FINAL REPORT
CALIFORNIA WATER RESOURCES RESEARCH AND APPLICATIONS CENTER
REGIONAL EARTH SCIENCE APPLICATIONS CENTERS PROGRAM
Principal Investigator: Norman L. Miller, Berkeley National Laboratory

Executive Summary

The California Water Resources RESAC objectives were to utilize NASA data to provide state-of-the-art real-time and forecast information (observation and simulation) on hydroclimate, water quantity and quality, and runoff related hazards to water resources managers (e.g. NWS, CA Dept. of Water Resources, USBR), the insurance industry, emergency response agencies, policy decision-makers, and the general public. In addition, the RESAC acts as an umbrella organization fostering growing collaborations and partnerships. It was built on the foundation established through the U.S. Global Change Research Program and the National and California Assessments. It is designed to support the on-going regional and national assessment process by improving our understanding of specific regional features of the climate system and its impacts, and facilitating the dissemination of these results through data, publications, and outreach.

The California Water Resources RESAC produces three types of regional climate products that are enhanced by incorporation of NASA satellite data: (1) short-term (2-3 day) weather and streamflow forecasts, (2) seasonal hydroclimate, and (3) long-term climate change scenarios and hydrologic impacts. Our team has built an excellent record in providing quantitative precipitation and streamflow forecasts to the water resources and weather prediction communities. We have been working with scientists from various University of California institutions and government agencies to improve weather and streamflow predictions and studies of regional hydroclimate, and its impacts on water resources, the environment, and the economy.

- California and southwestern US climate for several baseline and climate change simulations at 20 km resolution.
- California 48-hour advance weather forecasts at 10 km resolution posted daily.
- California streamflow sensitivities of 11 basins for application to water demand simulations used by the CA Department of Water Resources, California Energy Commission, and University of California.
- California streamflow 30-year data sets for control and climate change climate scenarios.
- California streamflow sensitivities for application to water demand simulations that the CA Department of Water Resources uses.
- California basin-mean-area precipitation, temperature, and streamflow climatologies for historical and projected climates.
- Satellite data analyses and snow hydrology modeling for improved runoff forecasting.
- Landslide Model maps of topographic gradient, contributing area, soil thickness, the factor of safety, water table elevation, and the unsaturated soil water.
- Real-Time San Joaquin streamflow and real-time salinity monitoring.

Products have been provided to the community through our URL site (esd.lbl.gov/RCC), our ftp site (climate.lbl.gov), publications, and presentations. These coupled sets of activities have advanced California water resources research, applications, and use. It has fostered new partnerships with state and federal agencies in a cost-effective way that is expected to continue into the future.

Statement of the Issues

Fresh water availability, water quality, and water-related hazards reduction are the three most pressing water issues within California and the U.S. Water supply and water quality are chronic high priority water issues in California. Short-term and long-term water availability is related to climate and weather variability, climate change, management, technology, economics, and planning. Innovative approaches are needed if California is to provide the fresh water required by its growing population, irrigated agriculture, industry, fisheries, and to maintain healthy natural systems.

California represents the seventh largest global economy. It has an infrastructure and ecosystems that are sensitive to weather extremes and climate variability. California water resources directly affect the economy of California and the U.S. Understanding the regional climate and its impacts on various natural and human sectors is of great importance to safety, future planning, and sustainability. The California Water Resources RESAC has combined and advanced capabilities for regional hydroclimate simulation, remote sensing, and water quality assessment, and provided an information distribution system to a well defined user base. Our information distribution system has been dynamically linked to state and federal agencies and continues to focus on water quality and quantity, and water related natural hazards such as floods, droughts, fire potential, high winds, river sedimentation, landslides, and runoff contamination.

This Center has helped to improve our ability to predict weather and streamflow for the Sacramento-San Joaquin drainage basin (representing up to 80% of California's fresh water), and seasonal to long-term climate variability and climate change of the western U.S.

In addition to these results, we have improved weather-related natural hazards in partnership with the National Weather Service Office (NWSO), the California-Nevada River Forecast Center (CNRFC), and real-time water quality monitoring in partnership with the U.S. Bureau of Reclamation (USBR). We have also advanced remote identification of hazardous mine tailing minerals that may runoff into the Sacramento-San Joaquin drainage and the USGS will benefit from this work as part of their clean-up efforts. These projects have been applied to planning and research by a number of our partners, including CA Energy Commission, CALFED, USBR, USGS, EPA, and the CA Dept. of Conservation.

