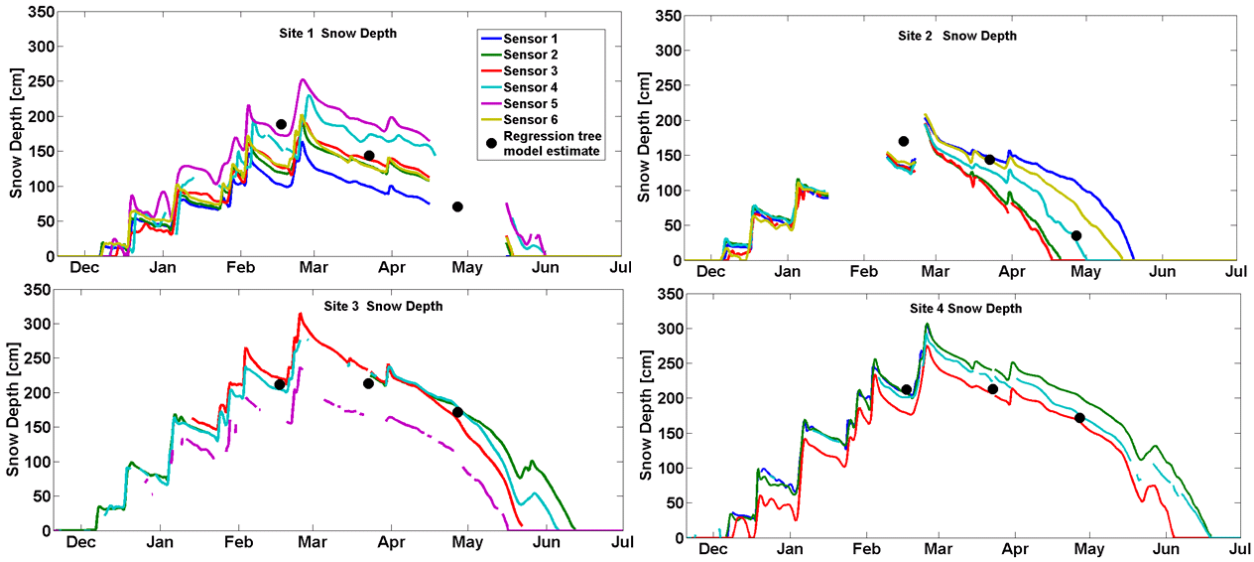

Figure 3. Measured snow depth at four instrument clusters in Sequoia National Park in 2007 – 2008. Sites are numbered 1 – 4 from low to high elevation.

Climate Variability of the Sierra Nevada over the last Millennium: Reconstructions from Annually Laminated Sediments in Swamp Lake, Yosemite National Park, California

Basic Information

Title:	Climate Variability of the Sierra Nevada over the last Millennium: Reconstructions from Annually Laminated Sediments in Swamp Lake, Yosemite National Park, California
Project Number:	2008CA243B
Start Date:	3/1/2008
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Funding Source:	104B
Congressional District:	43
Research Category:	Climate and Hydrologic Processes
Focus Category:	Geomorphological Processes, Climatological Processes, None
Descriptors:	None
Principal Investigators:	Daniel R. Cayan

Publication

1. Roach, Lydia, Daniel Cayan, Alex Sessions, Christopher Charles and R. Scott Anderson, 2009, Lake Sediment D/H Ratios, A Potential Tracer for Decadal Scale Hydroclimate Variability in the Sierra Nevada, in PACLIM Proceedings, Scott Starratt, Pacific Grove, CA, 29.

Climate change and growing demand for fresh water in Southern California over the 21st century leaves this region highly vulnerable to severe drought and the resulting environmental damage and socioeconomic disruption. For example, much of Southern California's freshwater supply relies on the accumulation snow pack and the release of snowmelt from the Sierra Nevada Mountains, processes which may already be impacted by the effects of a warming climate. It is therefore crucial that we understand the hydrologic response of the Sierra Nevada Mountains to projected climate change over the next few decades to centuries. As even the longest instrumental climate records only reach back to the late 19th century, we must relay on paleoclimate reconstructions to realize the multiple cycles of decadal scale variability necessary for a thorough knowledge of the region's hydroclimate. While existing reconstructions indicate that at certain periods over the last millennium, the entire western United States was witness to droughts of greater duration and severity than any in recorded history, many questions remain as to the impact of these droughts on the Sierra Nevada Mountains and the physical mechanisms driving them. This study aims to address these questions by reconstructing hydrologic conditions of these mountains over the last millennium through the collection and analysis of a suite of sediment cores from Swamp Lake, located in an isolated catchment at the northwest corner of Yosemite National Park.

We established two primary goals in carrying out this project: 1) create a time series of hydrologic variability in the western Sierra Nevada through analysis of Swamp Lake sediment morphology and stable isotope geochemistry and, 2) determine the quality with which climate information is recorded in the sedimentary archive through a comparison of the uppermost sedimentary layers with the instrumental record of the last several decades. Below we summarize earlier accomplishments and describe progress made in the last year (March 1st 2008 and February 28th 2009) through ongoing analysis of the Swamp Lake sediment cores.

Sediment cores were collected during field expeditions in the falls of 2006 and 2007. We employed two coring techniques, one that captured sediment frozen *in situ*, ideal for preserving the uppermost sedimentary layers, and another, more conventional method better suited for capturing longer cores and thus older material. Cores were processed at The Scripps Institution of Oceanography (SIO) and at the Limnological Research Center at the University of Minnesota, Minneapolis (LRC) in the months following each expedition. In addition to basic core processing, high-resolution digital images of core surfaces were taken at the LRC using DMT CoreScan (at 100 pixels per cm resolution) and Geotek GeoScan-III (at 200 pixels per cm resolution) digital linescan cameras. Using these images we created an age-depth chronology for the uppermost sediments (herein referring to sediment deposited from turn of the 20th century through the time of core collection) and conducted preliminary analysis of the thickness of annually deposited layers (varves), a property that has been shown to reflect hydroclimate in a variety of watersheds. Also at the LRC, subsamples of frozen sediment cores were embedded with epoxy resin. Inspection of the thin sections created from these embedded subsamples allowed us to determine the seasonal depositional cycle that generates the varve structure.

