I. GENERAL INFORMATION

Date submitted	10/1/01
Reporting period	1/1/01 – 12/31/01
Name of the Center	Sustainability of semi-Arid Hydrology and Riparian Areas
Name of the Center Director	Soroosh Sorooshian
Lead University	University of Arizona
Contact information	
Address	University of Arizona Hydrology & Water Resources PO Box 210011 Tucson, AZ 85721-0011
Phone Number	(520) 626-6974
Fax Number	(520) 626-7770
Email Address of Center Director	soroosh@sahra.arizona.edu
Center URL	www.sahra.arizona.edu
Participating Institutions	
Institution 1 Name	**Arizona State University**
Address	Nancy Grimm Arizona State University Department of Biology Box 871501 Tempe, AZ 85287-1501
Phone Number	480-965-4735
Fax Number	480-965-2519
Email Address of Center Director	nbgrimm@asu.edu
Role of Institution at Center	Partner in scientific research and education
Institution 2 Name	**Columbia University Biosphere 2**
Address	Steve Russell Biosphere 2 Center P.O. Box 689 32540 S. Biosphere Rd Oracle, AZ 85623
Phone Number	520-896-5005
Fax Number	520-896-6383
Email Address of Center Director	srussell@bio2.edu
Role of Institution at Center	Partner in development of educational systems and outreach
Institution 3 Name	**Desert Research Institute**
Address	Joseph R. McConnell 2215 Raggio Parkway Reno , NV 89512
Phone Number	775-673-7348
Fax Number	775-673-7363
Email Address of Center Director	jmcconn@dri.edu
Role of Institution at Center	Partner in scientific research and education
Institution 4 Name	**New Mexico Institute of Mining and Technology**

Address	Fred Phillips New Mexico Institute of Mining and Technology Department of Earth & Environmental Science 801 Leroy Place, Room 208 MSEC Bldg Socorro, NM 87801
Phone Number	505-835-5540
Fax Number	505-835-6436
Email Address of Center Director	phillips@nmt.edu
Role of Institution at Center	Partner in scientific research and education
Institution 5 Name	**Northern Arizona University**
Address	Aregai Tecle Northern Arizona University Huffer Lane, Building 82 PO Box 15018 Flagstaff, AZ 86011-5018
Phone Number	520-523-6642
Fax Number	520-523-1080
Email Address of Center Director	aregai.tecle@nau.edu
Role of Institution at Center	Partner in education and outreach to Native American
Institution 6 Name	**Pennsylvania State University**
Address	Chris Duffy Pennsylvania State University 212 Sacket Building University Park, PA 16802
Phone Number	814-863-4384
Fax Number	814-863-7304
Email Address of Center Director	cxd11@psu.edu
Role of Institution at Center	Partner in scientific research and education
Institution 7 Name	**University of California, Los Angeles**
Address	William Yeh University of California, Los Angeles 5732B Boelter Hall Mail Code 159310 Los Angeles, CA 90095-1593
Phone Number	310-825-2300
Fax Number	310-825-7581
Email Address of Center Director	williamy@seas.ucla.edu
Role of Institution at Center	Partner in scientific research and education
Institution 8 Name	**University of California, Riverside**
Address	Feike Leij University of California, Riverside U.S. Salinity Laboratory 450 W. Big Springs Road Riverside, CA 92507
Phone Number	909-369-4851
Fax Number	909-342-4964
Email Address of Center Director	fleij@ussl.ars.usda.gov
Role of Institution at Center	Partner in scientific research and education
Institution 9 Name	**University of California, San Diego**
Address	John Roads Scripps Inst. of Oceanography UC-San Diego Geosciences Research Div., 0244 La Jolla, CA 92093-0224
Phone Number	858-534-2099

Fax Number	858-534-8561
Email Address of Center Director	jroads@ucsd.edu
Role of Institution at Center	Partner in scientific research and education
Institution 10 Name	**University of New Mexico**
Address	David S. Brookshire University of New Mexico Dept. of Economics Social Sciences Room 1019 1915 Roma NE Albuquerque, NM 87131
Phone Number	505-277-1964
Fax Number	505-277-9445
Email Address of Center Director	brookshi@unm.edu
Role of Institution at Center	Partner in scientific research and education

2. Executive Summary

Vision of the Center

Approximately 33% of the land surface of the Earth, including 25% of the contiguous U.S., is arid or semi-arid. The semi-arid regions are experiencing higher than average rates of population growth and development, and are therefore faced with the critical problem of how to support *sustainable* development and, in particular, how to provide *sustainable* resources of water. Among the key issues faced by such regions are the water supply (including quantity and quality) and ecosystem health. Policy decisions, planning and management are complicated by various factors including a variable and uncertain global climate, strong heterogeneities in ecology and topography, and rapidly changing land use.

The vision of SAHRA, the NSF Science and Technology Center for *Sustainability of semi-Arid Hydrology and Riparian Areas* is to develop an integrated, multi-disciplinary understanding of the hydrology of semi-arid regions, and to building partnerships with a broad spectrum of stakeholders (public agencies and private firms) so that this understanding is effectively applied to the optimal management of water resources and to the rational implementation of public policy. The key question that we seek to address is "*How can SAHRA use science to help communities manage their water resources in a sustainable manner?*" This highlights the fact that SAHRA is concerned both with advancing the understanding of fundamental principles in semi-arid hydrology (through stakeholder-driven multi-disciplinary research), and with developing strategies for implementing scientific understanding on a practical level through aggressive outreach and strong education initiatives (K-16 and public).

Goals

The overarching goals of SAHRA are to make significant advances in the understanding of semi-arid hydrology, and to help bring that understanding rapidly to bear on the practical problems of water resources policy, management and operational decision making. The greatest challenge of SAHRA, therefore, is to bring about an unprecedented level of coordination and integration across a broad range of scientific disciplines, and between scientists, policy and decision makers, and the general public. This coordination involves the diverse talents of physical scientists, behavioral scientists (including economists), educators, practicing engineers (from both public agencies and private companies), legal experts and decision makers. This challenge can be considered met if new technologies, analytical tools and modeling approaches are rapidly assimilated into the understanding and management of water resources.

The science goal is to understand the demand and supply aspects of water resources and how these aspects interact. Five science areas have been identified, 1) Spatial and Temporal Components of the Water Balance, 2) Basin-scale Water and Solute Balances, 3) Functioning of Riparian Ecosystems, 4) Multi-Resolution Integrated Modeling of Basin-Scale Processes, and 5) Water as a Resource: Competition, Conflict, Planning and Policy.

The education and knowledge transfer goals are to build understanding of key water issues into K-16 science education and to promote hydrologic literacy throughout the population that makes water-use and related political decisions.

By combining scientific research with education and public outreach, SAHRA seeks to foster a multi-disciplinary perspective and build technological skills within the professional communities that develop and implement water resources policy and manage our water resources.

Plans

SAHRA began its operations as a Center in February 2000 and spent the first 6 months in getting the Center established as an organizational unit: a) selecting the executive committee and advisory board; b) recruiting and hiring professional and technical staff, postdoctoral researchers, and students; c) renovating and furnishing office space; d) implementing a structure for administrative management; e) implementing a structure for financial management, f) developing, implementing and submitting to NSF on March 31, 2001 a science-education-outreach work plan and operating budget; g) coordinating communication; and h) preparing and submitting the first annual report to NSF on Aug 1, 2000. Research was also initiated during this period, primarily by students already in our graduate programs, under direction of the core SAHRA faculty investigators. Other research was phased in as personnel were recruited. While the first Annual Report was submitted to NSF on Aug 1, 2000, the associated budget report was submitted on October 1, 2000. In coordination with NSF, it was decided that the annual reporting date for subsequent years would be October 1. This first 6-8 months can be characterized as having been dominated by start-up and implementation issues.

The second year of SAHRA (October 1, 2000 - September 31, 2001), has been equally (if not more) busy. The primary objectives of this past 12 months have been to a) recruit additional scientific and technical personnel, b) gain a better understanding of the priority water-related issues in the semi-arid southwestern United States, c) develop and strengthen partnerships with stakeholder groups in the region, d) refine the Centers' science-educational-outreach goals based on our early experience and on feedback from the advisory board and stakeholder groups, and e) develop a more strongly integrated program of research, education and outreach.

During the third year, we expect to continue working on the four primary objectives mentioned above, while beginning the task of reviewing all existing science tasks and activities supported by SAHRA to determine what has been learned. Tasks that do not integrate well with the developing science goals of SAHRA, or that are nearing completion will be phased out. New tasks will be selected for support. Particular attention will be given to including new and innovative science activities. At the end of the third year, we expect to move into new SAHRA facilities, the entire 5th floor of the new Marshall Foundation building currently under construction by the University of Arizona.

During the fourth and fifth years, the objective will be to increase involvement in international outreach, developing the transferability of knowledge and tools to and from the other semi-arid regions of the world.

Performance and Progress toward Meeting Goals

During the past 12 months, considerable progress in achieving the second year goals has been made:

a) *Science:* The science thrust areas are now well established and a complete season of field studies has been conducted. Stakeholders are actively involved in review and direction of many of the research activities. Selected science findings are listed at the end of this executive summary. Detailed reports appear in section II. Considerable integration of science activities across the thrust areas has also been accomplished.

b) *Education:* A significant amount of our educational effort has been placed on course development and internal education activities, based on a careful assessment of what is needed. These include a graduate seminar, undergraduate water issues course, high school science teachers workshop, seminar series, professional degree program in Water Resources Engineering, graduate assistantships for community service, research experiences for undergraduates and a high school intern program. External education activities have included a high school course in Science and the Environment, a joint SAHRA/GLOBE collaboration, a "Passport to Learning" water sustainability module, and a series of 8 EEO/ITEP workshops (Environmental Education Outreach & Institute for Tribal Environmental Professionals) for Native American K-12 teachers. Professional development activities included a Tribal Analysis & management Workshop, and a Northern Arizona Watershed Collaborations workshop. Details appear in section III. These programs will be judged to be successful by their persistence, growth in numbers served and quality of product.

c) *Knowledge Transfer:* While the objectives have not changed, our emphasis has shifted from internal KT to providing information to water resources professionals in the southwestern US and around the world. We have identified areas of critical water information that lack effective dissemination mechanisms and are beginning to provide these in specific areas. Examples include our web-based News Watch service, K-12 Curriculum Clearinghouse, and Conservation Information sites. We also are beginning to expand our international activities, having identified key issues and partners. Major emphasis currently is on studying impacts of privatization and decentralization of water and land resources, examining trans-boundary issues, and modeling water supply systems in northern Mexico.

d) *Recruitment:* Postdoctoral researcher, student, and staff recruitment has continued. Postdoctoral research associates (PDRAs) James Hogan (TA2), John Villinski (TA3), Luis Bastidas (TA4), and Anne Browning (TA 5) were selected and brought on board, bringing the total complement of junior scientists to five (Constance Brown, the TA1 PDRA, was recruited during year one). SAHRA is currently supporting 55 graduate and 10 undergraduate students, of which approximately half are located at the UA and half at the various partner institutions. Also, 7 high school student interns were recruited to work on SAHRA projects during the summer. Five new staff positions were also filled including two technicians (John Petti and Joel Gage), a computer/database person (Steven Schroeder), a web-editor (Louise Shaler), and an accountant associate (Gabriel Lopez).

e) *Communication:* Communication is carried out via in-person group meetings, phone conferencing, email, website and workshops. Activities and reports are coordinated by email and phone. The public web-site (www.sahra.arizona.edu) is now quite mature and has been updated to a new look and feel. In particular, the web site now also has a private side where information specific to SAHRA researchers can be accessed. A series of SAHRA sponsored seminars by prominent scientists has been initiated.

f) *Organizational Meetings:* The Executive Committee meets monthly, typically on the last Tuesday of each month. The pattern is two successive meetings by phone conference followed by an in-person two-day meeting at the University of Arizona every third month. Administrative staff meetings are held weekly on Thursday mornings. The five directors meet approximately monthly to coordinate and discuss strategy. The External Advisory Board meets once a year: this year the meeting was coordinated to occur in conjunction with the SAHRA annual meeting on February 20-23, 2001. The NSF site visit will be held in Tucson on October 16-17th, 2001.

c) *Annual Meeting:* The first annual meeting of SAHRA scientists and stakeholders was held in Tucson, Arizona on February 20-23, 2001. The 3 ½ days of activities included oral and poster science presentations with an emphasis on student participation, a "public" day to which numerous guests were invited, thrust area planning break-out sessions, and various student activities including a field trip to the San Pedro basin experimental sites. Members of the EAB and the NSF oversight team were also in attendance. The meeting resulted in important feedback from the EAB and NSF teams which significantly influenced activities during the remainder of the year.

d) *Science Workshops & Coordination Meetings:* A highly successful SAHRA workshop on "recharge " was held in Socorro, NM, on March 22-23, 2001, attended by approximately 30 scientists and students. An important outcome is the Fall 2001 AGU Special Session on "Recharge and Vadose Zone Processes in Semiarid and Arids Regions" organized by SAHRA researchers Phillips, Duffy and Hogan. An AGU monograph on recharge is planned. Several important TA4 and TA5 planning meetings were held in both Tucson and Albuquerque, in response to critical comments from the EAB and NSF teams regarding the coordination of the activities of these TAs. A major planning meeting to prepare a funding proposal to study the economic valuation of bird flyways in the San Pedro basin was held in Tucson. In addition, SAHRA sponsored and hosted the Interagency Hydrologic Modeling Task Group meeting (Tucson, November 2000), and the NSF STC Directors meeting (Tucson, December 2000).

e) *Facilities:* New SAHRA facilities were negotiated with the University of Arizona and architectural plans for the new facilities, to be located on the entire fifth (top) floor of the new Marshall Foundation building, have been drawn up. The building is scheduled for completion around December 2002.

f) *Funding:* We have leveraged NSF resources to develop several new partnerships and bring in additional resources. New partners include Cal State-LA's Center for Environmental Analysis ($517K NSF Glue grant), Sandia National Labs ($90K), The Nature Conservancy ($20K), and the Bureau of Reclamation, Audubon Society and Cochise County ($55K). The State of Arizona has committed $96K per year towards water-related social science and knowledge transfer and $96K towards water education. Other leveraging possibilities are being actively pursued.

Significant Changes from the Original Plans

The activities of the Center are firmly on track, and there have been no significant changes from our plans as outlined in the first annual report submitted last year. Of course, a number of evolutionary developments have occurred as mentioned earlier and will be discussed in context in the main sections of this report.

Overview of a Few Selected Accomplishments

A) Research:

- Snow water equivalent estimates and satellite-based high resolution rainfall estimates for the Southwestern US are now available. Experimental daily to seasonal climate forecasts are also available.
- An operational micro-meteorological network for alpine water balance studies has been established.
- Surveys of the spatial distribution of snow in the Rio Grande headwaters were conducted, and synoptic sampling of the Rio Grande has identified ~6 locations where significant salinity increases occur - both natural (saline ground-waters and hydrothermal waters), and anthropogenic(agricultural return flow).
- Studies indicate that the key control on spatial soil moisture variability in grass, shrub and mixed

environments appears to be the size distribution of inter-spaces, not the above-ground plant structure or geometry. This has implication for the susceptibility of vegetation communities to drought and long-term climate change.