Project Strategy

The California Water Resources RESAC goals and objectives were to:

- Improve water resources predictability via assimilation of satellite products into the Regional Climate System Model.

- Apply water quantity and quality research to the assessment of regional impacts on water resources, environmental quality, human activities, and natural disasters.
- To provide educational outreach to universities, and local and state agencies.

The research and applications that took place to meet the RESAC goals and objectives described above were split between six major elements, and outreach. These have been identified and written within each report as the following:

- Hydroclimate Simulations and Analysis
- Geostatistical Analysis
- Streamflow Modeling and Analysis
- Agricultural Impacts and Real-Time Monitoring
- Identification of Contaminants from Abandoned Mines
- Landslide and Sediment Transport
- Outreach

Most of the above elements began at the onset of the RESAC Program and continued through the 3-year cycle, several phased in and out at differing times due to costs and the time required to obtain the best qualified post-doctoral researchers. The hydroclimate and streamflow research carried on into March 2003 as a rollover activity.

The largest element, which is representative of our core area, focused on regional climate and streamflow modeling and analyses. The strategy was to gain greater visibility by the California community, and Local, State, and Federal Agencies as each element grew within our linked set of research, applications, and outreach. The approach visualized from the outset was that the water quantity and quality was an end-to-end system for predicting and monitoring water quantity, quality, and related impacts. This system begins with the global climate, which provides forcing to the regional hydroclimate, which in turn determines streamflow, runoff from the landscape, reservoir recharge, and contaminants and sediments that enter water systems. We simulated, monitored, and reported on many aspects of this water resources system in the form of peer-reviewed manuscripts, public workshops, and climate change impacts reports, as listed at the end of this report.

Remotely sensed products were used for climate and land surface characterization, model initialization, geostatistical downscaling, hazardous mineral identification, and for snow model improvements. As part of our coupled efforts with the Southwest RESAC, we have utilized the AVHRR Snow Cover Area (SCA) maps that they produced and incorporated the resulting fields into our snow modeling efforts for the Sierra Nevada.

Through the combination of these linked elements, publications, and outreach activities the California Water Resources RESAC has achieved the goals and objectives described above.

Partnerships

The majority of the RESAC partners were approached and brought into the project at the onset or were part of the earlier Regional Climate System Model collaboration team. New partnerships evolved based on outreach activities that have focused on improving our products and/or those of our partners.

AmazonTech[I]
Arkwright Insurance Company[I]
California Department of Conservation[S]
California Department of Forestry and Fire Protection[S]
California Department of Water Resources[S]
California Energy Commission[S]
Changwon National University, South Korea[U]
Chinese Ministry of Water Resources[G]
Coordinated Resources Management Program[L]
Energy Power Research Institute (EPRI)[I]
Korean Meteorological Administration[G]
McGulley, Frick, and Gilman, Inc.[I]
NOAA California-Nevada River Forecast Center[F]
NOAA International Research Institute[F]
NOAA National Weather Service-Sacramento[F]
NOAA NCEP Climate Prediction Center[F]
Queensland Department of Natural Resources[G]
San Joaquin River Management Program[S]
Silicon Graphics[I]
SIO Experimental Climate Prediction Center[U]
University of California Berkeley - Earth Resources Center[U]
University of Queensland, Australia[U]
U.S. Bureau of Reclamation[F]
U.S. Forest Service[F]
U.S. Geological Service[F]

[L]Local [U]University [S]State [F]Federal [I]Industry [G]Intergovernment

Research Accomplishments

Our RESAC research accomplishments have occurred within most every element and have been well represented by our peer reviewed manuscripts. The following summary describes the highlights for each of the elements with a list of peer reviewed papers for each element which are fully referenced at the end of this report.