Prior to March 2008, we also carried out preliminary geochemical analyses of Swamp Lake sediment samples in the lab or Dr. Alex Sessions at the California Institute of Technology (Caltech). Specifically, using standard solvent extraction and separation protocols we extracted organic lipids from the sediment, separated these lipids in the specific fractions, and, using a ThermoFinnigan Trace GC-DSQ mass spectrometer we detected the presence of several compounds with signatures promising for down-core analysis of stable hydrogen isotope (D/H) ratios. Aquatic plants growing in the lake shallows take up hydrogen from their surrounding

water and incorporate it into their organic matter. Upon decomposition, this matter is deposited in the lake sediments, carrying with it the isotopic signature of the lake water—an integration of both local and remote hydrologic processes such as moisture source, storm track, precipitation type (rain versus snow) and evapotranspiration. Previous isotopic studies of meteoritic, surface and ground water in California indicates that, in general, warmer, subtropical storms and/or drier conditions result in higher D/H ratios while the opposite is true for cooler precipitation and wetter conditions. D/H ratios therefore serve as a potentially diagnostic tracer of hydroclimate in the Sierra Nevada Mountains.

Over the last year, we have focused much of our efforts on measuring D/H ratios of the uppermost sediments and comparing the results of a variety of instrumental climate records. Frozen sediment cores were sampled at approximately biennial resolution in a -20ºC cold box at SIO and lipids were extracted and separated from these samples at Caltech as described above. The D/H ratios of specific lipid compounds from a total of 66 samples were measured on a Delta +XP Isotope Ratio Mass Spectrometer between February and November 2008. These measurements span the period 1898-2006 and display variability on the order of 50‰, which is an order of magnitude above the instrumental error of ~5‰. Comparison of the resulting 20th century time series with numerous local, regional, and synoptic scale climate records indicates that D/H isotope ratios do reflect aspects of Sierra Nevada hydroclimate and that of the western United States as a whole. We observe significant negative correlations with D/H values and total annual precipitation, such that years with lower ratios correspond to wetter conditions. An even stronger negative correlation with snow water content records indicates that the partitioning of snow vs. rain (snow has lower D/H ratios than rain) may also play a role in D/H variability, with lower D/H values reflecting snowier winters. This hypothesis is supported by analysis of atmospheric circulation patterns associated with the years of highest and lowest D/H values. For example, a composite of wintertime 700mb geopotential height anomalies over the North Pacific and western North America from years with the lowest ratios reveals a circulation pattern associated with cold, wet conditions in California. Establishing this relationship is a crucial step forward for this project, and will allow us to interpret isotopic results from older sediment, especially that deposited during the medieval period, in the framework of Sierra Nevada hydroclimate.

We have also furthered our digital image analysis of sediment core morphology. Through grayscale analysis we were able to isolate the annual oscillation of light/dark associated with varve formation, as well as lower frequency fluctuations in the decadal, multidecadal and centennial bands. These fluctuations may be related to subtle changes in the source or transport of terrigenous material to the lake, or the contribution of biogenic detritus associated with diatom blooms in lake surface water, which in turn are both likely linked to source and availability of moisture in the watershed.

The results of this study will help construct a climatologic framework within which the Sierra Nevada Mountains, the major source of California's water supply, has operated over the last millennium. This framework can then be projected onto the coming decades in order to anticipate how California's hydrology may vary in the future and to provide insight into how it will respond to climate change. Such information is crucial in the face of an already warming climate and continually growing demand.

High-Resolution Modeling of Flood Inundation

Basic Information

Title:	High-Resolution Modeling of Flood Inundation
Project Number:	2008CA245B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	43
Research Category:	Ground-water Flow and Transport
Focus Category:	Climatological Processes, Models, Floods
Descriptors:	None
Principal Investigators:	Brett franklin Sanders

Publication

1. Schubert, J.E., Sanders, B.F., Smith, M.J. and Wright, N.G. Unstructured mesh generation and landcover-based resistance for hydrodynamic modeling of urban flooding, Advances in Water Resources, 2008, doi:10.1016/j.advwatres.2008.07.012.
2. Sanders, B.F., Schubert, J.E. and Gallegos, H.A. Integral formulation of shallow-water equations with anisotropic porosity for urban flood modeling, Journal of Hydrology, 2008, doi:10.1016/j.jhydrol.2008.08.009

Government at all levels is increasingly investing in Geographical Information Systems (GIS) to archive, access and regularly utilize a wide range of important data resources. These data are particularly rich in urban areas due to the density of infrastructure, and data characterize a vast array of features ranging from parcel boundaries and building footprints, land cover attributes, critical lifeline infrastructure and census data, to name just a few. Flood risk management efforts increasingly rely upon economic, social and environmental factors to measure the consequences of flooding. By combining data archived in government GIS with flood inundation predictions, it becomes possible to make highly resolved damage assessments required for decision making. However, flood inundation modeling technology has not kept pace with the changes in data resources, and many of today's models are not well suited to the challenge of routing flow through urban areas, nor the diverse flooding threats that stem from infrastructure failures such as levee breaks. Research lead by Professor Sanders at UC Irvine is aiming to advance a new generation of high-resolution, multi-dimensional flood inundation models that leverage the data resources described above and build upon fundamental advances made in the computational sciences over the past decade. The goal of this research is to enable decision makers to better understand and predict the consequences of flooding, and to do with greater speed, frequency and precision than is possible with today's modeling technology.

To date, funding from the UC Water Resources Center has supported two modeling studies aimed at developing the knowledge base required for mechanistic, multi-dimensional modeling of urban flood inundation.

UNSTRUCTURED MESH GENERATION AND LANDCOVER-BASED RESISTANCE FOR HYDRODYNAMIC MODELING OF URBAN FLOODING

Urban flood inundation modeling with a hydrodynamic flow solver is addressed in this study, focusing on strategies to effectively integrate geospatial data for unstructured mesh generation, building representation and flow resistance parameterization. Data considered include Light Detection and Ranging (LiDAR) terrain height surveys, aerial imagery and vector datasets such as building footprint polygons. First, a unstructured mesh generation technique we term the building-hole method (BH) is developed whereby building footprint data define interior domain boundaries or mesh holes. A wall boundary condition depicts the impact of buildings on flood hydrodynamics. BH provides an alternative to the more commonly used method of raising terrain heights where buildings coincide with the mesh. We term this the building-block method (BB). Application of BH and BB to a flooding site in Glasgow, Scotland identifies a number of tradeoffs to consider at resolutions ranging from 1 to 5 m. At fine resolution, BH is shown to be similarly accurate but execute faster than BB. And at coarse resolution, BH is shown to preserve the geometry of buildings and maintain better accuracy than BB, but requires a longer run time. Meshes that ignore buildings completely (no-building method or NB) also support surprisingly good flood inundation predictions at coarse resolution compared to BH and BB. NB also supports faster execution times than BH at coarse resolution because the latter uses localized refinements that mandate a greater

number of computational cells. However, with mesh refinement, NB converges to a different (and presumably less-accurate) solution compared to BH and BB. Using the same test conditions, a team of researchers from the UK compared the performance of dynamic-wave and diffusive-wave models and reported that diffusive wave models under-predicted the longitudinal penetration of the flood zone due to important inertial effects. Here, we find that a relatively coarse mesh implementation of a dynamic-wave model suffers from the same drawback because of numerical diffusion. This shows that whether diffusion is achieved through the mathematics or numerics, the effect on flood extent is similar. Finally, several methods of distributing resistance parameters (e.g., Manning n) across the Glasgow site were evaluated including methods that utilize aerial imagery-based landcover classification data, MasterMap® landcover classification data and LiDAR-based feature height data (e.g., height of shrubs or hedges). Results show that landcover data is more important than feature height data in this urban site, that shadows in aerial imagery can cause errors in landcover classification which degrade flood predictions, and that aerial imagery offers a more detailed mapping of trees and bushes than MasterMap® which can locally impact depth predictions but has little impact on flood extent.