- Soil-water pressure profile measurements support the hypothesis that distinctly different soil-water flux regimes are associated with different vegetation. This finding indicates that vegetation distributions may be useful in upscaling point recharge estimates to basin scale.
- Measurements indicate that deep root sap flow prior to the monsoon is towards the tree, but after rain events, the direction reverses away from the plant into the deep soil.
- Transpiration measurements indicate decoupling between water sources of Mesquite and the understory (grasses and annuals). Trees rely mainly on groundwater and understory on recent precipitation.
- A new method for use of natural cosmogenic ^{32}Si as a tracer for determining long-term ground-water recharge rates is under development and testing.
- The RAMS mesoscale model has been coupled with the LADHS hydrology model within a parallel applications workspace (PAWS). This allows rapid real time data transfer between the two codes.
- A global to regional climate modeling system is being tested for its ability to predict short-term (daily to seasonal) and long-term (global change) characteristics of the hydrologic cycle for the Southwest.
- The MOCOM multi-criteria optimization code developed at the University of Arizona has been incorporated into the MMS environment.
- Institutional analyses and social assessments, including evaluation of drought coverage, intensity and duration were conducted for selected watersheds in the Southwestern US.
- Dynamic modeling analysis using an optimal control framework addressed the novel situation wherein private demands are consumptive-use related while, habitat demands, while clearly consumptive, are closely related to water stocks. Given the uncertainty of population growth and hydrologic related lags, these policy tools must be forward looking.
- A hydrologic-economic hybrid model has been developed that illustrates the value of capturing hydraulic interactions with water demand components in a single model. Household data for the city of Albuquerque have been linked to consumer demand modeling experiments.

B) <u>*Education:*</u>

- Successful workshops were held on a) Recharge, b) Integrated Modeling, c) Integration of Physical and Behavioral Sciences, d) SAHRA/GLOBE Collaboration to Monitor Conductivity on the Rio Grande, e) Tribal Watershed Workshop, and f) High School Teacher's Summer Water Science Workshop**.**
- A pilot Summer Program for Learning About Semi-arid Hydrology (SPLASH) was conducted this summer. Seven high school students provided valuable support to field research efforts, lab work, and knowledge transfer, and receiving positive media coverage. Five of them are now enrolled at the UA.

C) <u>Knowledge Transfer:</u>

- Our new dynamic and interactive web site includes a *Water News Watch* which monitors water news sources from around the world in six languages with English-language summaries and links to original sources and related articles. This is an important step towards our goal of being an international clearinghouse for many types of water related information.
- SAHRA personnel supported a Mexican grassroots Upper San Pedro watershed group with organization, establishment of goals, and outreach to stakeholders to foster capacity building. The group is seeking bi-national ties with a U.S. watershed organization in the same basin.
- Water resources management tools were developed in conjunction with local stakeholders to assist in decision-making for several watersheds in the Southwestern US.

D) <u>*Leveraged Funding:*</u>

- We have leveraged NSF resources to develop several new partnerships and bring in additional resources. New partners include Cal State-LA's Center for Environmental Analysis ($517K NSF Glue grant), Sandia National Labs ($90K), The Nature Conservancy ($20K), and the Bureau of Reclamation, Audubon Society and Cochise County ($55K). The State of Arizona has committed $96K per year towards water-related social science and knowledge transfer and $96K towards water education. Other leveraging possibilities are being actively pursued.

II. RESEARCH

1a. Research objectives

The mission of SAHRA is to "promote sustainable management of water resources in semi-arid regions". Because SAHRA is an NSF Science and Technology Center and is located at a university, its activities are strongly focused around the physical and behavioral sciences. Therefore the mission statement can be formulated into a question of the form "*How can SAHRA use science to help communities manage their water resources in a sustainable manner?*" This question highlights the fact that SAHRA is concerned both with advancing the understanding of fundamental principles in semi-arid hydrology (science research), and with developing strategies for implementing scientific understanding on a practical level (knowledge transfer and education).

Clearly, the ability of SAHRA to achieve its mission depends on a number of factors. On the one hand, SAHRA must advance the science. On the other, we must ensure that the principles and models in practical usage are kept up to date. The former involves coordination and integration of existing understanding and methods from a number of diverse physical and behavioral disciplines. In addition, it requires that we continue to target and support novel and cutting-edge research activities that advance our understanding of the fundamental principles in semi-arid hydrology.

To ensure that sound, up-to-date scientific understanding is properly integrated into the water allocation and management process (from operational practice through to policy making), the activities of SAHRA are organized towards establishing a smooth connection between the science process with the decision making processes at both the operational and policy levels. We recognize that the needs of decision-making at these two levels should influence the selection of SAHRA science activities by identifying areas where science can provide improved understanding of the physical and behavioral components of the system. At the same time, SAHRA aims to foster more effective application of existing and emerging scientific understanding. To achieve the former, SAHRA continues to develop strong interactive relationships with a broad spectrum of resource-manager stakeholders. With regard to the second, the science activities currently supported by SAHRA have been selected to emphasize important semi-arid regional water-related science issues that are either not well understood, or are not currently receiving sufficient attention. The key research objectives of SAHRA are listed below:

- To estimate and model the spatial and temporal components of the environmental water balance in semi-arid regions by intensive and continuous field observations, coupled with modeling, in sub-alpine areas and a variety of ecological locations on the desert floor.
- To understand surface and subsurface water and solute balances in semi-arid regions at large spatial and temporal scales (i.e., up to the scale of a river basin and up to decadal and longer time scales).
- To understand how riparian systems affect and are affected by changes in water quantity (e.g., due to ground-water pumping or conjunctive stream-water management) or water quality (e.g., nitrogen inputs from precipitation or agricultural runoff).
- To integrate emerging scientific understanding into comprehensive river basin models that can be used in the analysis of water resources management issues.
- To examine and analyze issues related to water-resources policy, including behavioral, sociological, and economic factors, in semi-arid regions of the Southwestern US and integrate current SAHRA modeling and physical sciences efforts with community water planning and management.

To achieve these five objectives, the science activities of SAHRA are organized into five Thrust Areas (TA) with the activities of each TA focused around several major topics as listed below. The list indicates which TA has the lead role for a topic; there is considerable interaction between TA's on most topics. Note that the natural sciences are represented by Thrust Areas 1-3, the integrated modeling sciences by Thrust Area 4, and the social and behavioral sciences by Thrust Area 5. The individual TA descriptions in section 2 provide details regarding the objectives and accomplishments of each thrust area.

TA1: Spatial and Temporal Components of the Water Balance	
	Environmental water balance above the mountain front
	Runoff and infiltration in semi-arid regions
	Remote sensing and modeling of precipitation
TA2: Basin Scale Water and Solute Balances	
	Vegetation and vadose zone processes of the basin floor
	Basin scale hydrologic systems
TA3: Functioning of Riparian Systems	
	Water and carbon exchange in riparian systems
	Nutrient cycling in riparian systems
TA4: Multi-Resolution Integrated Modeling of Basin-Scale Processes	
	Computational environment – Virtual watershed laboratory
	Fine resolution integrated modeling
	Medium resolution integrated modeling
	Basin scale systems modeling
TA5: Water as a Resource: Competition, Conflict, Planning and Policy	
	Institutional analyses and social assessments
	Behavioral aspects of water markets and water banking
	Non-market valuation
	Water resources management and operations

1b. Problems

Certainly this reporting period has not been free of problems that have hindered progress towards achieving our research goals – they can be categorized as a) Delays in development of the organizational structure, b) Delays in implementation of communication systems, c) Problems in science coordination, d) Financial limitations, e) Delays in obtaining permissions for access to field sites, and f) Need for development of a coordinated knowledge-base. These problems and how we are dealing with them are broadly discussed below with further detail for some of the issues provided in section VII (Management).

A) Delays in Development of the Organizational Structure:

As described in section VII, we have experienced delays in recruitment of personnel, and renovation of research facilities, thereby slowing the process of setting up the infrastructure that supports the research. Also, the considerable time spent responding to NSF requests for information during the first reporting period delayed much of the organizational development into the second year. However, we have been able to make significant progress during the second year towards resolving the organizational issues (see section VII). The facilities are mostly operational, and much of the recruiting has been accomplished. Further, the executive committee has been able to devote considerable attention to the task of developing the science agenda, resolving communication problems, and promoting integrative activities.

B) Delays in Implementation of Communication Systems:

Due to delays in renovation of SAHRA facilities, the phone and teleconferencing room was slow to become operational. Once the construction was completed, better communication was established via phone conferencing and the executive committee was able to establish regular monthly meetings, thereby reducing travel to four in-person meetings (in Tucson) a year. However, the video and data sharing facilities have yet to become operational. A recent teleconferencing supplement from NSF is enabling us to set up four identical teleconferencing (phone and data) rooms - one at the University of Arizona, and three others at partner locations. Completion of these facilities will be a priority during the next reporting period.

C) Problems in Science Coordination:

During this reporting period, the SAHRA administration and executive committee were able to give considerable attention to coordination of the science activities. While there were minor issues across the board, special attention was required with respect to TAs 4 and 5, as described below.

Through the early part of this year, problems were experienced with respect to communication and coordination of the activities of TA5. Feedback from the External Advisory Board indicated that the goals and activities of TA5 were not sufficiently well defined and coordinated. This was evidenced by difficulty, at several meetings of the members of TA5, in the ability to reach agreement on common research goals and budgetary allocations. It should be noted that TA5 is the activity that seeks to bridge the gaps between physical science and behavioral science, and to some extent these problems were related to differing perspectives, vocabularies and priorities. However, through a succession of meetings and after structural suggestions were advanced by the committee on integration, and further developed at a pivotal May 2001 workshop in Albuquerque (see section VII), these problems have been largely resolved, as reflected in the TA5 report presented later. Of course, some of the communication problems were a consequence of people from diverse disciplines not having worked together before, and these disappeared naturally and gradually as the members of the TA got to know and appreciate each others methods and objectives. At this point, the activities of TA5 appear to be well structured, and a primary objective during the next reporting period will be to develop further integration among the sub-tasks.

At the annual meeting, the EAB also pointed out that the objectives and methods of TA4 (Integrated Modeling) needed to be reviewed and developed further. Concern was raised that the “Virtual watershed lab” concept would take too long to develop (10 years) and would therefore not be able to adequately support the integration of the other science activities in the short term. Further, there was insufficient clarity of the relationship of the individual sub-component modeling efforts and the task of integrated basin scale modeling. The committee on integration examined this problem, and based on numerous discussions with various SAHRA researchers, finally proposed a a conceptual integration model for SAHRA research. Based on that conceptual model, the committee suggested that TA4 adopt a multi-resolution approach to basin scale modeling and focus its initial modeling activities on the Rio Grande basin (see TA4 report). This approach was adopted at the September TA4 workshop in Albuquerque. A primary objective of the next reporting period will be to develop implementation and coordination plans for each of the modeling resolution groups and make progress towards developing the conceptual and numerical models of the Rio Grande basin.

D) Financial Limitations:

The original proposal for the Center requested and was awarded only approximately $16M of the maximum possible $20M that could have been budgeted. In particular, the proposed budget did not include funds for certain critical activities such as development of teleconferencing facilities and development of the knowledge base. In response to guidance from NSF, we expanded our support for research related to demand-side water related economics. Further, the science ambitions of SAHRA researchers have expanded considerably as the Center has become established, and as the magnitude of the sustainability problem in semi-arid regions has become better understood.

In response, SAHRA has begun to seek out and leverage additional funding to support these needs.

- A proposal to the University of Arizona Board of Regents has resulted in a commitment that approximately $192K per year of the Arizona Proposition 301 Initiative funds will be made available to SAHRA for development of behavioral water science, education and knowledge transfer activities.

- Supplemental awards were solicited and obtained from NSF in two areas - REU (Research experiences for undergraduates; onetime $54K) and teleconferencing (onetime $33K).
- We obtained an NSF-initiated “glue grant” with Cal State-LA’s Center for Environmental Analysis to develop joint research activities ($517K over 3 years).
- A partnership was established with Sandia National Labs to jointly develop a dynamic simulation model of the Middle Rio Grande ($90K over 2.5 years).
- A partnership was established with The Nature Conservancy to develop an “alternative futures” groundwater-surface water model of the Middle San Pedro River ($20K over 2 years).
- A partnership was established with the Bureau of Reclamation, Audubon Society and Cochise County for analysis of domestic water demand (total of $55K over 2 years).
- Preliminary plans are in development to support research into the non-market economic value of migratory flyways in the San Pedro and Rio Grande basins
- Preliminary plans are in development to support research to extend and develop Virtual Watershed Laboratory concept to take advantage of advanced parallel computing platforms.

Other leveraging possibilities are also being actively explored. These additional funding sources will facilitate a more comprehensive implementation of the mission of SAHRA, while spawning offshoots to the primary research initiatives.

E) Delays in obtaining permissions for access to field sites:

Two unanticipated problems have caused delays to some of our planned field work. In the first case, we discovered (in late July) that Title 32 of the Arizona State Law requires all wells within the State of Arizona to be registered (at a cost of $10 per well), with a licensed driller present at the time of installation. This affects all 90 piezometers that we have installed in the San Pedro Basin. SAHRA Assistant Director Gary Woodard has approached the Arizona Department of Water Resources for an exemption from certain portions of this law. We have requested exemption from the requirement for presence of a licensed driller during installation since the wells are hand installed PVC, less than six feet deep, and are not used for water supply. We have also applied for an exemption from the $10 per well fee. We will of course register the wells with ADWR to appraise them of the location of all the wells.

In the second case, we experienced delays in getting access to government land to install an eddy correlation micro-meteorological tower and a network of smaller supporting micro-meteorological stations. Reconnaissance field trips during May – October 2000, identified a suitable site on Mt. Bigelow in the Santa Catalina mountain range, located within a National Forest. The permitting process was started in November of 2000, and involved several meetings with the Forest Ranger to determine the type of permit required, a meeting with the director and operations manager for the Stewart Observatory (UA) regarding the status of the UA lease for the proposed site (the lease was terminated 2 years ago), and meetings with the UA Lawyers. The formal proposal for the permit was submitted to the National Forest Service in Feb/March 2001. The proposal had to be sent to all other parties with scientific or commercial installations on Mt. Bigelow, the public, and the Native tribes for comment. An archeological survey for all 5 sites had to be conducted, and was done in May 2001. Final permission for the network was obtained in August 2001. As a result, the installation of the tower and network has been considerably delayed, and we have missed the snow accumulation/snowmelt observation period for 2000-2001, delaying much of the field work to the next reporting period.

F) Need for Development of a Coordinated Knowledge-base:

A remaining problem is the urgent need for development of an easily accessible web-based “knowledge-base” repository of information to enable sharing and communication of research plans and results, and to support science, education and knowledge transfer activities. We have begin working on development of this knowledge-base (see section VII). This will be a priority during the next reporting period.