Hydroclimate Simulations and Analysis
During the start-up year, a series of present day and climate change studies representing a 2040-2049 projected climate were performed for the western US. Remotely sensed LAI

and DEM data were utilized. Streamflow simulations accompanied these results and the significant findings were presented at a series of conferences and outreach workshops. The following years consisted of additional climate change studies, including contributions to several books/book chapters, plus a series of sensitivity studies representing climates for 2010-2039, 2050-2079, 2080-2099. An outcome of these studies were news reports by a number national and local newspapers, television, and radio. The California Department of Water Resources determined that these studies were of value for their water allocation models and began to integrate our findings into their climate change report. These activities, which align with one of the RESAC Program's priorities, that is, contribute to the USGCRP, is continuing into the future as a sustainable activity with California-based funding.

References: Miller, N.L., J. Kim, R.K. Hartman, and J.D. Farrara, **1999**; Miller, N.L. and J. Kim, **1999;** Field, C., G. Daily, R. Gaines, P. Matson, J. Melack, N. Miller, R. Pitelka **1999;** ; Kim, J., N. Miller, J. Farrara, and S. Hong, **2000**;. Miller NL. Kim J., **2000;** Kim, J., **2001** Kim, J., T. Kim, R. Arritt, and N.L. Miller, **2002**;

Geostatistical Analysis

Geostatistical Analysis was and continues to be an important element of our hydroclimate and hazards research. A new methodology for statistical-dynamical downcaling has been developed and applied. This activity began during the second year of the RESAC Program and will continue as a sustained activity via our collaboration with a UC-Santa Barbara Statistics Professor who held a RESAC-sponsored Post-Doctoral Researcher position at Berkeley National Laboratory during January to December 2000.

References: Holmes K.W., O.A. Chadwick, and P.C. Kyriakidis, **2000;** Kyriakidis, PC; J. Kim, J., and N.L. Miller, **2001**; Kyriakidis, P.C., N.L. Miller, and J. Kim **2001**; Kyriakidis, PC and J.L. Dungan **2001**;

Streamflow Modeling and Analysis

Streamflow modeling and analysis is tightly coupled with the hydroclimate simulations and geostatistics discussed above. Resulting research has led to a better understanding of the spatio-temporal distribution and sensitivity of stremflow response due to climate variability. This element began at the RESAC onset and includes partnered work with the California Nevada River Forecast Center, the Department of Water Resources, and the California Energy Commission. These activities are continuing as sustainable research, and are written into a follow-on project as part of a REASoN proposal submitted to NASA.

References:, N.L. **2000a**; Miller, N.L. **2000b** Bashford, K.E, K.J. Beven and P.C. Young. **2001**; Miller, N.L., K.E. Bashford, and E. Strem **2001**; Miller, N.L., **2001**; Miller Miller, N.L., K.E. Bashford, and E. Strem **2003**;

Agricultural Impacts and Real-Time Monitoring

The agricultural impacts and real-time monitoring element is linked to the hydroclimate and streamflow simulations and became part of an EPA project for evaluating the impacts of climate change on Central Valley agriculture. The potential shift in agricultural water demand and corresponding economics due to climate change was critically evaluated. This element is continuing with new CA Energy Commission and CALFED support and

ongoing partnered activities with the USBR.
References: Quinn, NWT; Miller, NL; Dracup, JA; Brekke, L **2001**; Brekke, L.D., N.L. Miller, N.W.T. Quinn, and J.D. Dracup: **2003**

Identification of Contaminants from Abandoned Mines
The abandoned mine hazardous mineral identification element resulted in new procedures and tools for identifying such hazards. The remotely sensed mapping techniques were discussed in annual reports, and have been well recognized as an important new advancement toward determining where mineral hazards are and how to begin clean-up operations. This research area continues to be used as a means to train and educate new geologists within UC-Berkeley.
References: Montero S., I.; and Brimhall, G.H. **2001**; Montero S., I. C., Brimhall, G. H., Alpers, C. N., Swayze, G. A., **2002;** Montero S., I.; and Brimhall, G. H. **2003**;

Landslide and Sediment Transport
Landslide and debris flow and sedimentation research has advanced within this project and a coupled NASA SENH project, as well as a joint Italian Space Agency project on landslides - Cassandra. Our work to develop a predictive scheme utilized remotely sensed fine scale DEM data. It has been tested at several locations where landslides are known to have occurred, and this summer will be advanced further and incorporated as a web-based tool accessible from our RESAC URL. This continuing work has educated graduate students and postdoctoral researchers through our partnered research with the University of California at Berkeley.
References: Casadei, M., W.E. Dietrich, and N.L. Miller **2003**