INTEGRAL FORMULATION OF SHALLOW-WATER EQUATIONS WITH ANISOTROPIC POROSITY FOR URBAN FLOOD MODELING

An integral form of the shallow-water equations suitable for urban flood modeling is derived by applying Reynolds transport theorem to a finite control volume encompassing buildings on a flood plain. The effect of buildings on storage and conveyance is modeled with a binary density function i(x,y) that equals unity when (x,y) corresponds to a void, and nil otherwise, and can be measured using remote sensing data such as classified aerial imagery; the effect of buildings on flow resistance is modeled with a drag formulation. Discrete equations are obtained by applying the integral equations to a computational cell and adopting a Godunov-type, piecewise linear distribution of flow variables. The discrete equations include a volumetric porosity that represents the integral of i over the cell, normalized by the cell area, and an areal porosity φ that represents the integral of i over an edge of the mesh, normalized by the edge length. The latter is directionally dependent which introduces anisotropy to the shallow-water equations and captures sub-grid preferential flow directions which occur in urban settings due to asymmetric building shapes and spacings and the alignment of buildings along streets. An important implication is that model predictions are necessarily grid dependent; therefore, a mesh design strategy is proposed. First- and second-order accurate numerical methods are presented to solve the discrete equations, and applications are shown for verification and validation purposes including the ability of the model to resolve preferential flow directions.

Securing Access to Water: Institutional Strategies for Coping with Drought and Water Scarcity

Basic Information

Title:	Securing Access to Water: Institutional Strategies for Coping with Drought and Water Scarcity
Project Number:	2008CA246B
Start Date:	3/1/2008
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Congressional District:	43
Research Category:	Water Quality
Focus Category:	Water Supply, Water Use, Drought
Descriptors:	None
Principal Investigators:	Ronnie D. Lipschutz

Publication

1. Ruth Langridge. 2009. Confronting Drought: Water supply planning and the establishment of a strategic groundwater reserve. University of Denver Water Law Review in press
2. Ruth Langridge Confronting Drought: Water supply planning and the establishment of a strategic groundwater reserve Groundwater Resources Association, August 2008,Climate Change Symposium, Sacramento CA

The first phase of this project examined the legal and institutional framework for drought planning in California and the different political and management approaches to achieve a reliable water supply during prolonged water shortages. Analysis demonstrated that throughout the state, current strategies fail to promote the establishment of sufficient buffers to reduce vulnerability to extreme drought events. Groundwater recharge and storage, along with an innovative strategy - the establishment of a strategic groundwater reserve – were proposed to increase long-term water supply security during extended, severe water shortages. State authority to establish the reserve was delineated, including Article X, Section 2 of the California Constitution, and other sections of the California Water Code. Approaches to establish the reserve were laid out including the need to create incentives to 1) bring groundwater basins into hydrologic balance through recharge processes, 2) promote the enhancement of groundwater storage, and 3) establish and maintain a groundwater reserve supply.

The second phase of the project is focusing on specific approaches to reduce vulnerability to extreme drought events utilized by the Sonoma County Water Agency on the North Coast and the Santa Cruz Water Agency and the Pajaro Valley Water Management Agency on the Central Coast. Analyses include how these agencies frame and experience the problem of a lack of water, past water rights and management histories, current access to surface and ground water, and current management strategies to reduce vulnerability to extreme drought events. The goal is to assess feasible options to increase water supply security for these agencies during severe drought periods.

2. Problem Statement, Research Objectives and Methods

Problem Statement

Water is California's lifeblood, and water institutions are the primary distributors of water. Yet while scholars acknowledge that the largest impediments to adequate water supplies in the 21st Century are institutions and public policies, there is limited in-depth research and analysis of how these institutions characterize the needs of their constituencies and then plan for water shortages. Water supply planning typically involves static assessments of status to define water needs and challenges to established patterns of water access, use and management are uncommon. This is despite significant stresses on the state's water resources that include a growing population and increasing physical and regulatory constraints on future supplies. These problems are especially acute during extreme drought events.

Current solutions to cope with a lack of water are primarily limited to technological strategies that emphasize new supplies such as recycling and desalination, and managerial practices to increase efficiency, for example programs focused on conservation and pricing. The problem is that these strategies fail to address how to reduce the vulnerability of communities to extreme drought events, the central focus of this research. The first phase of this project therefore provides a more multifaceted analysis of the state's overall institutional framework for water supply planning and details how current strategies are insufficient to reduce vulnerability to extended drought events. The second phase of the project is examining how selected coastal communities and their institutions frame and experience drought and then promote solutions. The goal is to generate a range of options to improve long-term water supply security under drought conditions both locally and within the broader California context?

Research was guided by the following proposition: *The definition of a need for water, the characterization of drought, and the strategies utilized to cope with drought, are linked to the biophysical and social histories of a region as these shape institutional configurations, legal rights, economic entitlements and social relations that affect a community's access to, and the use and management of water under extreme drought conditions.* This in-depth analysis is fundamental to understanding the root causes of water scarcity and establishing solutions to reduce vulnerability to drought.

Research Objectives

Questions addressed include:

Phase I – What strategies are currently being utilized by water agencies throughout the state to improve water supply security, and are they adequate? How can state and local institutions, policies and practices be broadly reconfigured to reduce vulnerability to extreme drought events?

Phase II - How do selected communities and their institutions settle on their water "needs," define a water shortage and then settle on strategies to cope with severe water shortages? What feasible options do these selected communities have to improve water supply security for potentially serious future droughts?