Thrust Area Descriptions

Thrust Area 1	Spatial and Temporal Properties of Hydrologic Variables	
PI Name (s)	Roger Bales (Thrust Area Leader)	
Participants		
	Name	Status
1	Ackroyd, Stephen	Graduate student
2	Bales, Roger	Faculty, Thrust Area Leader
3	Bardsley, Tim	Graduate student
4	Blumenfeld, Hana	Graduate student
5	Boyle, Doug	Postdoctorate
6	Brown, Constance	Senior Postdoctorate, Thrust Area Coordinator
7	Dressler, Kevin	Graduate student
8	Yang Hong	Graduate student
9	Fasnacht, Steven	Other Postdoctorate
10	Ferre, Paul	Faculty
11	Furman, Alexander	Graduate student
12	Quanfu Fan	Graduate student
13	Gao, Xiaogang	Faculty
14	Khodatalab, Neusha	Graduate student
15	Goodrich, David	Faculty
16	Gupta, Hoshin	Faculty
17	Hsu, Kuo-Lin	Other research scientist
18	Leij, Feike	Faculty
19	Mahani, Shayesteh	Postdoctorate
20	McConnell, Joe	Faculty
21	Mohanty, Binayak	Faculty
22	Molotch, Noah	Graduate student
23	Moradkhani, Hamid	Graduate student
24	Andrew Hinnell	Graduate student
25	Paige, Ginger	Postdoctorate
26	Schaap, Marcel	Faculty
27	Shouse, Pete	Other research scientist
28	Shuttleworth, Jim	Faculty
29	Simunek, Jirka	Faculty
30	Sorooshian, Soroosh	Faculty
31	Stone, Jeff	Other research scientist
32	Warrick, Arthur	Faculty
33	Zhu, Julian	Postdoctorate
34	van Genuchten, Rien	Other research scientist

Funding (reporting year)		
	NSF	464,930
	Other - University of Arizona match	29,996
Funding (anticipated for next year)		
	NSF	394,765
	Other - University of Arizona match	30,046

Thrust Area 1 - Spatial and Temporal Components of the Water Balance

The major goal of Thrust Area 1 is to estimate and model the spatial and temporal components of the environmental water balance (specifically snow accumulation, distribution, and melt, evapotranspiration/sublimation, runoff and infiltration) by intensive and continuous field observations, coupled with modeling, in sub-alpine areas and a variety of ecological locations on the desert floor.

There are three focus areas within TA1: 1) Environmental Water Balance above the Mountain Front, 2) Runoff and Infiltration in Semi-Arid Regions, and 3) Remote Sensing and Modeling of Precipitation. All three research areas are linked by the common goal of trying to understand the components of the water balance across a catchment area and are differentiated by location and scale. Within the first two research areas, there are multiple projects. Figure 1 illustrates the stratification within Thrust Area 1, the links within and across thrust areas as well as other research groups with which there are strong active partnerships.

<u>1.1 Environmental Water Balance above the Mountain Front</u>

The major goal of this group is to measure and model the components of the water balance above the mountain front. Determination of water yield from mountain precipitation and snowmelt is vital for estimating the annual water balance in large semi-arid watersheds. The primary emphasis of the research is snow accumulation, distribution, melt, runoff and evapotranspiration/sublimation processes above the mountain front. Investigations into soil water fluxes will also be carried out.

Individual research efforts include:
1) Relating sub-alpine hydrological and micrometeorological spatial and temporal conditions to snow distribution and melt (Mt. Bigelow sky island site).
2) Sub-alpine snow accumulation, distribution and melt and runoff in the upper Rio Grande and Salt-Verde basins.

The left side of Figure 1 shows the integration of these subtasks within TA1 and within SAHRA. Between the two individual research efforts there is direct sharing of the common primary data acquired in the field as well as common modeling efforts related to snow distribution, melt, runoff and evapotranspiration/sublimation. Similar energy balance, evapotranspiration/sublimation, soil moisture and carbon flux data sets are being collected by TA1 above the mountain front, TA2 on the desert floor and TA3 in the riparian zone. These data sets are necessary for model development, calibration, and validation, both within these thrust areas and for integration in TA4. The point and basin scale snowmelt models developed/refined by this group are to be integrated into TA4 modeling efforts. NASA Regional Earth Science Application Center (RESAC) provides remotely sensed snow products such as spatial snow cover areas (SCA) and snow water equivalent (SWE) information.

Activities

The primary objectives of this focus area over the past year have been 1) the establishment and smooth operation of a 30 m tall eddy correlation micrometeorological tower and a network of four 3 m tall micrometeorological towers within a subalpine area, 2) field snow surveys and development of snow estimation methods, 3) to finish the MMS/PRMS model developments and complete the initial model runs. The research efforts over the past year have focused on activities relevant to the production of inputs for estimating the water balance above the mountain front. The major activities and research efforts directed at fulfilling these objectives are listed below:

Sub-alpine Micrometeorological data network

- Survey and select appropriate site within a sky island subalpine area, for the establishment of a 30 m eddy correlation (EC) micrometeorological tower. A reconnaissance survey of potential sites were carried out October 8 –17, 2000, in which Dr Tilden Myers from the NOAA ATDD participated. A suitable site on Mt Bigelow in the Santa Catalina ranges of the Coronado National Forest was selected.
- Survey and select several sites within 1-2 km of the EC tower to install a network of smaller micrometeorological towers 3 m in height. Potential sites were selected in November 2000; reconnaissance survey of the sites was done in April 2001; and an archeological survey of the tower sites (including the EC site) was done on May 30, 2001.
- Obtain special permission from the National Forest Service to install the EC tower and the small micrometeorological towers. Permission was received from the National Forest Service for the installation of the network of small micrometeorological towers in May 2001. Permission for the installation of the EC tower was received in August 2001.
- Acquire instruments. A suite of micrometeorological instruments and four 3 m towers were acquired in December 2000. A 30 m scaffolding tower was ordered in August 2001.
- Recruited and hired a research technician in February 2001
- Install network of 3 m micrometeorological towers. Four 3 m towers were installed and instruments mounted between June 08 and July 11, 2001. The towers are instrumented to measure wind velocity, wind direction, air temperature, relative humidity, barometric pressure, infrared surface temperature, snow depth, net radiation, soil moisture at 2 depths below the surface and soil temperature at the surface and at 6 depths below the surface. Currently the data is averaged over 15 minutes and logged to a data logger. The data is downloaded onto a computer every week.
- Organize database. Data from the towers are being organized into a database to be analyzed and used for investigation of research questions within SAHRA.

Hydrologic modeling above the mountain front

- Restructure and refine spatial snowmelt model. A spatial snowmelt model was restructured refined and tested at the watershed scale.
- Hydrologic modeling of test basin. Hydrologic modeling of the Salt River Basin has begun. The White River Basin has been modeled at a 1 km, and 5 km grid scale. After the initial modeling success, a comparison between different vegetation type classifications (e.g., Brown and Lowe, IGBP, USGS, TM-reclassed scene) was performed to determine the sensitivity of streamflow simulation to model vegetation inputs.
- Snow water equivalent was geostatistically interpolated for the entire Colorado River basin using a variety of techniques (IDW, ODA, Hypsometric, Multivariate Regression) over the years 1990-1999. A comprehensive analysis of the differences between snow cover measured from SNOTEL and snow course stations has begun and should be completed by December 2001.
- Background studies on surface/soil – atmosphere interactions during snowmelt. A spatial database from low flying aircraft, over different ecosystems during and after snowmelt has been used to examine the dynamics of energy partitioning and surface responses and distribution characteristics.
- Parameter estimation for distributed snowmelt and runoff. Accomplishments included development and implementation of a MOCOM (Multi-Objective Criteria Optimization Method) module within MMS and initial runs of MMS/PRMS on the Headwaters of the Rio Grande (above the Del Norte Gage). Because better prediction of runoff timing and quantity is crucial to optimum river system management, such modeling efforts are a key component of SAHRA's overall aim of improving the sustainability of water resources in semi-arid regions.
- The University of Arizona group, in collaboration with the DRI group, organized and completed a 1-week research snow survey in the headwaters of the Rio Grande in April 2001. Research activities primarily focused on detailed measurements of snow depth and snow water equivalence (SWE) in order to validate SWE estimates derived from regional-scale snow depletion models and interpolation of SNOTEL data. Field sites were located near the SNOTEL automated SWE measurement devices in the region. This resulted in a data set capable of accommodating multiple research objectives.

- The same sampling strategy was repeated at the field sites in the Rio Grande headwaters in May and June of 2001.
- In December 2000, a number of snow depth and SWE measurement traverses were conducted in the Headwaters of the Rio Grande during a 3-day field campaign.
- In March 2001, a preliminary snow survey of the lower lying areas of the Rio Grande headwaters was conducted.

Plans for the next reporting period

The objectives for the next year are divided into three primary activities: 1) the development of a sub-alpine micrometeorological data network; 2) improved hydrologic and snowmelt modeling above the mountain front; and 3) development of snow interpolation methods. The research plans and objectives are outlined below.

Sub-alpine micrometeorological data network

- Install and instrument the 30 m eddy correlation tower on Mt Bigelow
- Design real time data acquisition system.
- Create a communication link between all the micrometeorological towers for the acquisition of near real time data.
- Create database for measurements taken from micrometeorological network
- Analyze data from the towers in terms of fluxes, energy balance, seasonal conditions, in particular, before, during and after snowmelt.
- Characterization of study site. In order to accurately interpret the micrometeorological data the study site needs to be characterized. This involves acquiring (or establishing) 1) fine resolution elevation characteristics within the footprint of the EC tower, 2) spatial variability of soil moisture and temperature of semi arid-sub-alpine areas, 3) spatial variability of thermal diffusivity, 4) spatial soil/surface characteristics and 4) description of canopy structure.
- Characterize turbulence within the footprint of the EC tower.
- Establish the EC tower as a validation site for Land Data Assimilation Systems (LDAS)

Improve hydrologic and snowmelt modeling above the mountain front

- Update hydrologic model for the Salt-Verde basin using interpolated SWE, satellite-derived snow pack water volumes for both the White and Black basins, and improved canopy opening calculations and other inputs such as leaf area index, vegetation NDVI through using 30 meter TM images and band ratioing techniques.
- The Sagehen research basin in the eastern Sierra Nevada has been added as a DRI site for snow distribution and melt research. Systematic snow measurements around the basin will begin this winter. Sagehen is a forested catchment and was chosen for study because of its (1) proximity to DRI, (2) guaranteed seasonal snow cover, and (3) very extensive and high quality temporal record of stream flow, meteorology and snow depth (SNOTEL). We are also investigating placement of a flux tower at Sagehen as part of graduate education activities at the University of Nevada, Reno.
- DRI researchers are in contact with Bureau of Reclamation staff to discuss future investigation of influences of climate change on streamflow generation in the Truckee and Carson River systems.
- Initial results of hydrologic modeling in the headwaters of the Rio Grande were used to obtain supplemental funding from the USGS (with some DRI/State of Nevada match) for additional modeling in the Upper Rio Grande. This work includes the development of real-time forecasting ability at seven nodes of the Rio Grande River system using the USGS MMS/PRMS model.
- Continue making improvements to the spatial snowmelt model for subalpine areas.

Development of snow interpolation methods

- Analysis of the measurements from the Upper Rio Grande snow surveys is ongoing and preliminary results will be presented at the fall 2001meeting of the American Geophysical Union. The time-series SWE data will be used to validate the snow depletion model.
- Install 2 SNOTEL sites on Mt Bigelow
- Organize and execute 2 snow surveys on Mt Bigelow

- A level of field surveys similar to the Spring 2001 campaign is planned for the Spring of 2002 in the Upper Rio Grande.
- Information collected during the Upper Rio Grande and Mt. Bigelow surveys will be used to build on existing works to identify the best geostatistical method for interpolating snowcourse/SNOTEL data.

Relevance of Focus Area efforts to SAHRA Goals

The micrometeorological network on Mt Bigelow will provide valuable empirical relationships and understanding of linked processes involved in subalpine snowmelt dynamics. It will also form a primary validation site for all the many modeling activities within SAHRA. Snow melt modeling and basin scale hydrologic modeling and model parameter improvement efforts will be directly integrated with the modeling efforts of Thrust Area 4 to address the various established scenarios.

1.2 Runoff and Infiltration in Semi-Arid Regions

In semiarid regions, the partitioning of precipitation into surface runoff, infiltration and potential recharge is highly variable in space and time. Understanding the spatial and temporal variability of these processes at a range of scales improves our ability to quantify and manage the available water resources. This research group is interested in understanding and quantifying the relationships among soils, their hydraulic properties, and hydrologic processes (rainfall, infiltration, and runoff) on upland areas and within ephemeral channels. Developing relationships between easily measured soil properties and vegetation characteristics and hydrologic processes is essential for up scaling from point, plot, and sub-watershed to basin scale.

Individual research efforts include:

1) *Unsaturated hydraulic conductivity and recharge within ephemeral channels*
2) *Characterization of soil hydraulic properties*
3) *Infiltration and runoff response in semi-arid rangelands*

The right side of Figure 1 illustrates the integration among the individual research groups within TA1 and across SAHRA. Soil cores from the different research sites is sent to the US Salinity Lab along with measured hydrologic properties for input into pedo-transfer and neural network models. Basic soil hydraulic properties generated for those sites and a comparison of hydraulic conductivity properties derived from this traditional techniques to those derived from the development and testing of a new instrument for measuring soil moisture fluxes in ephemeral channels, is in progress. Measurements are made at TA3 San Pedro sites, and hydraulic conductivity properties will be provided to researchers for model development. The research of upland rainfall, infiltration, runoff and recharge in ephemeral channels, will integrate with TA3 (riparian hydrology) for San Pedro basin scale modeling. Hydraulic properties and hydrological processes will also be provided to TA2 for a range of soil and vegetation complexes.

The primary goals and objectives for this research focus area are to 1) develop and test the ERT (electrical resistance tomography) method to measure soil moisture fluxes in ephemeral stream channels. ERT is a promising geophysical method for characterizing the subsurface distribution of soil water. The method relies on the dependence of the bulk electrical conductivity of a medium on its volumetric water content; 2) develop hierarchical pedo-topo-vegetation transfer functions (PTVTFs) to estimate soil hydraulic properties at different spatial scales (point, plot, patch, sub-basin, basin, region); 3) determine the relationships among ecological site characteristics, rainfall intensity and the hydrologic response of an area.

Activities

The research objectives for the past year were to 1) complete the forward modeling of the ERT method and its spatial and aggregate sensitivity analysis, 2) develop and improve pedotransfer functions to predict soil hydraulic properties and develop a framework for a) incorporating spatio-temporal analysis into the pedotransfer functions and b) upscaling methods; and 3) identify and select a range of ecological sites within the San Pedro Basin, measure the site characteristics and begin to conduct rainfall simulator (rainfall –runoff) experiments on the first set of sites. The research activities and accomplishments undertaken to meet these objectives are described below.