Products and Services

The California Water Resources RESAC maintains an active URL (esd.lbl.gov/RCC) with 48-hour weather forecasts for California at 10km resolution. Downloadable climate change impacts documents are available from this site, as are numerous related types of information. Several specific products have been produced and are available from our server (climate.lbl.gov) and by direct request. These products include:

- California and southwestern US climate for several baseline and climate change simulations at 20 km resolution.
- California 48-hour advance weather forecasts at 10 km resolution posted daily.
- California streamflow sensitivities of 11 basins for application to water demand simulations used by the CA Department of Water Resources, California Energy Commission, and University of California.
- California streamflow 30-year data sets for control and climate change climate scenarios.
- California streamflow sensitivities for application to water demand simulations that the CA Department of Water Resources uses.
- California basin-mean-area precipitation, temperature, and streamflow climatologies for historical and projected climates.
- Satellite data analyses and snow hydrology modeling for improved runoff forecasting.

- Landslide Model maps of topographic gradient, contributing area, soil thickness, the factor of safety, water table elevation, and the unsaturated soil water content are available.
- Real-Time San Joaquin streamflow and real-time salinity monitoring.

Outreach

Outreach consisted of workshops on California Climate and Impacts, data, and data needs with State, Local, and Federal Agency Representatives and with ESIPs and University Representatives. We have had annual RESAC Workshops with students presenting progress. We have maintained our strong ties to the local and state agencies and are gaining federal agency recognition for multi-agency collaboration in California. We have had meetings with the California Energy Commission, California Department of Water Resources, Central Valley Water Quality Control Board, US Fish and Wildlife Service, US Bureau of Reclamation, and the Coordinated Resource Management Program (CRMP) to provide updates on all projects, explore opportunities for cooperative research and monitoring, and to educate the community. The Berkeley RESAC is linked to the ESIP Federation and will have increased visibility.

One of our most visible tools is our 48-hour forecasts that are posted on the California Water Resources RESAC URL (http://esd.lbl.gov/RCC). Our contributions to the IPCC 2000 Scientific Assessment -Third Assessment Report, Chapter 10. Regional Climate Simulation – Evaluation and Projections; U.S. National Assessment 2000 - Mega-West Report, Coastal Report, U.S. National Assessment 2000 Water Sector, and the California Climate Assessment have given the California water Resources RESAC additional visibility.

Our California Modeling and Information Workshop - Lawrence Berkeley National Laboratory, Sept. 18, 2000, activities on the California Climate Change California Panel, and National coverage of our climate change studies (Newpapers, NPR, SF TV) have also brought attention to our activities.

Sustainability

California Water Resources RESAC scientists contributed to the DOE Accelerated Climate Prediction Initiative (ACPI) plan for a Regional Climate Network and the DOE Water Cycle Dynamics and Prediction Plan (WCDPP). A successful outcome of these contributions was an initial water cycle pilot study, “Modeling and analysis of the hydrologic cycle: Seasonal and event variability at the Walnut River Watershed.” We have contributed to the NSF Consortium of Universities for the Advancement of Hydrology (CUASH) Initiative, the NSF Science and Technology Center (STC) known as Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA) at the University of Arizona-Tucson. At present, a DOE-sponsored California Water Resources Initiative is in review and we have begun stronger Statewide collaborations as a means for sustaining our follow-on RESAC activities at Berkeley Lab. A REASoN proposal is in review as a

follow-on to our snow and hydroclimate modeling work.

Conclusions

The California Water Resources RESAC team advanced climate modeling techniques through the use of coupled dynamic and statistical modeling. We integrated the AVHRR SCA products produced by the Southwest RESAC and have begun to produce new simulations with highly improved snow simulations. This is an important component, as California water resources are approximately 80% Sierra Nevada snowmelt and understanding potential future climate impacts to this resource hinges on how well we can simulate present snow. Our landslide prediction work advanced to the point where we can provide coarse resolution likelihood maps that will be posted on our web site during this summer. A roadblock to the accuracy of this prediction is the so-called legacy affect. New remote sensed data will help to gain further insight to this and it is part of a follow-on study.