Research Sites

The first year of research examined water supply planning throughout the state. The second year focused on water supply planning by selected agencies: the Sonoma County Water Agency on the North Coast and, the City of Santa Cruz Water Department and Pajaro Valley Water Management Agency on the Central Coast. The two regions share a climate characterized by great physical and biological heterogeneity, with almost no rain in the summer and periodic long-term physical droughts. None of the communities in these coastal regions receive water from the federal and state water projects and they all rely exclusively on local or regional sources. The regions nevertheless are geographically distinct, they contain extensive social and economic diversity and their entitlements to water and abilities to access water are different. It is an ideal situation for an exploration of how physical context and local histories, embedded in the broader political economy, shape how communities frame their water needs and characterize drought, and how institutions then generate plans to cope with water scarcity and who benefits from these plans. The project addresses these issues in an area of medium sized communities that are not connected to California's large water projects, and that are often neglected in state assessments of drought planning. Yet these communities can be most affected by a physical drought with respect to public health and safety impacts such as basic domestic, sanitation and firefighting purposes.[1]

Tasks:

A detailed account of the institutional framework for water supply planning in the state as a whole and for the selected sites including:

- Present state, regional and local strategies to cope with drought and their impacts
- Cooperative projects and water conflicts in the selected sites
- Access to water and perceptions and definitions of drought in the selected sites, including physical attributes, legal rights, rules of allocation and management and political and social relations
- An assessment of winners and losers over time in the selected sites

Feasible future policy options to enhance water supply security for extreme drought events, particularly for more vulnerable communities

Methods

Methods comprise and legal, policy and historical analysis, and incorporate both archival and field research. Sources include government documents, agency reports, scholarly papers, newspapers, and water policy related publications, as well as structured and open-ended individual interviews with key informants and participant observation to ensure access to the day-to-day decision making processes of local water institutions.

3. Principal Findings and Significance

Phase I

California's rainfall varies considerably from year to year, and data indicate that in the past California experienced very dry climatic conditions. Evidence also continues to accumulate that global climate change will

[1] Governor's Advisory Drought Planning Panel, 2000

have significant impacts on the state's water resources, including increased warming effects in the Sierra Nevada Mountains that will affect snow pack, snowmelt and the timing and magnitude of runoff in California.[2] Scientists warn that California could be subject to more very severe climate-induced droughts in the future. [3]

At the same time, human-generated pressures on the state's water supplies have also increased. More than 6 million people have been added to the population since the last relatively short dry period from 1987 to 1992, [4] and legal mandates are having major impacts on water availability for consumptive use.[5] Concomitantly, the financial, environmental and social costs of building new above ground water storage reservoirs and transmission systems to accommodate increasing demand have become formidable.[6]

Californians are more at odds then ever about how to establish sufficient and reliable water supplies to address these dual issues, and while they are related, as climate-induced water scarcity will intensify demand-induced water shortages, to a large extent researchers and policymakers have failed to focus on strategies that could mitigate *both* conditions. A significant problem is that some solutions proposed to address human generated water problems could create increased water shortages when a severe dry period does occur.

The first year of research examined the fragmented system of water supply planning in California, including the management of state and federal water projects, the most recent draft state water plan, urban water management planning, and local groundwater management planning. Significant areas of disconnect were uncovered between planning for a prolonged drought and planning to accommodate the state's burgeoning demand for water. Planning for a drought, including generating surface and groundwater data and preparing and implementing water shortage contingency plans, is primarily response oriented. Planning for ways to generate additional water to satisfy increasing demand includes strategies such as desalination, recycled water, water use efficiency, and the construction of new storage and conveyance systems. While often described as also creating water for dry periods, a central concern is that if water generated through these latter strategies is primarily utilized to support increased demand, the outcome could be an eventual upsurge in overall water demand in the future along with a hardening of demand side conservation strategies. This could actually increase vulnerability to water shortages when a severe dry period does occur.

Analysis of the legal, institutional and management issues surrounding alternate strategies to augment supply – groundwater recharge, storage, and conjunctive management – led to an innovative proposal to establish a strategic groundwater reserve as a key strategy to mitigate severe water shortages. Groundwater is a major contributor to the state's water supply, and more so in dry years. Annual overdraft from groundwater pumping throughout the state is currently in the range of one million to two million acre-feet and many aquifers remain overdrawn. This is despite the influx of state funding for the establishment of more sustainable groundwater programs. In addition, there is very limited state regulation of groundwater, and control over groundwater management is lodged in a myriad of different districts with varied incentives and limited capabilities to develop sustainable and enforceable long-term groundwater management programs.[7]

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[2] California Energy Commission Staff Report, June 2005, "Climate Change Impacts and Adaptation in California"

[3] DWR defines a climatic drought when, "broad areas are subjected to drier conditions than normal, imposing—at least temporarily—arid climatic conditions on many semiarid and even humid areas." DWR 2008 California Drought: An Update: Sec. 1.54. (Drought Update)

[4] DWR: 2008 Urban Drought Guidebook 2008 Updated Edition. DWR projects that California's population could grow by approximately 15 million by year 2020 and that an additional 2 to 3 million acre feet (af) per year would then be needed to supply the state's new population. California Water Plan Update Vol. 1 (1998)

[5] DWR 2008 Drought Update 2008

[6] Inflation and budget deficits have reduced funding for large storage projects and no new large dams have been built in California since the proposed Dos Rios dam construction was halted in 1969 (Langridge 2002, "Shifting Legal Regimes and the Allocation of Water Between Two Northern California Watersheds, *Natural Resources Law Journal*, 42, 238 – 330,). See also Brian Gray,1994, "The Modern Era in California Water Law," *45 Hastings L. J. 249, 278.*

[7] Langridge 2009 "Confronting Drought: Water supply planning and the establishment of a strategic groundwater reserve." *University of Denver Water Law Review – in press*

While some water districts in the state have groundwater management programs, these are primarily voluntary and they are not sufficiently centered on creating and maintaining a sufficient buffer for a long-term drought. Establishing a reserve would involve creating incentives to 1) bring groundwater basins into hydrologic balance through recharge processes, 2) promote the enhancement of groundwater storage, and 3) establish and maintain a groundwater level sufficient to provide a buffer during extreme water shortages. The reserve is critical to conserving nature's capital for the inevitable long-term drought. Conjunctive management of surface and groundwater, currently a popular strategy for many water agencies, could be re-designed to encourage recharge processes, to augment supply, and most important to safeguard the strategic reserve from being overdrawn during normal rainfall years.

The legal authority presently available to the state to establish and maintain healthy groundwater aquifers including a strategic groundwater reserve was analyzed including provisions in the California Constitution, Article X, Section 2, and sections of the California Water Code. Given the political resistance so far to state regulation, local authority to establish these goals is also detailed. Although large financial assistance programs have been put in place for local communities to implement groundwater improvement programs, groundwater overdraft and deteriorating quality remain significant problems. To address the consequences of a potential severe drought, research suggests that planning must move beyond the general notions of reducing water use when a drought occurs to establishing mandated standards for groundwater reserves sufficient to buffer a long term drought. In thinking proactively about reducing vulnerability to a drought through the establishment and maintenance a strategic water reserve, this research contributes to the debate over how to live sustainably in a fundamentally dry landscape.