Development and testing of ERT method

- A series of electrical resistivity measurements were made. These measurements can be used to infer electrical conductivity, monitor rapidly changing redistribution of soil water beneath ephemeral streams, as well as allow for realtime nondestructive monitoring of stream bank storage and root water uptake.
- Extensive numerical analysis was conducted for a wide range of electrode geometries to select general characteristics that can be used to identify optimal array sets. This understanding is crucial in choosing the set of measurements with the highest data value. The results show that the ERT arrays can be optimized to collect very high temporal resolution data with little or no loss in spatial conductivity information.
- An analytical expression was developed to describe the spatial sensitivity of the ERT method.
- A field site has been selected in the Walnut Gulch Experimental Watershed, and a background survey conducted to ensure that subsurface conditions are amenable to ERT.

Development of Pedotransfer Functions

- We have completed a computer program (Rosetta) that implements pedotransfer functions (PTFs) to predict soil water retention, saturated and unsaturated hydraulic conductivity with neural network analysis.
- In collaboration with USDA-ARS in Tucson, and collaborators at the University of Arizona, we have initiated several field experiments to study hill-slope hydrologic processes under different ecological scenarios in the San Pedro basin. Soil cores were collected and we are currently measuring the soil water retention and hydraulic conductivity functions at U.S. Salinity Laboratory hydraulic Lab. These data will ultimately be used to study spatial evolution of soil properties and they will also be included in our database for unsaturated soil hydraulic properties (UNSODA).
- In a conceptual framework, we examined the impact of areal heterogeneity of soil hydraulic parameters on soil ensemble behavior for steady state and transient evaporation, and infiltration. In this work we investigated the impact of different averaging schemes of shape parameters and parameter correlation, on ensemble behavior of upward/downward fluid flux. Candidate hydraulic functions for this study included Brooks and Corey, Gardner and Russo, and van Genuchten and implemented with Richards' equation for unsaturated flow.

Infiltration and runoff processes on upland areas

- In collaboration with stakeholders and partners, the ecological sites for rangeland characteristic measurements and the rainfall simulator experiments have been selected. The selected sites include five ecological sites within the Walnut Gulch Experimental Watershed, two sites in the east range of Ft. Huachuca, four sites at the Audubon Research Ranch, and one site within the Babocomari Ranch. All sites are located within the Upper San Pedro Basin and together they represent a full range of soil texture and vegetation characteristics. Agreements have been made with Sheridan Stone and Gretchen Kent (Ft. Huachuca) to make sure that all NEPA and Environmental Impact statement requirements are met before experiments are conducted on the Ft Huachuca sites.
- Rainfall simulator plots have been installed and the surface and vegetation characteristics have been measured for 16 plots at three ecological sites within Walnut Gulch. Preliminary data analysis has begun including soil textural analysis and soil surface and vegetation characteristics of the plots (species composition and spatial distribution).
- Analysis of the WEPP rainfall simulator experiment rangeland database is also being conducted. The analysis includes determining the relationship between observed hydrologic processes and the rangeland characteristics. The results to date show the same trends that were observed in the rainfall simulator experiment conducted on Walnut Gulch, but over a larger range in soils and vegetation types. (These data will compliment the data gathered from the current rainfall simulator experiments.)
- Modifications have been made to the equipment and instruments used for the rainfall simulator experiments. A new trough and flume design to measure runoff volume and rate at the end of a plot was developed and tested. A rating curve for the new flume to convert flow depth measurements into runoff rate was determined. This new trough/flume design eliminates the need for a large trench at the end of each plot, thereby minimizing the destruction to an area.
- Significant changes and improvements have been made to the computer-controlled, oscillating boom rainfall simulator. The oscillation method has been changed to a chain and sprocket system enabling the simulator nozzles to traverse the width of the plot in less than 0.5 seconds. This modification improves the ability to simulate rainfall intensities at lower rainfall intensities (50 – 75 mm/h.) The necessary changes to

the simulator controls and computer programs have been made and tested. Final testing of the rainfall intensities and distributions as well as the final preparations to take the simulator out to the field sites is in progress.

Plans for the next reporting period

The objectives for the next year are divided into three primary activities 1) further development and testing of the ERT method, 2) incorporation of topographic and vegetation characteristics into the pedrotransfer functions and, 3) determination of infiltration parameters for individual soil and soil vegetation complexes at a range of scales. The research plans and objectives are outlined below.

Development and testing of ERT method

- Currently, we are working with researchers at the USGS to begin a field measurement campaign in the Walnut Gulch Experimental Watershed. This effort will examine stream bank storage mechanisms following an ephemeral flow using ERT.
- Continue testing and validation of the ERT method.
- Extend the study areas to include characterization of reaches of the San Pedro River relevant to SAHRA research in other Thrust Areas.

Improvements to Pedotransfer Functions

- In the future we hope to recalibrate the PTFs using additional soil cores obtained from SAHRA study sites (Mt. Bigelow site, Walnut Gulch, San Pedro). The current PTFs are biased toward data collected in temperate climates.
- We will develop hierarchical pedo-topo vegetation transfer functions (PTVTFs) to estimate soil hydraulic properties at different spatial scales (point, plot, patch, sub-basin, basin, region) using NRCS soil maps, USGS Digital elevation model, and available remotely sensed vegetation/ land cover information. A neural-network based approach will be used to develop the hierarchical system with increasing input data layers and accuracy

Infiltration and runoff processes and parameter identification

- Complete initial set of rainfall simulator experiments on selected sites
- Conduct analysis of rainfall –infiltration –runoff relationship using a distributed process based hydrologic model and spatial analysis methods.
- Determine infiltration parameters for the individual soil and soil vegetation complexes from rainfall simulator experiments.
- Begin comparison among soil infiltration parameters determined from rainfall simulator experiments and PTFs and PTVTFs.
- Set up framework to begin upscaling of infiltration parameters from point and plot scale to patch and sub-watershed scale in collaboration with USSL.
- Complete site selection and site setup for second set of rainfall simulator experiments. Begin data collection and conduct rainfall simulator experiments.

Relevance of Focus Area efforts to SAHRA Goals

The research methods and resulting databases from field experiments and modeling activities will be directly integrated with the modeling efforts of Thrust Area 4 to address the various established scenarios

1.3 Remote Sensing and Modeling of Precipitation

The primary goal of this research area is to provide rainfall and snowfall estimates for the other groups within TA1 and for, TA2, TA3 and TA4. There are many areas across the southwestern U.S. without rainfall data from gages or radar. The development of a precipitation model that integrates data from both satellite and ground measurements will improve our ability to model rainfall across these regions. Research within this group is focused on the development of an improved distributed precipitation model. This research is heavily leveraged by the NASA EOS project, which provides the various satellite images.

The primary objective of this research is to develop a new technique, which will enable us to produce more accurate and high resolution (6-hour, 12 km x 12 km) precipitation data covering southwestern U.S.

Activities

Over the past year, we have been 1) evaluating monsoon season diurnal rainfall pattern over the southwest U.S. using PERSIANN rainfall estimates, 2) generating rainfall estimates over the southwest U.S. 3) improving PERSIANN rain estimates, and 4) estimating snowfall from GOES infrared data using PERSIANN algorithm. The activities for past year are summarized below.

- Document monsoon season diurnal rainfall patterns. Multiple years (1998-2001) of hourly PERSIANN rainfall data were used to produce seasonal diurnal rainfall. Significant seasonal diurnal patterns over various regions, such as southwestern United States, northwestern Mexico, Central America, and land/ocean boundaries were found.
- Generate rainfall estimates over southwestern U.S. The PERSIANN system generated daily rainfall estimates for southwestern U.S. at $0.25^{o}x0.25^{o}$ and $1^{o}x1^{o}$ lat/long resolutions.
- Algorithm development in high resolution rainfall estimation. Improvement to the system was made by including more effective satellite cloud features in rain estimation. Development of the cloud type classification algorithm using regional scale cloud texture is ungoing. This procedure was set to classify the cloud types into many characteristic groups. Different rain rate-brightness temperature relationships was then applied to the cloud pixel after its cloud type was identified. Our preliminary experiment demonstrates that the rainfall estimates using cloud type classification are improved from the original PERSIANN estimates (Figure 2). The original PERSIANN estimates tend to over estimate rain coverage and underestimate rainfall intensity on the heavy rain area. Rain estimates from cloud classification procedure show smaller rain coverage with heavier rainfall on local storm centers.
- Estimate snowfall depth. Daily snowfall depth was estimated from GOES infrared imagery, daily minimum temperature, and surface elevation data. A neural network model is used in the study. In the experiment, two months of data were collected and tested. Good agreement between observed and estimated snow depths for the calibration events were found. Evaluations of the validation events are going on.

Plan for the Next Reporting Period

The objectives for the next year are to provide 6 hourly rain estimates at 12x12 km^2 scale over southwestern U.S. The research plans and objectives are outlined below.

- Evaluate the 6-hourly, 12 x 12 km^2 precipitation data for the southwestern U.S. region and investigate the usefulness of the precipitation data for research projects within SAHRA.
- Continue testing the neural network system with the objective of providing improved 6 hourly rain estimates at 12x12 km^2 scale over the southwest US within the next year.
- Finalize the PERSIANN system to regularly produce high-resolution snowfall/rainfall data and organize the precipitation data in the forms to best support research projects within SAHRA as well various other groups.
- Summarize the achievements and weaknesses of the system for future improvements.

Relevance of Focus Area efforts to SAHRA Goals

The results from this research effort will provide precipitation input for Thrusts 1,2 and 3 and will be conducted in close coordination with climate modeling in Thrust 4.

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Figure 1.1 Integration schematic for Thrust Area 1. Square boxes represent individual research projects within TA1. Small circles represent linkages to research TA1: un-shaded circles represent internal SAHRA activities and shaded circles represent external research activities.

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Figure 1.2 Comparisons of hourly rainfall estimates from radar, cloud type classification maps, and PERSIANN systems

Thrust Name	Basin-Scale Water and Solute Balances		
PI Name (s)	Fred Phillips, Thrust Area Leader		
Participants			
	Name	Status	
1	Dody, Avraham	Visiting faculty	
2	Dolmar, Dan	Graduate student	
3	Duffy, Chris	Faculty	
4	Eastoe, Christopher	Other research scientist	
5	Einloth, Sharon	Graduate student	
6	Ekwurzel, Brenda	Faculty	
7	Elliott, James	Undergraduate student	
8	Gu, Ailiang	Graduate student	
9	Guan, Huade	Graduate student	
10	Hogan, James	Postdoctorate, Thrust Area Coordinator	
11	Hong, Sung-ho	Graduate student	
12	Kurc, Shirley	Graduate student	
13	Lal, Devendra	Faculty	
14	Lee, Dennis	Graduate student	
15	Long, Austin	Faculty	
16	McGhee, Douglas	Graduate student	
17	Mills, Suzanne	Graduate student	
18	Moayyad, Ben	Graduate student	
19	Neville, Paul	Other research scientist	
20	Phillips, Fred	Faculty, Thrust Area Leader	
21	Pockman, Will	Faculty	
22	Qu, Yizhong	Graduate student	
23	Rodrigeuz-Marin, Graciela	Graduate student	
24	Rosenau, Naomi	Graduate student	
25	Sedmera, Kris	Graduate student	
26	Small, Eric	Faculty	
27	Walvoord, Michelle	Graduate student	
28	Wang, Bei	Graduate student	
29	Wilson, John	Faculty	
Funding (reporting year)			
	NSF	474,668	
	Other - University of Arizona match	1,700	
Funding (anticipated for next year)			
	NSF	483,580	
	Other –		

Thrust Area 2 - Basin-Scale Water and Solute Balances

The major goal of Thrust Area 2 is to understand the dynamics of water and solute balances in semiarid regions at large spatial and temporal scales (i.e. the river basin scale and decadal and longer time scales).

The research in TA2 is divided into two groups: 1) Vegetation and vadose zone process of the basin floor; and 2) Basin-scale hydrologic systems. These two groups are both placed under TA2 because of their common interest in water and solute balances at large spatial and long temporal scales.

2.1 Vegetation and Vadose Zone Process of the Basin Floor

The desire to better manage groundwater resources in arid and semiarid regions results in a need to better quantify all components of water and solute budgets of a basin. Basin floor environments have been given little attention until recently even though they represent a large proportion of the land area in the Southwest (e.g. ~50% of the Rio Grande drainage in CO and NM). Basin floor vadose zones are significant sites of salt storage and - over decadal to century time scales - perhaps water flux. Researchers in this group seek to understand the role of vegetation and soil structure in controlling the water and solute balances of the basin floor. Perturbations to water and solute balances caused by vegetation change (resulting from human land use practices or climate change) are of critical importance. Individual research efforts include:

- Response of rangeland vegetation to multiyear drought: integrating water, plant, and soil processes and their role in vegetation change – *Eric Small (NMT)*
- Vegetative control on the hydrodynamics of semiarid vadose zones - *Fred Phillips (NMT)*
- Soil-water processes in semiarid basins - *Jan Hendrickx (NMT)*
- Quantifying groundwater recharge using ^{32}Si – *Brenda Ekwurzel (UA-HWR)*

The left side of Figure 2.1 illustrates the connections both between the various basin floor vadose zone projects and with projects in other thrust areas. The research of Small, Hendrickx and Phillips are all closely related and aimed at achieving a better understanding of the basin floor vadose zone. The sum of these research projects will be a better conceptual understanding of how the basin floor functions hydrologically and a model component for a basin scale model in TA4. Field work for these vadose zone studies are taking place, in part, at the Jornada and Savilleta long-term ecological research sites (LTER's). Accordingly, these research projects can take advantage of long term records of vegetation changes, soil moisture, etc. Because this vadose zone research is interested in recharge rates, there are connections with the infiltration / runoff studies in TA1. In addition, the work of Small involves micrometeorological flux measurements; this work will have close connections with other micrometeorological studies in TA1 and TA3. The micrometeorological data will also be used to calibrate land surface models in TA4. Finally within this group, the research of Ekwurzel involves the development of ^{32}Si as a tracer for recharge. This research will take advantage of sites being investigated within TA2, the alluvial recharge sites in TA1, and sites being studied by the USGS in the San Pedro Basin.

Response of rangeland vegetation to multiyear drought: integrating water, plant, and soil processes and their role in vegetation change

Multiyear dry and wet periods have been observed throughout the 20th century in the southwestern U.S. For example, precipitation was far below normal during the "1950s drought". In contrast, precipitation has been above average since the mid 1970s. In semiarid regions water is a limiting resource and as such the temporal variability of rainfall strongly influences the growth and reproduction of plants in these areas. Importantly, certain species may enjoy a competitive advantage under anomalous rainfall conditions, allowing for expansion of their range into new areas. This project tests the hypothesis that multiyear drought accelerates the degradation of rangeland resulting from shrub invasion into grass-dominated environments. In contrast, multiyear wet periods decelerate degradation, but do not reverse the invasion process.

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Figure 2.1. Integration schematic for TA2. Note that square boxes are TA2 research activities, white ovals are other SAHRA research activities outside TA2, and gray ovals are research activities outside SAHRA.