The California Water Resources RESAC advanced climate, hydrology, and impacts research at Berkeley and strengthened a California-based collaboration network. Our modeling and analysis was a primary activity, however, the Center utilized numerous NASA data products. In addition, our research complemented well with the Southwest RESAC activities. The Principal Investigator gained an increased understanding of NASA procedures and management of large projects/Centers. This experience will prove to be important, as these activities continue to grow and the PI takes on more challenges as a researcher and representative of the hydrometeorological scientific community.

Publications

Peer-Reviewed Publications

Bashford, K.E, K.J. Beven and P.C. Young. 2001: Observational data and scale dependent parameterisations: Explorations using a virtual hydrological reality. Hydrological Processes. 16(2):293-312, 2002 Feb 15.

Brimhall, G. H and Vanegas, A., 2001, Removing Science Workflow Barriers to Adoption of Digital Geological Mapping by Using the GeoMapper Universal Program and Visual User Interface: in D. R. Soller ed., Digital Mapping Technqiues'01- Workshop proceedings: *U. S. Geological Survey Open File Report 01-223*, p. 103-114, <http://pubs.usgs.gov/openfile/of01-223/>.

Brekke, L.D., N.L. Miller, N.W.T. Quinn, and J.D. Dracup: 2003 Climate Change Impacts Uncertainty for San Joaquin River Basin. J. American Water Resources Assoc. In Press

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Kim, J., T. Kim, R. Arritt, and N.L. Miller, 2002: Impacts of Increased Atmospheric CO_2 on the Hydroclimate of the Western United States. J. Climate, 15(14):1926-1942, 2002 Jul..

Kim, J., 2001: A nested modeling study of elevation-dependent climate change signals in California induced by increased atmospheric CO_2, Geophys. Res. Letters, **28**, 2951-2954.

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Holmes K.W., O.A. Chadwick, and P.C. Kyriakidis, 2000: Error in a USGS 30m digital elevation model, and an evaluation of its effects on digital terrain modeling. Journal of Hydrology, 233(1-4), 156-175

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Miller, N.L., K.E. Bashford, and E. Strem. Climate change sensitivity of California hydrology: A report to the California Energy Commission. LBNL Tech Rep. 49110, November 2001, 31 pp.

Miller, N.L., 2001: (Contributing Author) IPCC TAR Chap. 10. Regional Climate Simulation – Evaluation and Projections. 79pp., March 2001.

Miller, N.L. (Contributing Author).2000a: Preparing for a changing Climate. The potential consequences of climate variability and change. Southwest. U.S. Global Change Research Program. 60 pp. ISPE.

Miller, N.L. (Contributing Author) 2000b: Climate change impacts on the United States. The potential consequences of climate variability and change. Overview. U.S. Global Change Research Program. 154 pp. Cambridge University Press.

Miller NL. Kim J., 2000: Climate change sensitivity analysis for two California watersheds. J American Water Resources Association. 36(3):657-661.

Miller, N.L., J. Kim, R.K. Hartman, and J.D. Farrara, 1999: Downscaled climate and streamflow study of the southwestern United States, *J American Water Resources Association* – Special Issue on Climate Change and Water Resources, **35**, 1525-1537.

Miller, N.L. and J. Kim, 1999: The Regional Climate System Model: Southwestern United States, Eastern Asia, and Northeastern Australia. WMO/ICSU/IOC *World Climate Res Progr*, **28**, WMO/TD-No. 942.

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Selected Presentations

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Brimhall, G., and Vanegas, A., 2001, GeoMapper: A completely integrated digital mapping system with a practical end user focus. Proceedings 2001 Annual Conference of the International Association for Mathematical Geology. IAMG, Kansas. June 2001

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Customer Feedback

The most significant aspect of the RESAC was building up collaborations with the National Weather Service's River Forecast Center and the California Department of Water Resources. We have developed a special expertise that the National Weather Service has come to rely on as part of the climate prediction activities within California. Evidence of customer feedback can been seen via letters of support from California Agencies and the National Weather Service which were included in our part of a proposed REASoN as a follow-on to the RESAC. Letters of Support are available upon request.