Part II

It is also noteworthy that in past droughts those not connected to the major water projects in the state were particularly vulnerable to water shortages, including rural and less populated coastal areas and new developments in the Sierra Nevada foothills, both places where communities typically rely on small capacity storage systems fed by annual rainfall and on groundwater. As California's population growth shifts from the State's densely urbanized areas, these regions could become even more vulnerable (DWR 2008). The project therefore is currently assessing water supply planning, and particularly groundwater management, in several communities in the north and central coastal regions. These will serve as models to understand the opportunities and constraints involved in developing more sustainable groundwater management programs, including a reserve. The results of the project can then be applied more broadly in other settings.

Selected sites are the Pajaro Valley Water Management Agency (PVWMA), and the Santa Cruz Water Agency on the central coast, and the Sonoma County Water Agency on the north coast. The central coast communities do not receive imported water whereas the many north coast communities serviced by the Sonoma County Water Agency receive water imported from the Eel River via the Potter Valley Hydropower Project. None of the water agencies examined however import water from the state or federal water projects, leaving them with significant but varying degrees of vulnerability in the case of a severe drought. The needs of these and similarly situated agencies have not been fully addressed within California's institutional framework for drought planning.[8]

City of Santa Cruz Water Department

The City of Santa Cruz Water Department serving ~90,000 residents receives its water primarily from the San Lorenzo River and North Coast streams. It has one reservoir with a modest storage capacity that was built in 1960 when the population was 31,000. It is the only municipality around Monterey Bay that does not rely heavily on groundwater. Its biggest problem is that surface runoff and storage do not furnish an adequate supply during dry years. The rules and regulations governing the use of water during a water supply shortage are contained in the City's Drought Emergency Ordinance (Appendix E). The ordinance adopts a typically reactive

[8] Governor's Task Force Discussion Paper on Drought 2003

approach to drought planning, requiring that rules to conserve be put into effect when the Water Department staff determine that available supplies will be inadequate due to the lack of sufficient rainfall, runoff, and reservoir storage to support the community's normal water needs.

Along with concerns about drought, studies of existing water supplies and demand projections have concluded that water demand will continue to increase in the future. The city proposes that these needs could potentially be satisfied by conservation, full development of existing supplies, and new supplies. Water Code section 10632 (b) requires water suppliers to estimate the minimum water supply available during each of the next three years based on the driest three-year historic sequence for the agency's water supply. The city projects that after a serious three-year drought its available supply, which is limited by reservoir storage, would extend to only one more dry year. As a result, the city is exploring a conjunctive management project with the adjacent Soquel Creek Water District that involves the construction of a pilot desalination plant.[9] In contrast to the City of Santa Cruz, Soquel Creek has access to groundwater resources, but lacks a large surface water supply. Conjunctive management would provide desalinated water to Soquel Creek during wet years when Santa Cruz receives its water from normal precipitation. Soquel Creek would use this water during wet years in lieu of pumping groundwater, thereby recharging its aquifer. During dry years, Santa Cruz would use the desalinated water and Soquel Creek would use its groundwater to supply its constituents.

Pajaro Valley Water Management Agency

In 1980, the State Department of Water Resources issued Bulletin 118-80, which identified the Pajaro Valley basin as one of just eleven basins with critical conditions of overdraft. Significant development of rural and agricultural areas reliant primarily on groundwater, and the associated increase in population in the four major cities of the watershed – Watsonville, Hollister, Gilroy, and Morgan Hill, contributed to the overdraft, as did a shift in the types of crop grown in the watershed towards higher value more water intensive crops. In addition, as a result of excessive groundwater pumping, portions of the Pajaro Valley currently lie at or below sea level. Community leaders in the area recognized that local management of the basin was needed to halt seawater intrusion, which was impacting the groundwater supply for large areas of coastal farmland as well as domestic water supply wells. They also recognized that no single agency had the jurisdictional authority to manage the entire groundwater basin, which overlaps four major jurisdictions: the City of Watsonville, and Santa Cruz, Monterey and San Benito Counties. The PVWMA was formed as a state-chartered water management district approved by the local voters in a 1984 election to manage existing and supplemental water supplies in the Pajaro River watershed in order to prevent further increase in, and to accomplish continuing reduction of, long-term overdraft, and to provide and ensure sufficient water supplies for present and anticipated needs within its boundaries. The Agency's boundaries were drawn as closely as possible to match the same basin boundaries described in Bulletin 118-80. A central objective of PVWMA is to manage local groundwater to avoid and prevent conditions of long-term overdraft, land subsidence, and water quality degradation, and to provide and insure sufficient water supplies for present and anticipated needs within the boundaries of the agency. While the PVWMA has the authority to manage groundwater resources in the basin, litigation under Proposition 218 has limited the Agency's ability to raise sufficient funds. As a result, while the PVWMA's main concern is to halt seawater intrusion, individual agencies under their umbrella currently primarily focus on managing their own potable water supplies, as well as flood control, stream restoration and habitat management.

Sonoma County Water Agency

Most communities in Sonoma County currently rely on a combination of Russian River water and native ground water to meet demand. The Sonoma County Water Agency (SCWA) is the main entity responsible for supplying Russian River water to about 570,000 people throughout Sonoma County and neighboring Marin County. The region has experienced rapid population growth and accelerated urbanization in response to economic expansion over the past few decades. Groundwater conditions have changed significantly since the DWR conducted countywide studies 20–25 years ago, and there is current concern that in some areas there is

[9] City of Santa Cruz 2005 Urban Water Management Plan, 8-1, CHAPTER 8WATER SHORTAGE CONTINGENCY PLAN, Seals 2003, 2005, Goddard 2009, Presentation at University of California, Santa Cruz

degradation of water quality from sea-water intrusion, high nitrate concentrations, and mixing with waters high in mineral content. The quantity of water available from the Russian River system will also be reduced because of changes in water rights related to its diversions from the Eel River Basin. This will result in less water being imported from the Eel to fill the SCWA's primary storage reservoir, Lake Mendocino. A large increase in population, concomitant changes in land use, and the diminished imported supply from the Eel River that is also a main source of recharge to the groundwater system in the Russian River, make it critical that groundwater resources in the individual basins be managed sustainably. The agency is presently working with scientists from the U.S. Geological Survey to evaluate groundwater resources in several groundwater basins within the county to develop a detailed understanding of the ground-water/surface-water system, including the Santa Rosa Plain, and Sonoma Valley.

Additional information is currently being assembled and analyzed for a final report.