Activities

We completed setting up the infrastructure at the rainfall manipulation plots, including (1) installation of automated drought plot covers; (2) construction and testing of a rainfall application system; and (3) installation of gutters to collect runoff and gauges for hydrograph measurement. The rainfall application system applies water to a 20 x 15 m area (the size of one drought plot) from six sprinkler heads. Drop sizes are similar to natural rainfall and the application rate is ~50 mm/hr.

Instrumentation of the drought plots was also completed during the previous year. This activity included: (1) building and calibrating over 300 TDR probes; (2) calibrating 60 heat dissipation probes and 120 thermocouple psychrometers; (3) programming and wiring of data acquisition systems; and (3) and installation of soil probes in the plots. Probes were placed in arrays that are oriented vertically and horizontally.

We have recorded rainfall, soil moisture and temperature, and soil water potential continuously since July 2001, leading to the following result. The changes in soil moisture and soil water potential caused by rainfall events is dramatically different between canopy and interspace patches: sub-canopy soil receives more water and stays wetter longer than interspace. However, differences between the soil beneath grass and shrub canopies are negligible, because both plant types receive runoff from the same set of interspaces. This differs from our previous findings when we compared pure grass and shrubs stands (rather than the mixed assemblage studied here). In pure stands, shrub canopies receive more moisture and stay wet longer because interspaces are larger and yield more runoff. This suggests the size distribution of interspaces is the key control on spatial soil moisture variability in this environment, not above-ground plant structure or geometry.

Plans for next reporting year

During September 2001, we are using the rainfall application system to simulate a 15 mm storm at each of the nine plots. In addition to the continuously recorded soil moisture and potential data, we are also monitoring plant water status and gas exchange before, during, and following these events. This will enable us to explore the links between soil and plant water potential and how this link varies through space. We will initiate drought and water addition treatments at the rainfall manipulation plots beginning on October 1, 2001. This allowed us to collect data to characterize the initial state of all nine plots.

Planned activities during the next year are as follows. First, we will analyze data from the initial reference storms. We expect to produce a manuscript that combines data from these experiments with background monitoring data to constrain spatial variability of water cycling at the plant-interspace scale. Second, we will begin drought and water addition treatments in fall 2001. Third, we will complete a second set of reference storms following one year of treatment (September 2002). This will provide initial results of how rainfall anomalies influence plant-water interactions at a semiarid herbaceous-woody ecotone. Fourth, we will combine soil moisture (TDR) and soil water potential data (psychrometer and heat dissipation probes) to produce soil moisture release curves in situ. These will be compared to curves produced in the lab from the same soils.

Vegetative control on the hydrodynamics of semiarid vadose zones

This research addresses the contribution of soil-water fluxes in thick vadose zones to the underlying aquifers by exploring the link between vegetation type and moisture fluxes. This effort builds on a conceptual framework of deep vadose zone hydrodynamics that researchers at New Mexico Tech developed over the past few years. Previous results imply that vegetation is a major control on the hydrologic regimes in desert vadose zones. Our current objective involves testing the hypothesis that vegetation type may be a suitable proxy for upscaling recharge estimates to the basin scale. An ultimate research goal is to develop a quantitative methodology of upscaling recharge estimates to the Rio Grande basin based on vegetation patterns. Such a methodology could then be applied to other arid and semiarid basins.

Activities

The Trans-Pecos region was selected for a site to test the vegetation – recharge hypothesis as it encompasses the Chihuahuan Desert transition zone and accommodates a diverse population of plant communities (owing to significant variations in elevation, and thus temperature and precipitation). Five sites associated with different vegetation communities were targeted to address the link between vegetation type and vadose-zone moisture-flux regime. Vegetation types included a long-established Chihuahuan mixed desertscrub, a recently-encroached creosote-dominated desertscrub, a plains grassland and a juniper woodland.

Soil samples were collected in mid-October, 2000, from seven boreholes at the five drilling sites in the Trans-Pecos region. Soil sample analyses for all cores included gravimetric water content, water potential (ψ), soil-water extract chemistry, and bulk density.

Interpretation of the hydraulic and porewater geochemical data supports our original hypothesis and indicates that distinctly different soil-water flux regimes are associated with vegetation type. Soil-water pressure profiles under desertscrub and grassland show much drier conditions near the surface and greater upward moisture flux gradients than beneath profiles from the juniper stand. The grassland supports extremely dry conditions and high upward flux gradients within the upper few meters, but these conditions do not propagate very deeply suggesting a high seasonal variability within the root zone. In contrast, the desertscrub supports a deeper zone of very dry conditions and upward fluxes, suggesting less near-surface transients and deeper drying than under the grassland. Assuming a constant chloride deposition of 80 mg m^2 yr^{-1}, profiles under desert vegetation, both shrubs and grasses, generally contain chloride inventories of 12 – 32 kyrs in the upper 10 m in contrast to inventories of 130 - 220 yrs under the wooded site. Chloride profiles imply that desert vegetation reflects vadose-zone conditions in which infiltration has not penetrated below the root zone for several thousand years, whereas the presence of mesic vegetation indicates regular or episodic infiltration past the root-zone.

Our results and interpretations regarding the link between vegetation and vadose-zone moisture flux regime shows encouraging potential for using spatial distributions of vegetation as a basis for upscaling point recharge estimates to the basin scale in arid and semiarid regions. If vegetation type, a readily observable surface property, serves as a reasonable indicator of deep moisture fluxes, then the spatial distribution of recharge through desert floors might be characterized using vegetation maps. Further development of quantitative ecohydrological relationships is the next logical step.

Soil-water processes in semiarid basins
SAHRA funding was leveraged with support from another NSF grant, a grant from the State Engineer's Office, a grant from the Los Alamos National Laboratory, and a grant from the USBR Field Office of El Paso. Progress has been made in several areas:

Activities

● The flow of water and transport of solutes through pipes in indurated calcic horizons. We have obtained field data and conducted simulations of water flow with HYDRUS2D. The experimental and simulation results demonstrate that pipes and their fillings have a substantial effect on water and solute movement through desert vadose zones. A recent trench opened on the Las Cañas Surface near Socorro revealed again that pipes are a common feature in New Mexico. We have drilled a hole to a depth of 25 m through the center of a pipe on the Las Cañas Surface without encountering a calcic horizon. Our data on chloride content, hydraulic soil properties, and our simulation results indicate that these pipes may play an important role in the regional water and solute balance. Our computer simulations indicate that pipes can substantially increase groundwater recharge.

● We are concluding a study on solute movement over a period of 600 years using field data obtained under a former Indian pueblo near Socorro, NM. This study reveals interesting features of water movement and solute transport over time periods covering several hundreds of years, as well as the effects of a 20 m deep confined aquifer on solute and water movement in a desert vadose zone. It was shown that a 20 m deep confined aquifer is discharging a small amount of water to the root zone of the overlying soil, effectively stopping any deep recharge in a desert vadose zone. The environmental solutes entering from the soil surface and from the confined aquifer are trapped at the bottom of the root zone.

● We are concluding a study on the modeling of actual evapotranspiration rates from riparian areas. We use one year of field data on groundwater level depth, actual evapotranspiration measurements using the eddy-correlation method, and LIDAR measurements to validate the HYDRUS1D model for prediction of water balances for Cottonwood and salt cedar stands. It is shown that HYDRUS1D can model actual evapotranspiration rates of Cottonwood and Salt Cedar quite well. It is also shown that actual evapotranspiration depends much more on groundwater table depth and soil texture than on the type of vegetation, i.e. Cottonwood or Salt Cedar.

● We have modeled soil salinization with HYDRUS1D for a riparian area north of Albuquerque. Using soil profile description, groundwater table depth, daily weather data, and vegetation type as input data, we can predict quite well which soil types will not be subject to increased salinity in the future. However, the degree of soil salinization was not predicted well. The likely reason is that the HYDRUS1D model does not include the dynamic effects of the unconfined aquifer on soil salinity.

● We have tested the SEBAL algorithm for determining actual evapotranspiration rates from LandSat images. The first results in which we compare SEBAL derived ET rates with those measured in the field with eddy covariance techniques are very promising in both riparian and desert areas. The SEBAL algorithm appears to be an effective tool for prediction of actual evapotranpiration rates in the Middle Rio Grande Valley of New Mexico. The coming year we will spend considerable effort on evaluating the strength and weakness of the SEBAL algorithm for evaluation regional distributions of actual ET rates.

Quantifying groundwater recharge using ^{32}Si

The ^{32}Si project is the first application of this tracer to determine long-term recharge rates and therefore the first year activities are dominated by method development. ^{32}Si has a 140 year half-life and theoretically can be a useful tracer for processes on the 100 to 1000 year time-scale, a time length which there are few other available tracers. Because of its half-life, investigators have attempted to measure ^{32}Si in groundwater. Studies have found that ^{32}Si is not an ideal groundwater tracer because most of the tracer is lost during transit through the vadose zone before reaching the groundwater table. It is this "loss" in the vadose zone that will be exploited in this investigation for recharge research in semiarid regions.

Activities

The first phase of this project has been to establish a method and build a laboratory at the University of Arizona for measuring ^{32}Si in precipitation and vadose zone samples. In this endeavor we have benefited from active consultation with Professor D. Lal at Scripps Institution of Oceanography and Professor B.L.K. Somayajulu at The Physical Research Laboratory in the Department of Space for India. Project participants have established a laboratory for natural low-level ^{32}Si sample extractions in facilities at the University of Arizona dedicated for this project. To date, the laboratory equipment procurements are about 40% of those necessary to complete the lab. We expect the cosmogenic ^{32}Si lab to be 100% functional by the spring of 2002.

Precipitation samples have been the initial focus of the project to establish the natural cosmogenic ^{32}Si input function for each study area. The design for the automatic ^{32}Si precipitation collectors was completed for deployment in secured USGS precipitation station shelters. To date, one ^{32}Si collector is operating at a USGS station in the San Pedro study area and two more will be installed in fall 2001 at USGS stations in the Mojave Desert study area. About 500 L of snow were collected from near the Mt. Lemmon summit in early spring 2001. In addition, "event-based" precipitation samples are collected on a more frequent basis in the Tucson Basin to test for any fluctuations in the cosmogenic ^{32}Si flux with time. These samples have been used for testing different chemical extraction procedures in the lab and have already lead to improvements in the extraction procedures.

A critical goal of this project is to measure ^{32}Si in vadose zone samples collected from extremely thick unsaturated zone settings where the history of long-term recharge theoretically may be preserved. In order to obtain the high quality samples required for this project, we are collaborating with the USGS. The two major study locations where collaboration will occur will be the Mojave Desert in California and the San Pedro Basin in Arizona. The USGS is measuring other soil, hydrologic, geophysical, and geochemical properties with which we may place the ^{32}Si results into context. For example, the short-term residence time tracers measured by the USGS such as tritium should indicate the limits of recent recharge penetration that may be contrasted with the ^{32}Si (~ 140 year half-life) accumulation depths.

Plans for next reporting year

The second project year will be dominated by field collection and lab analysis of the San Pedro and Mojave Desert precipitation and vadose zone samples. Project participants will join the USGS during a planned three week drilling effort in the San Pedro during fall 2001.

It is believed that the behavior of ^{32}Si within the vadose zone is influenced by soil properties. Therefore, laboratory column and batch experiments will be conducted with different soil types representative of those found in the semiarid study regions. These tests are important for establishing basic silica exchange behavior under various saturated and unsaturated soil conditions. We may find that in order to mimic natural conditions that unreasonable quantities of water and soil at natural ^{32}Si precipitation concentrations are required. If so, the batch experiments may have to be conducted with artificially enriched ^{32}Si tracer experiments to reduce the time for processing and the size of samples used.

2.2 Basin-Scale Hydrologic Systems

Groundwater stored in alluvial aquifers is by far the largest reservoir of water in semiarid basins. In addition to providing a ready source of water, groundwater also sustains the baseflow of many rivers for most of the year. Understanding the dynamics of this system is of critical importance for balancing sustainable water use and maintaining the remaining riparian areas. The objective of the Basin-Scale Hydrologic System group is to develop tools for determining recharge areas, flowpaths of groundwater, and residence times along those flowpaths at the scale of a basin aquifer, using a combination of emerging and routine environmental tracers. Individual research efforts include:

- Mountain-block recharge – *John Wilson (NMT)*
- Isotopic tracers of the sources, flowpath and ages of groundwater at the basin scale - *Austin Long and Chris Eastoe (UA-GEO)*
- Solute balance of the Rio Grande –*Fred Phillips (NMT) /Jan Hendrickx (NMT) /James Hogan (UA-HWR)*
- Mountain-Front Recharge: Hydroclimatic Variability and Low-Dimensional Recharge-Runoff Models – *Chris Duffy (PSU)*

The right side of Figure 2.1 illustrates the integration of projects investigating basin-scale hydrologic systems. The work of Wilson, investigating mountain block recharge, has close ties with the TA1 work on the water balance above the mountain front. Results from the TA1 group will be used to constrain the amount of water that travels through the mountain block. In addition, Wilson's research will employ environmental tracers for determining the source and rate of recharge through the mountain block and will be closely tied with the work of Long and Eastoe. Ultimately, a hydrologic model will be developed for the mountain block and the interface with the basin aquifer system. This model component will be added to the integrated model effort of TA4. The work of Long and Eastoe employs a variety of environmental tracers to determine areas of recharge, groundwater flowpaths and ultimately discharge. Such environmental tracers will be valuable for understanding the paths and rates of groundwater flow within basins. Preliminary results indicate that these tracers are especially sensitive to alluvial recharge. As such, this research will have close ties with various groups investigating recharge, such as the alluvial recharge work of TA1. Tracing groundwater flowpaths to discharge into river drainages will link the work of Long and Eastoe to the work of Phillips et al. on solute balances of basin river systems. The solute balance research of Phillips et al. will link with Duffy's low-dimensional models through investigating how the solute balance of a river system changes with climatic perturbations. Furthermore, investigation of the river solute balances will have direct linkages to nutrient cycling in riparian areas (TA3) (nutrients are biologically important solutes) and to river management in TA5 (URGWOM Model, etc.). Finally, Duffy's research investigates how long-term changes (climate, vegetation, human use) propagate through a basin hydrologic system and result in changes in river discharge and solute burden. These results will be used to develop a low-dimensional model for a basin system and ultimately incorporated within the basin-scale systems modeling (Coarse Resolution / Lumped) effort of TA4.

This group has also developed several important collaborations outside of SAHRA. These include a study funded by the New Mexico Interstate Stream Commission (NM-ISC) to investigate surface water-groundwater interactions in the Middle Rio Grande from San Acacia to Elephant Butte reservoir. There is a collaborative research project with the CEA-CREST (Center for Environmental Analysis - Centers of Research Excellence in Science and Technology) group at Cal State LA focused on understanding the flowpaths, residence times and sources of salinity within the Hueco Bolson near El Paso, TX and Juarez, MX. Finally, the isotopic analyses of the Rio Grande will be incorporated into the International Atomic Energy Agency's (IAEA) worldwide investigation into isotopic mass balances for river basins.