Integrated Regional Water Management Planning in California: Developing Institutions for Collective Action

Basic Information

Title:	Integrated Regional Water Management Planning in California: Developing Institutions for Collective Action
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Focus Category:	Management and Planning, None, None
Descriptors:	None
Principal Investigators:	Mark Lubell

Publication

1. Lubell, Mark, and Lucas Lippert. 2009. Integrated Regional Water Management: Collaboration or Water Politics as Usual. Under review, International Review of Administrative Sciences.
2. Lippert, Lucas. 2008. An Assessment of Integrated Regional Water Management Planning (IRWMP) in the San Francisco Bay Area . Master s Degree Thesis, UC Davis, 31 pages.
3. Water Resources Research Institute Reports

The goal of this project is to use theories of institutions and collective action to understand the factors contributing to the effectiveness of Integrated Regional Water Management Planning (IRWMP) in California. IRWMP provides state grant funding to local stakeholders to develop integrated regional water management plans. These plans are designed to encourage cooperation and integration within the fragmented institutional setting that has traditionally characterized water management in California.

The research focused on the Bay Area IRWMP, and used personal interviews of key participants, a quantitative survey of over 200 stakeholders, and analysis of priority water projects. We evaluate the effectiveness of IRWMP by focusing on three questions: levels of collaboration/participation, integration, and project effectiveness. Data collection was completed in June 2008, and our preliminary analysis finds mixed support for the effectiveness of IRWMP. Stakeholders are generally dissatisfied with the process, especially the role of the state government. Participation in IRWMP does not appear to increase overall levels of collaboration. Integration mainly occurs within functional domains such as water supply and flood control, and there is little integration with ecological issues. Environmentalists and watershed groups believe that IRWMP is not fair to their interests.

On the other hand, stakeholders indicate that the IRWMP has increased levels of trust and policy networks, which may be critical to future water management decisions. It may be too early to expect widespread increases in integration and collaboration; building an initial basis may be enough for now. Furthermore, the distribution of priority projects that emerged from the IRWMP planning process is relatively consistent with stakeholders' issue priorities. However, the actual money available for implementing these projects was heavily skewed towards previously existing projects from water supply and flood management sectors.

Simulating and understanding variability in runoff from the Sierra Nevada

Basic Information

Title:	Simulating and understanding variability in runoff from the Sierra Nevada
Project Number:	2008CA248B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	43
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Alex Hall

Publication

1. Kapnick, S. and A. Hall, 2009: Observed climate-snowpack relationships in California and their implications for the future. Conditionally accepted to Journal of Climate
2. Kapnick, S. and A. Hall, 2009: Observed changes in the Sierra Nevada snowpack: potential causes and concerns. California Environmental Protection Agency and California Energy Commission Draft Report CEC-500-2008-XXX, in press

This study aims to understand the origins of recent and future changes in snowpack and runoff in the Sierra Nevada using both observational and modeling techniques. Together, observations and models indicate the snowpack will likely undergo dramatic changes in the coming decades, and moreover that those changes are already detectable and well underway.

To study the snowpack from an observational perspective, we examined snow station observations and surface temperature data. Monthly snow water equivalent measurements were combined from two data sets to provide sufficient data for statistical analysis of snowpack evolution during the snow season from 1930 to 2008. The monthly data is used to calculate peak snow mass timing to assess variability in timing and magnitude of snow accumulation and melt from February 1st to May 1st. Since 1930, there has been a trend towards earlier snow mass peak timing by 0.6 days per decade. Since 1948, regional averaged March and April temperatures have also increased at a rate of 0.1ºC per decade. Statistical analysis shows that the trend in snow mass peak timing can be explained by its sensitivity to local March and April temperatures (see accompanying figure, which shows how closely linked averaged March and April temperatures are to the peak of the Sierra snowpack). The snow mass peak timing is shown to shift earlier in the season by 3 days per 1ºC increase in averaged March and April temperatures. Given scenarios of warming in California, we can expect to see acceleration in this trend; this will reduce the warm season storage capacity of the California snowpack.

This observational study paints a picture of a rapidly changing snowpack already responding to global climate change. These results are consistent with the modeling component of our study. To model the changing snowpack, we carried out a climate simulation with a 36-km regional atmospheric model covering all of California. In this simulation, the model is forced at its lateral boundaries with output from a global model simulating future climate change. This allows us to examine the effect of increasing greenhouse gases on the Sierra snowpack. By the mid-21st century, we project significant decreases in snow water equivalent averaged over the wet season in the Sierra Nevada. The projected snow decrease is especially large in the lower-elevation northern Sierras. Here it is about 30-40% in fall and almost 60-80% in winter. The decrease in snow is due to a significant decrease in snowfall and is likely augmented by increased likelihood of melting due to warming. Though the likelihood of snow melting is greater in the warmer climate, reducing snowpack, the amount of snowmelt itself decreases throughout the cold season in response to the reduced snowfall. Again, the largest reduction occurs in the northern Sierra Nevada where the snowmelt decreases by 38% and 54% for fall and winter, respectively.

A theme emerges from our observational study showing recent earlier snowmelt in response to warmer temperatures and our modeling study showing reduced snowpack in future decades due to warmer temperatures. Together, they indicate the snowpack will likely undergo dramatic changes in the coming decades, and moreover that those changes are already detectable and well underway. These results are directly relevant for California's reservoir infrastructure, whose capacity was designed assuming continuation of the natural hydrologic reservoir of the Sierra snowpack. Clearly this is not the case.

To complement observational studies of Sierra Nevada snowpack, we have constructed high-resolution simulations of California climate and hydrology using the Weather Research and Forecasting (WRF) regional climate model. We compare model output on a 3 km grid over the central Sierra with daily snowpack observations at 41 sites during the 2001-2002 water year. Preliminary results suggest that WRF accurately reconstructs snowpack development through March 1, 2002 at 18 of the stations, with substantial underestimates of snowpack at the others. Likely sources of error include primitive energy balance calculations in the 1-layer snowpack model currently coupled to WRF and inaccuracies in the partitioning of precipitation into rain and snow.

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:	9/30/2011
Funding Source:	Supplemental
Congressional District:	
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	

Publication

1. Husak G, J Michaelsen, and C Funk, 2007. Use of the Gamma Distribution to Represent Monthly Rainfall in Africa for Drought Monitoring Applications. International Journal of Climatology, 27: 935-944.
2. Funk C, J Michaelsen, J Verdin, G Artan, G Husak, G Senay, H Gadain, and T Magadazire, 2003. The collaborative historical African rainfall model: Description and evaluation. International Journal of Climatology, 23(1): 47-66.
3. Husak GJ, MT Marshall, J Michaelsen, D Pedreros, C Funk, G Galu, 2008. Crop Area Estimation Using High and Medium Resolution Satellite Imagery in Areas with Complex Topography. Journal of Geophysical Research, 113, D14112.
4. Verdin, J, G Galu, R Choularton, G Husak, 2008. Integrating Seasonal Forecasts into Food Security Outlook Analyses. Submitted to Food Security and Environmental Change (ENVR 2008): April 2008.