Mountain-block recharge
Mountainous regions play a critical role in the hydrology of semiarid drainage basins. Due to orographic forcing of precipitation, they receive much more water than surrounding areas and, as a result, provide most of the runoff and groundwater recharge. It seems likely that a significant proportion of groundwater recharge for the entire basin originates as infiltration through fractured bedrock high in the mountains and reaches the alluvial aquifer systems by permeating range-bounding faults, but in the past this has proved very hard to quantify. Recent studies in humid climates in the northwest Continental US and in Japan indicate from 20 to close to 100% of the recharge can be via such subsurface pathways. There are few similar quantitative semiarid climate studies.

This raises the question: In arid and semiarid regions, is mountain front recharge diffuse or focused, surface or subsurface, deep or shallow, linear or non-linear, and intermittent or quasi-steady?

Activities
In the first stage of this study we are using existing information, remote sensing, cursory field visits, and groundwater modeling to address some fundamental questions, and to improve our conceptual understanding. By the end of this stage we should have built site specific, conceptual groundwater flow and surficial process models for three or four areas representing differences in space and time scales, climate, landscape, and geology. In collaboration with Chris Duffy and others, we have identified the San Pedro Basin, AZ, the Albuquerque Basin, NM, the Magdelana Mountains, NM, and the San Luis Valley, CO, as study locations. Initial models of each site will be uncoupled, cross-sectional, and highly conceptualized. These initial models will lead to more fully coupled and three-dimensional models, using more realistic geology, hydrology, and forcing.

For budgetary reasons this project began at the end of August, 2000. The first three months were devoted to compiling existing information, exploration of approaches, field visits, and training a new PhD student. Unfortunately that student then decided to change majors (transferring to computer science), presenting a major setback for this project. A new Ph.D student, began full time work on the project in mid July, 2001. His initial activities have been divided among background reading, preliminary computer simulations of groundwater flow in idealized mountain block cross-sections, and field visits, with spring and stream sampling, to the Sandia Mountains of the Albuquerque Basin, and the Magdelena Mountains near Socorro. The collected water samples have been sent to the Isotope Laboratory at the University of Arizona for stable isotopes analysis, to delineate recharge elevation, and tritium analysis, to constrain travel time through the mountain system. These are preliminary samples, which will be used to develop a broader sampling program. To further our collaboration with Chris Duffy, we have agreed to exchange graduate students during the year.

Isotopic tracers of the sources, flowpath and ages of groundwater at the basin scale
The Tucson Basin study will provide a classic example of application of isotope techniques to the determination of origins and ages of groundwater in a large semiarid basin. It will be possible to identify mountain-front and mountain-block recharge, and to specify which parts of the basin aquifers receive water from the major drainages entering the basin.

Activities
● We have extended sampling of groundwater to SE Tucson Basin (Pantano Wash to the Santa Rita Mountains); to northern Avra Valley; to Sabino Canyon, and to Mt. Lemmon. The sampling is mainly from

private wells, and is time-intensive. We have completed isotope measurements on almost all of the new water samples.

● Combining $\delta^{18}O$ and $\delta^{34}S$ data, we can now draw a basin map showing the areas of the basin that are recharged from the major drainages. The patterns are apparently related to the surface drainage pattern prior to capture of Cienega Creek by Pantano Wash, which possibly occurred between 18000 and 8000 BP according to radiocarbon dates from paleosoils. The combined data require that high-elevation (Rincon Mts.) water emerging into basin sediments in the SE corner pass upward through Pantano Formation gypsum.

Combining tritium and $\delta^{34}S$ data, we have identified a small zone of rapid recharge where Rincon Creek meets Pantano Wash. The water is from Rincon Creek.

At Marana, we have distinguished a zone of the Santa Cruz flood plain that is recharged with high-elevation water from the Santa Catalina Mts. from another recharged with low-elevation water from Brawley Wash.

The completed ^{14}C map of the basin shows a concentration of old (<40 pMC) water along the Santa Cruz fault northwest of central Tucson. S-isotope data indicate mixing of this water with water derived from the Rillito. Other water of similar pMC content occurs in the south-central part of the basin, and is emerging from rock fractures on the NE flank of the basin.

● We have undertaken NETPATH modeling of ^{14}C data for several sets of wells. NETPATH modeling is proving difficult, no doubt as a result of the complexity of the basin and the disturbance of flow by historical pumping. One useful result concerns the relationship between water recharging from Tanque Verde Creek near Houghton Road and Central Well Field water down-gradient. NETPATH indicates that Central Well Field water can be generated by interaction of Tanque Verde Creek water with sediments, and that the travel time is about 700 years. Tritiated water is present almost as far along the flow path as Pantano Wash, implying very slow flow from there to points farther southwest.

● We have checked the record of bomb tritium using samples archived in the laboratory.
We have shown that tritium in late 1970s rain collected in central Tucson at times exceeded the levels due to bomb tests in the 1960s. This effect is no doubt due to escape of tritium from the American Atomics factory that closed in 1981.

● We have taken numerous samples of surface water entering the basin at present, with a view to determining the range of pMC and major ion chemistry. Surface water currently has pMC values ranging between 85 and 110 (cf. atmospheric CO_2 with 107 pMC in the city, and 109-110 pMC outside the city). This finding has modified our interpretation of groundwater pMC values between 85 and 100. Several such instances correspond with finite tritium measurements, confirming recent recharge.

● We have continued our long-term monitoring of stable H and O isotopes in Tucson rain, along with seasonal tritium measurements, and annual ^{14}C in the atmosphere.

Plans for next reporting year
We intend to focus mainly on writing papers, with downscaled sampling, in the coming year. We intend to produce papers on 1) H and O isotopes, 2) ^{14}C and NETPATH modeling and, 3. S isotopes. Further sampling will be focused in the foothills of the Santa Catalina and Tucson Mountains. We also anticipate involvement in a major isotopic study of groundwater in the El Paso area as part of SAHRA's collaboration with CEA-CREST.

Solute balance of the Rio Grande
The immediate goal of this research project is to identify and quantify the sources of salinity to the Rio Grande. The long-term goal of this research is to develop a water / solute mass balance model for the Rio Grande that is capable of modeling past temporal variation and can investigate future-use scenarios.

Activities

During the past year we conducted synoptic sampling of the Rio Grande in August of 2000 and January of 2001. During these sampling campaigns, roughly 100 sites were sampled along the river. Samples were analyzed in the field for TDS, EC, pH and in the laboratory for Cl and Br concentrations. Results from these sampling trips led to the recognition of roughly five localized sections of the river where there are significant increases in river salinity (Figure 2.2). Some of these increases are correlated with known sources (agricultural drains, hydrothermal areas). Others are not correlated with known discharges but occur at the lower end of sedimentary basins leading to the speculation that they are the result of discharge of deep, saline, groundwaters. Of particular interest is the Albuquerque Basin where, in two distinct steps, the TDS of the river doubles from ~150 mg/L to ~300 mg/L. With little change in river discharge for this reach, this represents a significant increase in the solute burden of the river. Mixing plots using Cl/Br ratios indicate three solute end-members: atmospheric deposition, which dominates in the headwater region; a hydrothermal end-member localized around Truth of Consequences, NM; and a third end-member that may represent groundwater. Samples collected during the summer months are shifted off the winter mixing lines due to concentration through evapotranspiration. A subset of samples is currently being analyzed for $^{36}Cl/Cl$ and $^{87}Sr/^{86}Sr$ ratios with the intention of using these ratios in mixing calculations.

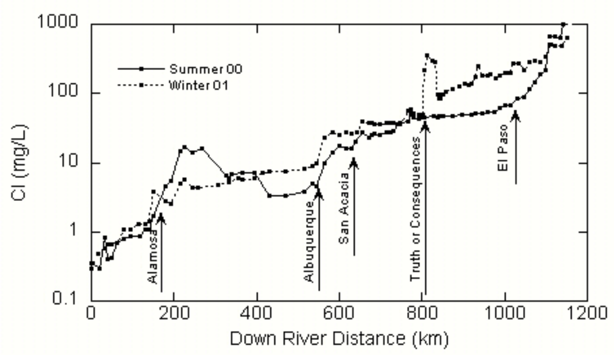

Figure 2.2. Chloride concentration versus distance along the Rio Grande. Note that concentration increases in a series of steps.

In year 2 we have refined our sampling effort to better investigate the observed salinity increases. The number of river sampling points was decreased, however sampling of significant tributaries and agricultural drains were added, as these are potentially important salinity sources. The August 2001 campaign represents the first sampling effort with a full set of chemical tracers. Water samples were collected for basic chemical analysis. In addition we collected samples for oxygen and hydrogen isotope analysis (work being done collaboratively with Chris Eastoe), filtered and acidified samples for metals analysis, and filtered samples for organic/nutrient analysis (TA3 researchers: Brooks, Conklin, Villinski).

Finally, researchers involved with this study have put considerable effort into developing partnerships with researchers working on the groundwater system of Rio Grande valley. As the Rio Grande travels from Colorado to Texas it passes through several sedimentary basins. Past research efforts have tended to be isolated and focused on one basin at a time. Our study represents the first attempt to gain a holistic understanding of salinity sources through all basins. In order to understand these sources one must also have an understanding of basin-scale groundwater systems. To this end we have developed partnerships with the USGS (Albuquerque basin), New Mexico Interstate Stream Commission (Socorro basin), and through SAHRA's new partnership with the CEA-CREAST (Hueco Bolson - El Paso area). It is our belief that by linking these groundwater basin studies with our sampling of the Rio Grande we will develop a holistic understanding of salinity sources to the Rio Grande.

Mountain-Front Recharge: Hydroclimatic Variability and Low-Dimensional Recharge-Runoff Models

In the western US, the Rio Grande Basin forms a macrocosm of the water cycle where a balance of regional-scale natural and human impacts can be studied in a system forced by global weather and climate. Our preliminary hypothesis is that random fluctuations and weak low-frequency oscillations in seasonal to interdecadal climatic forcing, may interact with the longer time scales of deep soil-moisture and groundwater storage to amplify low-frequency modes in runoff in ephemeral, intermittent and perennial streams of the basin. Much evidence suggests that low-frequency components in the runoff record of mountain fronts are consistent with the El Nino-Southern Oscillation, quasi-biennial, and quasi-decadal signature. However, the physical role that the basin hydrology, topography and geology play is unresolved. This research is formulating multi-scale physical models of regional subsurface-surface hydrologic processes where soil moisture and groundwater interact nonlinearly with runoff at multiple scales. This research deals with TA-2 and

TA-4 and forms a fundamental linkage to closing the water budget and assessing time scales of change in arid regions.

Activities

We have compiled long-term historical records of precipitation, temperature and discharge for the Rio Grande Basin in Colorado and New Mexico; these are accessible through our on-line database located at http://cataractis.cee.psu.edu/riogrande/. A GIS for the New Mexico-Colorado Rio Grande has been developed. This virtual field trip is meant to be a contribution to information technology and scientific exchange among scientists and the stakeholders.

Using singular spectrum analysis (SSA), also known as Karhunen-Loev decomposition, and our compiled historical records, we have examined the relationship between precipitation and runoff within the Rio Grande basin. Time series analysis is being used as a tool for recharge estimation and dynamical model building. SSA allows correlation of dominant modes in the climate signal with groundwater levels and stream discharge in order to isolate the contributions from: 1) mountain-front recharge from diffuse infiltration, perennial, and ephemeral streams, 2) the effect of land use changes (reservoirs, irrigation, urbanization) on runoff, and 3) the role of basin groundwater on low-frequency variability in streamflow. The approach will attempt to resolve the large-scale role of basin geometry and storage of soil moisture and groundwater on streamflow response at daily, seasonal, interannual and interdecadal time scales.

Based on SSA and available basin geology, a conceptual model of fluid storage and flux has been formed at several locations in the river basin. A low-dimensional dynamical model will integrate the local conservation equation over the estimated physical storage volumes. In this way, the multidimensional local conservation equations in physical space are transformed to a low-dimensional state space, where a limited number of ordinary differential equations need to be solved. The genetic algorithm (GA) technique has been implemented to identify the model parameters with the observed daily precipitation (rain and snow), temperature and runoff. The GA method is shown to be useful where parameter ranges of the dynamical system can be specified a-priori. The research is concentrating on recharge-discharge simulation and forecasting in the upper Rio Grande basin, from the headwater in the San Juan Mountains of southern Colorado to El Paso Texas. During the past year we have emphasized how to uncover nonlinear processes, feedbacks and resonance-like effects from observed hydroclimatic, groundwater and runoff data in the basin. In the 3rd year we will begin model parameter estimation.

Additional TA2 Activities

SAHRA Annual Recharge Workshop, March 22-23, 2001, New Mexico Tech, Socorro, NM.
Organizers: Fred Phillips, James Hogan.

On March 22-23, 2001, ~30 participants gathered at New Mexico Tech in Socorro New Mexico for a SAHRA-sponsored workshop on recharge in semiarid regions. The purpose of the workshop was to bring together SAHRA researchers investigating recharge in order to present recent advances in the understanding of groundwater recharge and vadose-zone processes in semiarid regions and foster cross-thrust area integration to develop a unified approach to understanding this key parameter. The workshop was broken into five sessions as well as a period for discussion at the end of the workshop. The five sessions included: 1) New approaches to investigating vadose-zone processes, 2) Mountain-block recharge: can it be quantified?, 3) Recharge along ephemeral stream: scaling up from the borehole to the basin, 4) Recharge data: how does it fit into the model? and, 5) The basin floor: “Swiss cheese” or “vegetation sucks”?. Presentations and summaries of the discussion from each of these sessions can be found on the SAHRA website. As result of interest expressed at the workshop, an AGU Special Session on “Recharge and vadose zone processes in semiarid and arid regions was organized by Fred Phillips, Chris Duffy and James Hogan for the Fall 2001 meeting; the ultimate goal is publication of an AGU monograph on recharge.

$\delta^{37}Cl$ – A test for diffusive chloride movement in vadose zones
Chris Eastoe, Michelle Walvoord and Fred Phillips

An outgrowth of the vegetative controls on vadose zone hydrodynamics project has been a collaborative effort with Chris Eastoe of the Isotope Laboratory at the University of Arizona. As a direct result of conversations held during the SAHRA Annual Meeting in Tucson, AZ, we formed a collaboration to investigate the isotopic signature δ^{37}Cl in vadose zone profiles as tool for understanding flow and transport processes in desert soils. While the stable isotopes of chlorine do not exhibit much isotopic fractionation in nature, one process where fractionation is known to occur is diffusion. The modeling of vadose zone processes, outlined previously, was expanded to include Cl isotope fraction. Model results indicate large negative isotopic shifts in the lower part of the vadose zone as a result of diffusive movement of chloride. We submitted soil-water extract samples to the for δ^{37}Cl analyses.

To date δ^{37}Cl analysis for one vertical section has been completed. Results are indicative of diffusive movement of chloride below the level of maximum chloride concentration. However, the Cl isotope profile was more complex than anticipated from the model results, possibly indicating the persistence of chloride from earlier accumulation events. Further work is planned in other areas. We have agreed to measure stable Cl isotopes on core from the San Pedro valley, with researchers from the USGS, with the aim of distinguishing diffusive from advective movement of solutes.

Thrust Area 3	Functioning of Riparian Systems	
PI Name (s)	David Goodrich, Thrust Area Leader	
Participants		
	Name	Status
1	Bagstad, Ken	Graduate student
2	Blattstein, Ayelet	Undergraduate student
3	Brooks, Paul	Faculty
4	Cable, William	Other research scientist
5	Conklin, Martha	Faculty
6	Edwards, Eric	Graduate student
7	Ellsworth, Patrick	Undergraduate student
8	Ferre, Paul	Faculty
9	Flores, Tracy	Support staff
10	Garatuza, Jaime	Other participant
11	Goodrich, David	Faculty
12	Grimm, Nancy	Faculty
13	Haas, Peter	Graduate student
14	Hamblen, Jennifer	Graduate student
15	Hultine, Kevin	Graduate student
16	Huth, Anne	Graduate student
17	Lawler, David	Graduate student
18	Leake, Stan	Other research scientist
19	Lewis, David	Postdoctorate
20	Lin, Guanghui	Faculty
21	Lite, Sharon	Graduate student
22	Lopez-Coreas, Marcela	Undergraduate student
23	Maddock, Thomas	Faculty
24	Martens, Dean	Other research scientist
25	O'Reilly, Catherine	Graduate student
26	Paradzick, Charles	Graduate student
27	Petti, Jonathan	Support staff
28	Pierce, Danielle	Other research scientist
29	Schade, John	Postdoctorate
30	Scott, Russell	Postdoctorate
31	Stromberg, Juliet	Faculty
32	Villinski, John	Postdoctorate, Thrust Area Coordinator
33	Wagber, Tracy	Undergraduate student
34	Watts, Chris	Other participant
35	Welsch, Ada	Undergraduate student

36	Williams, David	Faculty
37	Yepez, Enrico	Graduate student
38	vanHaren, Joost	Postdoctorate
39	von Glinski, Gerd	Graduate student
Funding (reporting year)		
	NSF	383,340
	Other - University of Arizona match	34,289
Funding (anticipated for next year)		
	NSF	329,085
	Other - University of Arizona match	20,000

Thrust Area 3: Functioning of Riparian Systems

The major goal of Thrust Area 3 (TA3) is to understand how riparian systems affect and are affected by changes in water quantity (e.g., due to ground-water pumping or conjunctive stream-water management) or water quality (e.g., nitrogen inputs from precipitation or agricultural runoff).

Research in TA3 is generally separated into two foci: 1) Water and carbon exchange in riparian systems and 2) Nutrient cycling in riparian systems. These two groups are linked through the common need to understand the dynamics of the water balance and movement within the riparian zone, as well as within the basin. This need for common knowledge also necessitates the collaboration of TA3 members with researchers from TA1, TA2 and TA4 for understanding the possible long-term effects of climate-change and anthropogenic stressors on the health of the riparian system. Figure 3.1 illustrates the stratification within TA3, the links within and across the SAHRA TAs, and the collaboration with other research groups with which there are strong active partnerships. Much of the research being performed is a continuation of the SALSA (Semi-Arid Land Surface Atmosphere) project, and is heavily leveraged with many entities in the Upper San Pedro River Valley.

<u>3.1 Water and Carbon Exchange in Riparian Systems</u>

The major goal of this group is to develop a holistic approach for assessing the effects of ground-water development and conjunctive surface-water management on riparian ecosystems. Most of the historic riparian areas in the southwest have disappeared over the last century. This is believed to be a direct consequence of groundwater pumping for agriculture, mining, and municipal needs. These riparian corridors harbor a large majority of the regional biodiversity, and provide an aesthetic value for many humans, and presently, they are facing great stress. Researchers in this group seek to understand the effects of changing hydrologic dynamics (ground, vadose, surface, and plant water movements) on riparian ecology on the time scales of hours to years.

Individual research efforts include:

3.1) Determination of the interplay of the riparian plants and the movement and availability of water, and how the water usage is related to nutrient storage and fluxes. *Dave Williams (UA), Russ Scott (UA), Guanghui Lin (Biosphere 2)*

3.2) Response of riparian vegetation water uptake under stress due to groundwater pumping. *Paul Ferré, Tom Maddock (UA)*

3.3) Relationship between hydrologic and geomorphologic conditions and survival rate of exotic versus native riparian tree seedlings. *Julie Stromberg (ASU)*

3.4) What are the hydrologic, ecological, and anthropogenic controls on spatial and temporal distribution of flowing and non-flowing reaches of desert streams? *Stan Leake (USGS)*

The collaborative relationships both within this subtask and with other projects are illustrated in left side of Figure 3.1. These projects are closely related as they are focused directly on the interplay of the riparian plants with the movement and availability of water. The sum of these projects will be new tools to predict ecological succession with changing hydrologic stress. Since this work is interested in long-term effects of hydrologic changes on the riparian ecology, there are connections with the infiltration/runoff studies in TA1 and the basin-scale, water-balance studies in TA2. In addition, the micrometeorological flux measurements will tie into similar measurements in TA1 and TA2. This data will also be used to calibrate land-surface models in TA4. Furthermore, the understanding of what sources of water are used by which plant communities will be critical information for basin management, and therefore will tie into TA5.

Activities and plans for next reporting period

The major activities of the various task areas for the last year are listed below:

Determination of the interplay of the riparian plants and the movement and availability of water, and how the water usage is related to nutrient storage and fluxes.
Mesquite forests constitute the largest component ecosystem within the Upper San Pedro riparian corridor. Previous studies have focused their attention of the other ecosystems. Thus, these current activities focused on mesquite biohydrology are expected to result in a more accurate model of riparian ecosystem water use. The goal for this reporting period was to begin the first full year of monitoring of mesquite biohydrology.

- Continuous monitoring that has been established includes distributed meteorological stations, above-canopy water, carbon and energy exchanges, stem- and branch-level sap flow, soil water and energy stores, groundwater depth, stream stage, and plant water sources.
- Additionally, a series of intensive monitoring campaigns were conducted 12 – 15 June, 24 – 27 July, and 19 – 23 September. These dates were chosen to capture the effects of variable climatic forcing on ecosystem functioning. During these campaigns, additional measurements were made of leaf gas exchange, leaf area index, leaf water potential, plant water isotopes, atmospheric profiles of carbon and water isotopes, understory water/carbon/energy exchanges, soil respiration, and soil hydraulic properties. Measurements include:
    - micrometeorology (eddy covariance).
    - plant physiology (sap flow, stem flow, isotope vapor partitioning, isotope source water determination).
    - soil and vegetation sampling (nitrogen, carbon stores, soil respiration).
    - SVAT modeling.
    - vegetation mapping (distributed vegetation maps).

The results of these activities are expected to result in an improved understanding of this riparian ecosystem. Improvements in understanding will be made in 1) mesquite water use and water source, 2) the partitioning of the atmospheric fluxes of carbon, water, and energy amongst the overstory and understory components, 3) the scaling of fluxes across the soil-understory-overstory continuum, and 4) the cycling of nutrients in riparian terraces.

Plans for the next reporting period

- Compiling the results of this field season's activities and publishing the results in a special issue.
- Continued monitoring will focus on gaps that will be identified after analysis of collected data.
- Modeling activities will commence and be aimed at representing all component fluxes in an integrated ecosystem model.

Response of riparian vegetation water uptake under stress due to groundwater pumping.
Riparian plant communities can exist only where and when their roots have access to plentiful supplies of surface and/or groundwater. Due to the population increases in the semi-arid Southwest, groundwater pumping exceeds the rate of recharge. Therefore, sustainable development of this area requires an improved understanding of the response of these systems to increased water extraction through improved hydrologic models.

In coordination with an EPA/NSF project managed by Tom Maddock and Kate Baird studying the effect on evapotranspiration of cottonwoods caused by the lowered water table, drainage in the unsaturated zone due to lowering the water table by pumping was monitored by Gerd von Glinski in late May/early June when cottonwood growth was strong. Monitoring soil moisture drainage as well as re-saturation after recovery of the water table provided a picture over time (one week) as well as over distance. Four access tubes at 11 m depth were used to monitor an area of approximately 10 m^2. The contribution of root uptake to drainage will be accounted for by repeating the test later in the year when tree growth has subsided. Comparison of two methods of monitoring soil moisture drainage showed downhole ground penetrating radar had high reproducibility and vertical spatial resolution compared to time domain reflectometry. This method is helpful in determining the relation of streambank storage with fluctuations in the water table. The results show clearly the ability of this new method to monitor drainage.

Plans for the next reporting period

Gerd von Glinski will return for a second field measurement campaign this fall. His data will be used to aid interpretations of measured changes in sap flow measured on site. Coupled with numerical modeling of drainage, this work will be published in a refereed journal, and will be the basis of von Glinski's Master's Thesis.

Relationship between hydrologic and geomorphologic conditions and survival rate of exotic versus native riparian tree seedlings.

The goals of this task area are to understand the effects of human activities, such as groundwater pumping, and global climate change on the structure and functioning of riparian ecosystems.

The research task area has been broadened to encompass the following questions:

1) How do community structure, composition and diversity of riparian vegetation, and population structure of trees species, vary longitudinally across spatial gradients of

- a) stream flow frequency and depth to ground water?
- b) channel and floodplain geomorphology?
- c) elevation and rainfall?
- d) riparian-zone fire?

2) What are environmental thresholds for establishment and maintenance of selected riparian plant species and community-types, with respect to stream flow frequency and ground water depth?

3) How might the San Pedro riparian vegetation be expected to change with climate-based changes in rainfall and flood flow patterns, and with natural and anthropogenic changes in stream flow and ground water availability?

- To address the first two questions, field data were collected during 2001 on vegetation structure and composition at 26 sites along the San Pedro River. Various criteria included:
  - sites were selected for a span of a hydrologic gradient from perennial to ephemeral stream flow, and for a span of a large elevation gradient.
  - sites were selected to provide matched pairs of burned and unburned sites within perennial and intermittent segments of the upper elevation zones.
- Vegetation was sampled during dry and wet seasons for herbaceous plant cover and richness; shrub cover; tree stem density, stem diameter, height, and canopy cover; and total vegetation volume.
- Data are being collected monthly on site hydrology (stream flow stage and depth to ground water).
- Data will be obtained from the USGS on inundation frequencies for each site.
- Twice during summer, data were collected on gravimetric soil moisture and soil texture and chemistry.
- Geomorphic structure is being assessed in terms of flood plain width and topographic diversity, and channel form and sinuosity.
- Data are being analyzed with regression analysis, to determine the influence of site hydrology and other abiotic factors on riparian vegetation abundance, diversity, and composition.
- We also are analyzing data with respect to inferred successional changes over time.

Plans for the next reporting period

Work will continue towards the development of a general model that indicates how riparian vegetation structure changes across spatial environmental gradients, and how it changes over time as key, controlling variables change. This will lead to the next phase, predictive modeling of changes to the San Pedro riparian vegetation in response to various scenarios of climate change and anthropogenic stream dewatering (and rewatering).

What are the hydrologic, ecological, and anthropogenic controls on spatial and temporal distribution of flowing and non-flowing reaches of desert streams?
A current concern is whether or not the San Pedro River is drying out. To complement the data currently available from existing stream gages, the goal of this task is to use new techniques to determine the spatial temporal variation of in-stream flow.

- Forty temperature sensors were installed along the San Pedro River and in tributary washes from the headwaters below Cananea, Sonora, Mexico, to the mouth near Winkleman, Arizona, U.S.A.
- Data have been collected for over a year at many locations and thermographs have been constructed. The spatial and temporal distribution of stream flow was determined by statistical analysis of the temperature data.
- Because of the relation between temperature fluctuations and stream condition, it is possible to detect the presence and absence of stream flow by monitoring streambed temperature.

Plans for the next reporting period

- A decision support system will be developed to further estimate patterns of flow and no-flow in the San Pedro River so that the technique can be applied to future data.
- Collected data will be imported into a GIS to help establish a multi-year pattern of streamflow along the entire San Pedro River.
- Results of this project will be related to other ephemeral streams in the southwest.
- This work will result in a Master's Thesis and a refereed publication.

Relevance of Focus Area efforts to SAHRA goals

A primary objective of SAHRA is to perform stakeholder driven research. The research being performed by the above areas is directly related to the goal of one of our major partners, the Upper San Pedro Partnership. This goal is to determine how to balance the water needs of the human populations in the area with the needs of the riparian system. In addition, the data collected, and the models developed, along with similar work done in TA1 and TA2, will be integrated with the modeling efforts of TA4 to address the various established scenarios.

3.2 Nutrient Cycling in Riparian Systems

The central objective of this group is to understand the role of biogeochemical cycling in the hyporheic zones of streams as a pathway for removal of natural and anthropogenic solutes in riparian ecosystems. Riparian zones can be highly variable, depending on channel type, perturbations, and local vegetation. The interaction of nutrients and biota affects redox conditions in shallow ground water, which influences the movement of anthropogenic inputs in the system (e.g., metals). The efficiency of this biogeochemical cycling depends on availability of nutrients, characteristics of the riparian ecotone, and hydrologic characteristics of hyporheic flow paths. In streams of the semi-arid Southwest, the common limiting nutrient is nitrogen. Large nitrogen inputs from precipitation, fertilizer applications, and other human activities thus could potentially contribute to eutrophication of aquatic ecosystems. In addition, rainfall and nitrogen inputs from floods exhibit seasonal patterns.

Individual research efforts include:

3.5) Understanding the links between hydrology, geomorphology and nutrient cycling within the semi-arid riparian/stream system *Grimm (ASU), Conklin (UA), Villinski (UA)* (was Science Question 3.4).
3.6) Determination of the contribution of terrestrially produced dissolved organic matter (DOM) to carbon and nitrogen cycling in semi-arid riparian ecosystems *Brooks (UA)* (new this reporting period).

The relationships between these projects are illustrated in the right half of Figure 3.1. These projects are closely related as they all concerned with nutrient cycling in the riparian/stream system. Crucial to all these projects and those of the other focus of TA3 is the understanding of the flow of water in the various hydrologic units within the system. Therefore, these projects will not only share data within themselves, but will also need to share data with TA1 and TA2 regarding hydrologic inputs into the riparian system.

Understanding the links between hydrology, geomorphology and nutrient cycling within the semi-arid riparian/stream system.
The goal of this research is to understand the coupling between nutrient cycles (nitrogen and carbon) and the hydrologic cycle in semi-arid riparian systems. Initially, we plan to focus on the nitrogen cycle. The work plan includes the development of innovative methods to characterize the amount of nitrogen (nitrate, ammonia, organic nitrogen) and the rate of nitrogen retention (e.g., plant uptake and denitrification) in semi-arid riparian systems. Specific aims include determining nitrogen retention along different flow paths in the riparian system, developing a nitrate/chloride (in collaboration with others) balance for the watershed, and to develop a model that links stream and hyporheic zone processes for nitrogen cycling.