The Department of Geography at UCSB has 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 techniques for monitoring the physical variables governing crop growth, such as the timing and amount of precipitation, evapotranspiration and temperature, along with human-related factors such as cropped area, agricultural inputs, and economic indicators. We combine university-based research in the modeling, monitoring and analysis of remotely sensed estimates of environmental variables with science advisory, training, and development activities in Africa and Central America. This project brings together field scientists from Africa and Central America with research scientists at the University of California, Santa Barbara, in a single team of the UC Center for Water Resources, assembled to take on the activities needed to deal with threats to food security in the developing world.

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. In addition to the impacts of these disasters on food supply is the effect these extremes have on the entire economy of developing countries (Kreimer and Arnold, 2000). The economic effects of hydro-climatic extremes in developing countries can easily be equivalent in cost to war (Kates, 2000).

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.

The University's strengths in statistical climatology, hydrology, GIS, remote sensing, and geostatistics match up well with the goals and priorities of FEWS NET. The university can use these strengths to improve the scientific research, capacity building, and applications of the USGS component of FEWS NET. Both on-campus and off-campus activities (in FEWS NET countries) are proposed.

The university's scientific focus will be on estimating food production, with emphasis on monitoring and forecasting the natural and human inputs to food production. Basic research will address improved monitoring of rainfall, crop modeling, and cropped area estimates in FEWS NET countries. Better techniques, algorithms, and modeling applications, involving exploitation of remote sensing and other geospatial data, will emerge. Uncertainty associated with monitoring products and seasonal forecasts will be made clear to users, and the spatial data infrastructure underpinning the analyses will strengthened.

1. Crop area estimation

Tools such as the GeoWRSI focus on the estimation of crop yield. While variability in crop yield is a large source of uncertainty in the estimate of food production, the amount of cropped area is also carries large uncertainty, especially in areas where changes in land tenure and expanding or moving populations have resulted in sudden changes in cropped area. Traditional cropped area estimates have resulted from statistical sampling through either field visits or farmer surveys. This proposal plans to improve on these estimates through the use of satellite imagery.

An example of one strategy to improve on this has been exhibited for a portion of Ethiopia (Husak et al, 2007). This study used interpreted high resolution satellite data, combined with physical information such as slope, elevation and rainfall, along with interpreted variables like landcover to estimate the cropped area in select districts. In this modeling, the interpreted high resolution imagery serves as a surrogate for field visits. High resolution image interpretation has been shown to be reasonably accurate in identifying cropped area from non-crop for studies in Niger. Using this data the model is based on tens of thousands of site "visits", far beyond a typical field visit. Another advantage of these estimates is that the uncertainty in the model is defined, allowing for an approximate range of values which the cropped area falls within.

Studies like the one performed in Ethiopia can be replicated in other locations to ascertain cropped area for countries of interest. The statistical model needs to be developed for each country to account for local relationships between physical variables and cropped area, but the general methodology should remain consistent. Additionally, this proposal will look to include additional variables which may provide more explanatory power in defining cropped area.

2. Improved rainfall estimates

Integration of data from a variety of sources can result in a product that exploits the positive characteristics of all the input datasets. This is especially true for precipitation where satellite derived estimates can be merged with station values to create a rainfall field that is superior to either of these sources individually. The team at UCSB has developed a series of tools and techniques that allow the analysis and integration of points and raster rainfall datasets. Many of these techniques have bee developed for specific regions or to work with specific datasets and, in many cases, they are isolated and are not in a format that is easily replicated in other regions.

The work for this proposal is to integrate the existing techniques and develop new ones to create a straightforward process for the development of the most accurate possible rainfall data sets that

serve as input to crop, rangeland or hydraulic models. The process would include the analysis of station data using conventional and geostatistical techniques, unbiasing satellite data using climatological means, the integration of station data with raster rainfall fields, and the creation of historical datasets in raster format. The final product is the development of a standard set of tools which can be broadly applied to many regions for local scientists to implement using available data.

Some of the work that is already done includes: high resolution (5km) cliamtological monthly means which have been temporally downscaled to create dekadal mean fields for Central America, techniques to unbias TRMM data using climatological means, integration of station data with raster rainfall. Formalizing these techniques into a suite of tools which can be universally applied is necessary to insure a widespread use and formalized methodology in the application.

Information Transfer Program Introduction

None.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	33	2	0	3	38
Masters	38	3	0	4	45
Ph.D.	6	6	0	1	13
Post-Doc.	5	4	0	3	12
Total	82	15	0	11	108

Notable Awards and Achievements

Bayen, A. (UCB)

This work was instrumental in establishing a partnership with the Department of Water Resources to conduct joint experiments in the San Luis Reservoir Forbay. The experiments were in the process of being planned, but after the budget crisis hurt, they were frozen. One DWR team member left DWR following this, leading to the termination of the project.

Cohen, Y. (UCLA)

a. A pilot and demonstration studies on high recovery desalination was demonstrated in a joint collaboration between the Metropolitan Water District of Southern California and the UCLA Water Technology Research Center. This is part of a larger effort to develop a design for a large desalination plant for desalting brackish Colorado River Water (salinity of ~700-1300 mg/L TDS).

b. A pilot study was also carried out in collaboration with the Zuckerberg Institute for Water Research at Ben-Gurion University during the summer of 2007. This study demonstrated an operational approach to scale-free RO desalting. The approach is being considered for full-scale commercialization by a number of companies.

c. Our approach to antiscalant evaluation has been used to for optimizing antiscalant usage by the Metropolitan Water District of Southern California, and accepted by the California Department of Water Resources as an efficient approach to optimizing antiscalant use in RO desalting. antiscalant use the approach adopted as and a major number of companies. Our approach was also used by a major water services and antiscalant manufacturer to guide their antiscalant synthesis efforts.

d. Our approach to high recovery is now being evaluated in a pilot study by a University/industry consortium (which also involves our research group) in Australia, the effort being led by Victoria University.

e. We are currently pursuing a major opportunity for implementing our RO desalting process for high gypsum containing brackish water with a water district in the San Joaquin Valley.

Goldhamer, D. (UCD)

With reduced water supplies in the declared 2008 CA drought, there is increased interest in RDI. Peter Gleick has built a large part of his review of potential ag. water "savings" around RDI. An ever increasing number of tree/vine crop growers are using RDI although it's not possible to quantify these numbers.

Grattan, S.R. (UCD)

Substantial increase in the area planted to Jose tall wheatgrass in drainage impacted areas in SJV. This is based largely on the results from a project funded by the UC Salinity Drainage task force where this forage was found to have high salt tolerance, high biomass production and high forage quality. Boron is not a limiting to drainage water reuse systems as previously thought.

Libecap, G. (UCSB)

The data base on western water transfers has been maintained on the Bren School Web page since December 2007: http://www.bren.ucsb.edu/news/water_transfers.htm and a link is provided to CWR. This is a public

good for researchers as the most complete and comprehensive listing of water transfers across the western states since 1989: type, prices, duration, sectors involved. Since its listing, multiple researchers have accessed the data base.

Loaiciga, H. A. (UCSB)

We are interacting with the Watershed Protection District in Ventura County, where one of our study aquifers is located. The WPD wants to implement our method into their future ground water management strategies.

Lovatt, C. (UCR)

Charles McKenney manages 50 'Washington' navel orange trees in a public garden in Pasadena. Mr. McKenney, working with the City of Pasadena, wanted to irrigate the trees in the most efficient and water-wise way possible. He contacted me and I introduced him to partial root zone drying. He was very interested in the technique and requested detailed instructions for implementing it, which I provided to him. However, in the end he opted to let a commercial company, Netafim - largest low-volume irrigation company in the world, pioneer and global leader in drip irrigation, use the site to demonstrate the use of low-volume irrigation to the public in exchange for free irrigation equipment and technical assistance.

Quinn, N. (UCM and LBL)

The export of salts and other potential contaminants (such as algae) from San Joaquin Basin wetlands has become very controversial in the past year. The US Fish and Wildlife Service has been actively lobbying against regulation of wetland discharges to the San Joaquin River. The other wetland entities (California Department of Fish and Game and Grassland Water District) have become more sensitive to the political implications of salt loading and algal export. This political reality affected the project and necessitated a redesign of the sampling protocols to remain in good standing with our host institutions. This also provided an opportunity to develop a closer working relationship with these entities. Updates on the project were provided at quaterly meetings. Staff from the Los Banos Wildlife Management Area actively participated in some of the field survey work.

Weston, D. (UCB)

The work funded by NIWR/WRC was extremely influential in setting pesticide policy in the State of California. This work was the first to demonstrate that pyrethroid pesticides, the dominant insecticides for urban uses, were present in the sediments of urban creeks at concentrations toxic to aquatic life. In large part as a result of these findings, the California Department of Pesticide Regulation placed these compounds in to a process known as "re-evaluation", in fact the largest re-evaluation the State of California has ever conducted. The outcome of this process, when complete in a few years, could change both the pesticides available to the public and also the manner in which they are used. Our work was also critical in shifting the emphasis on pesticide regulation in California from agricultural pesticide uses, long the primary focus of the Department of Pesticide Regulation, to urban uses of pesticides and their effects on urban water bodies.

Molotch Co-PI (E. Njoku PI): Optically equivalent snow grain size detection to enhance the multi-scale, multi-frequency snow datasets of the NASA Cold Lands Processes Experiment. (2009 2011)

Molotch Co-PI (M. Durand PI): Relating in situ snow cover properties to multi-scale, multi-frequency remote sensing data utilizing CLPX datasets. (2009 2012)

Publications from Prior Years

1. 2007CA189B ("Determining factors for Eurasian watermilfoil (Myriophyllum spicatum L.) spread in and around Lake Tahoe, CA-NV ") - Other Publications - Chandra, S. and Wittmann, M., 2007. Invading Lake Tahoe: Dangers of invading organisms. Keep Tahoe Blue News: Summer Newsletter: pg 2.
2. 2007CA193B ("Distribution, Movement, & Outmigration of Juvenile Coho Salmon in the Shasta River: Relationships with Environmental Factors and Irrigation Water Management") - Other Publications - Thompson, Lisa C., Gerard Carmona Catot, Teresa Pustejovsky, and David Lile. 2007. Pine Creek and Eagle Lake Rainbow Trout Study 2007: Spawner Migration, Upper Watershed Habitat and Rearing Survey, and Bogard Spring Creek Brook Trout Removal Experiment. Report to the Pine Creek Coordinated Resource Management Planning Group. 30 November 2007. Lassen County Publication. 22 p.
3. 2004CA92B ("Feasibility of Snowpack Characterization Using Remote Sensing and Advanced Data Assimilation Techniques") - Articles in Refereed Scientific Journals - Chen, G. and Walker, S.L., The role of solution chemistry and ion valence on the adhesion kinetics of groundwater and marine bacteria Langmuir (2007) 23 (13) 7162-7169
4. 2007CA192B ("Influence of Bacterial Pathogen Condition on Cell Transport in Groundwater Environments: Implications of Extracellular Polymeric Substances (EPS) Production and Composition") - Other Publications - Haznedaroglu, B., Bolster, C.H., and S. L. Walker The role of starvation on bacterial adhesion and transport in saturated porous media Water Research (2008) 42:1547-1554
5. 2007CA192B ("Influence of Bacterial Pathogen Condition on Cell Transport in Groundwater Environments: Implications of Extracellular Polymeric Substances (EPS) Production and Composition") - Articles in Refereed Scientific Journals - Bolster, C.H., Haznedaroglu, B., and Walker, S. L. Diversity in cell properties and transport behavior among 12 environmental Escherichia coli isolates Journal of Environmental Quality (2008, in press)
6. 2007CA192B ("Influence of Bacterial Pathogen Condition on Cell Transport in Groundwater Environments: Implications of Extracellular Polymeric Substances (EPS) Production and Composition") - Other Publications - Kim, H.N., and Walker, S.L., 2008 Escherichia coli transport in porous media: Influence of cell strain, solution chemistry, and temperature Colloids and Surfaces B: Biointerfaces (under review)
7. 2007CA192B ("Influence of Bacterial Pathogen Condition on Cell Transport in Groundwater Environments: Implications of Extracellular Polymeric Substances (EPS) Production and Composition") - Other Publications - Chen, G., Bedi, R., Beving, D, Yan, Y., and Walker, S.L. The antimicrobial effect of zeolite surfaces on bacterial deposition in a parallel plate flow chamber
8. 2007CA192B ("Influence of Bacterial Pathogen Condition on Cell Transport in Groundwater Environments: Implications of Extracellular Polymeric Substances (EPS) Production and Composition") - Other Publications - Gong, A. S., Benavides, M., and S. L. Walker Influence of extracellular polymeric substances extraction method for Salmonella enterica serovar pullorum on the quantification of starvation effect