- Two sites were chosen along the Upper San Pedro River for a comparative analysis of nitrogen and carbon chemistry at each site. Sites chosen were at Grayhawk Ranch (gaining reach) and Boquillas Ranch (losing/intermittent reach).
- The two reaches have been instrumented with 90 piezometers, installed in gravel bars and the riparian zone, arranged in transects perpendicular to the flow of the river. Transects are spaced 50-100 apart longitudinally, and wells range from a few centimeters to 100 meters laterally away from the river. All wells and transects have been surveyed.
- We have sampled these wells five times since February 2001 for nutrients, anions, and cations.
- In early July, we performed a short-term tracer injection at both reaches.
- Graduate student Anne Kramer Huth is determining the sources of nitrogen entering the San Pedro.
    - Two ISCO stream autosamplers were installed at the Boquillas Ranch site at the 0 m and 450 m transects. A 300 cfs flood during July 17-18, 2001, was sampled every half hour during the storm event.
    - Three nests of soil lysimeters were placed on the left bank of Boquillas with a lysimeter at depths of 1-2 feet, 2-3 feet, and approximately 4 feet. Samples were also collected within a few days after the storm event.
    - In June/July 2001, the groundwater, baseflow, and precipitation were sampled.
    - The samples were analyzed for chloride, nitrate, and ammonium within 2-3 days of collection. Remaining samples were frozen and will be analyzed for dissolved organic nitrogen, dissolved organic carbon, and ^{18}O when facilities become available.
- Graduate student Jennifer Hamblen's project addresses how changes in geomorphology due to flood events affect hyporheic respiration. She will look at both a losing (Boquillas) and gaining (Grayhawk) reach.
    - Prototype scour chains were installed in March 2001 at both sites. Thirty scour chains have been made and will be installed at both sites.
    - In June 2001, 48 bank stability pins were installed at the 8 established cross sections in the 500 m reach at Boquillas. These pins will be used to monitor erosion/aggradation within the reach after flood events.
    - Respiration chambers have been built from PVC pipe and initial measurements conducted. Respiration will be measured in 15 cm depth increments to depths depending on degree of microbial activity at the location.
    - We have built pressure sensors that will have two purposes: stage measurements and scour and fill measurements. These will be installed this fall in conjunction with the scour chains.

- An integrated research effort was started with TA2. James Hogan, as part of his bi-annual Rio Grande sampling trip agreed to collect samples for us. These samples will be taken along Rio Grande twice annually, from near the head of flow to south of El Paso, as well as from tributaries and major agricultural drains that flow into the Rio Grande. The samples will be analyzed for various form of nitrogen (nitrate, ammonium, and dissolved organic nitrogen) as well as dissolved organic carbon, and major anions. As one of the goals of this task is to scale up from the San Pedro to the Rio Grande, this collaboration will enable us to begin to develop a baseline understanding of the general nitrogen balance in the Rio Grande.

Our results so far suggest that the form and concentration of nitrogen varies by subsystem, with riparian zones tending to be low in nitrate and relatively high in ammonium, and gravel bars showing the reverse. Surface water tends to show greater variation in time, with concentrations of nitrogen appearing to vary with changes in algal biomass. In general, temporal variation in nitrogen was highest in surface water, lower in gravel bar and lowest in the riparian zone. The predominant form of nitrogen is significantly related to redox potential, with low oxygen wells tending to be dominated by ammonium.

Plans for the next reporting period

- For the remainder of the calendar year, we plan to continue monitoring chemistry and water table depth in the existing wells to look for changes in relation to the leaf fall period.
- We also plan to install well grids at a finer scale in preparation for a longer-term tracer injection this fall, with the goal of determining flow paths of hydrologic exchange between river and riparian zone.
- Next calendar year we will shift our focus to gaining understanding of nitrogen retention along riparian flow paths, using stable isotope tracer experiments to determine retention rates and mechanisms.
- Installation of the chains and scour sensors will occur this fall. Data collection for J. Hamblen will be initiated during the winter rains.
- Continue our collaboration with TA2 through sampling and analysis of the Rio Grande River.
- Expand our coordination with TA2 by sampling along well transects on the middle Rio Grande being established by Professor Robert Bowman at New Mexico Tech.

Determination of the contribution of terrestrially produced dissolved organic matter (DOM) to carbon and nitrogen cycling in semi-arid riparian ecosystems.

This task area is new this reporting period, and commenced in March. The research questions being investigated are:

1) How do the availability, structure, and composition of DOM affect instream and hyporheic processes controlling surface water nutrient concentrations?
2) Is DOM production related to labile carbon availability and heterotrophic soil activity?
3) Does the source and amount of labile carbon affect the incorporation of “older” carbon into DOM?

- An analytical biogeochemical facility for the measurement of dissolved and solid carbon and nutrients was established. We have obtained, installed, and calibrated (though other funding) the following equipment:
    - o Shimadzu 5050 TOC Analyzer - This machine quantifies the total amount of dissolved organic carbon in any aqueous solution, including surface water, ground water, soil solution, and soil extracts.
    - o Antek 9000VTN Trace Nitrogen Analyzer - This instrument quantifies the total amount of dissolved organic nitrogen in any aqueous solution, including surface water, ground water, soil solution, and soil extracts. With a relatively inexpensive modification it can be used to analyze samples for total sulfur as well.
    - o CE Instruments Elemental Analyzer Flash EA1112 - This instrument quantifies the total amounts of solid organic carbon and solid nitrogen in any soil, sediment, litter, or vegetation sample. With a relatively inexpensive modification it can be used to analyze samples for total sulfur content as well. Additionally, this instrument was purchased in a configuration that will allow conversion from a simple elemental analyzer (EA) to an elemental analyzer coupled to a mass spectrometer (EA-MS) for isotopic analysis of C, N and S.
    - o Additionally we have established preparatory scale column chromatographic facilities and a wide range of ancillary lab equipment needed for sample analyses.

- Staff and students were hired to work on the project.
  - Peter Haas was hired to work on this project as a graduate research assistant beginning in May 2001.
  - Catherine O'Reilly was hired as a postdoc and has been a key resource in establishing the laboratory. While her primary responsibilities and funding are on another project, having a more advanced person has facilitated instrument analyses needed for this project.
- The initiation of a field based sampling effort, including.
  - Sampling on the San Pedro River, focusing on flood events. Analyses include total organic carbon and organic nitrogen, as well as chemical fractionation to identify source areas.
  - Synoptic sampling of a subset of sites identified by James Hogan in Thrust Area 2. We also will analyze aliquots of his samples to provide some measure on temporal variability at the sites for comparison with his record of spatial variability
  - Sampling sites on tributaries within the upper Rio Grande basin surrounded by low productivity, hydrologically flashy sites for comparison with San Pedro data.
- Collaboration and integration with existing researchers and students.
  - We are obtaining sub-samples of water not needed by these individuals to increase our chemical fractionation/source area analyses.
  - We are working with TA1 on questions of snow accumulation in the upper reaches. The accumulation and melt of snow provides a flashy hydrograph similar to that experienced by lower reaches and we are exploring the conceptual linkages between biogeochemical cycles and sites with episodic periods of water availability/excess/runoff.

Plans for the next reporting period

- Continue analyzing samples from both the San Pedro and the Rio Grande systems.
- Explore the utility of a recently published excitation–flouresence method in fingerprinting carbon sources.
- Present preliminary results at the fall AGU meeting in San Francisco
- Collect and analyze soil cores from riparian and hillslope locations for bulk carbon and nitrogen amounts, as well as chemical signatures.
- Expand our coordination with TA 2 on by sampling along well transects on the middle Rio Grande being established by Professor Robert Bowman at New Mexico Tech.
- Expand our coordination with TA 1 by sampling soils, soil water, and snowmelt runoff in the upper Rio Grande basin
- Begin stable isotopic analyses of carbon and nitrogen in DOM fractions collected along the San Pedro

Relevance of Thrust Area efforts to SAHRA goals

The results from these research activities will be included in the integrated modeling effort of TA4, adding the critical nutrient component that is often overlooked in hydrologic modeling.

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Figure 3.1 Integration scheme for Thrust Area 3. Square boxes represent individual research projects within TA3. Small ovals represent linkages to research within TA3: unshaded ovals represent internal AHRA activities, and shaded circles represent external research activities.

Thrust Area 4	Multi-Resolution Integrated Modeling of Basin-Scale Processes	
PI Name (s)	Larry Winter, Thrust Area Leader	
Participants		
	Name	Status
1	Bastidas, Luis	Postdoctorate, Thrust Area Coordinator
2	Chen, Ji	Postdoctorate
3	Costigan, Kelley	Other research scientist
4	Cui, Yifeng	Postdoctorate
5	Fasel, Patricia	Other research scientist
6	Gupta, Hoshin	Faculty
7	Ip, Filipe	Graduate student
8	Leavesley, George	Other research scientist
9	Maddock, Thomas	Faculty
10	Markstrom, Steve	Other research scientist
11	Mniszewski, Susan	Other research scientist
12	Murray, Reagan	Postdoctorate
13	Raghava, Srinivasa	Graduate student
14	Rivenburgh, Reid	Other research scientist
15	Roads, John	Other research scientist
16	Schmid, Wolfgang	Graduate student
17	Sorooshian, Soroosh	Faculty
18	Springer, Everett	Other research scientist
19	Tomkins, Claire	Graduate student
20	Tseng, Peng-Hsiang	Other research scientist
21	Viger, Roland	Other research scientist
22	Winter, Larry	Other research scientist
Funding (reporting year)		
	NSF	383,340
	Other - University of Arizona match	34,289
	Other – LANL match	400,000
Funding (anticipated for next year)		
	NSF	357,176
	Other - University of Arizona match	31,222
	Other – LANL match	400,000

Thrust Area 4: Multi-Resolution Integrated Modeling of Basin-Scale Processes

The major objective of Thrust Area 4 is to integrate emerging scientific understanding into comprehensive river-basin models that can be used in the analysis of water resources management issues.

After the SAHRA Annual Meeting in March 2001, a suggestion arose to reorganize the structure of the Thrust Area to better coordinate the efforts of the different Thrust Areas. A document is being prepared to formalize that reorganization (Proposal for Integrated Management Strategy for SAHRA). In that document a multi-resolution approach to integrated modeling is proposed and Thrust Area 4 is reorganized into four focus areas: (1) Computational Environment –Virtual Watershed Laboratory; (2) Fine Resolution (100 m) Integrated Modeling; (3) Medium Resolution (1-25 km) Integrated Modeling; (4) Basin Scale (coarse resolution) Integrated Modeling. The rationale for such restructuring is based on the assumption that a fine resolution effort might not often be necessary to address a broad spectrum of questions ranging from the precise prediction of hydrologic behavior to the abstract consequences of policy decisions. Simpler models may facilitate studies of the socio-economic responses within a watershed, while being unable to give precise spatio-temporal estimates of hydrologic behavior. Figure 4.1 illustrates the framework for the present multi-resolution approach and the linkages with other Thrust Areas, Figure 4.2 represents the processes to be taken into consideration, and Figure 4.3 represents the linkages with other support projects.

4.1 Computational Environment –Virtual Watershed Laboratory

The objective of this focus is to develop a computational "plug and play" environment that includes a library of process models and submodels –land surface, routing, groundwater, atmosphere, whose interfaces are compatible and well defined. The Virtual Watershed Laboratory (VML) will be based on the USGS Modular Modeling System (MMS) and LANL Parallel Application Workspace (PAWS).

PAWS is software developed at Los Alamos National Laboratory that allows sharing of data between two or more parallel applications. For the integrated modeling effort on massively parallel computers, PAWS will allow direct data transfer between RAMS (Regional Atmospheric Modeling System), LADHS (Los Alamos Distributed Hydrology System), and FEHM (Finite Element Heat and Mass) reducing the need to write intermediate files for data transfer. PAWS efforts have focused on coupling RAMS and LADHS this reporting period. The implementation requires three communication strategies, 1) one to all, where a single processor of one application sends information to all processors of the second application, 2) parallel to all, where multiple processors are sending information to all processors in the other application, and 3) parallel to parallel, where appropriate processors in each application are communicating with each other. The RAMS/LADHS implementation required some innovative developments of PAWS to address issues these include: 1) flipped axis data (negative stride) 2) strides > 1, allowing data size to change, 3) working successfully with a master/slave model and 4) sending of local data within guard cell bound memory.

In the last year, a number of sensitivity analysis and optimization tools have been incorporated into the USGS Modular Modeling System (MMS). These include the General Likelihood Uncertainty Estimation (GLUE) procedure and the Multi-Objective Complex Evolution (MOCOM) optimization method, developed at the University of Arizona. The MOCOM procedure is currently being used on the Thrust Area 1 efforts for modeling the headwaters of the Rio Grande (see MMS/PRMS modeling effort in Thrust Area 1 report).

Plans for the Next Reporting Period

The Shuffled Complex Evolution optimization algorithm, developed at the University of Arizona, will be implemented in the MMS framework. In addition, a number of parameter estimation methods that use available digital databases, currently under development, will be tested to determine the most robust methods for use in applications where observed data are not available for the application of parameter optimization methods. These tools will facilitate the development of a robust set of procedures to estimate and optimize parameters and to evaluate the effects of uncertainty in these parameters on model results.

PAWS efforts for the linking of RAMS and LADHS will continue and all the procedures will be thoroughly tested.

4.2 Fine Resolution Integrated Modeling

This task is developing an integrated model of the Rio Grande that couples an existing regional atmospheric model with a surface water model, and a groundwater model. The development is occurring on a parallel computer at Los Alamos National Laboratory. The atmospheric model is RAMS (Regional Atmospheric Modeling System), the surface hydrology component is LADHS (Los Alamos Distributed Hydrology System) and the groundwater code is FEHM (Finite Element Heat and Mass).

The task during this reporting period has been refining the interface between RAMS and LADHS and bringing the code into the PAWS (Parallel Applications Workspace) framework.

The simulation period is water year 1993 (10/92 – 9/93) for the upper Rio Grande Basin. RAMS uses a nested grids with grid spacing over the Rio Grande of 5 km. LADHS downscales the 5-km RAMS variables (rain, snow, temperature, radiation and wind speed) to the 100-m LADHS grid cells. The downscaling algorithm is a linear estimator that uses elevation as a covariate. We have been comparing the downscaled precipitation to the RAMS estimate and quantifying the variability of the downscaled precipitation across RAMS grid cells.

The LADHS algorithms for estimating evapotranspiration and snow accumulation and melt have been modified. Also, new equations for estimating soil hydraulic properties have been programmed.

Simulations for the Rio Grande using the current version of the code are continuing and results are being analyzed.

Coupling Between Subsystems. Stream – aquifer modeling

Many numerical models have been developed to simulate hydrological fluxes within defined basins. To model an entire watershed, one must link together these separate models. While flow within hydrologic regions is described by familiar equations, flow between such regions is less understood. The dynamics at such interfaces involve complicated feedback mechanisms occurring at many time and space scales. Determining the boundary conditions that apply at such interfaces is one of the main challenges facing integrated modeling.

Using first principles, a set of boundary conditions applicable at a stream-aquifer interface has been developed. By assuming that Darcy's Law applies in the entire aquifer region and that the Saint-Venant Equations apply in the entire river region, the pressure and velocity are required to satisfy a complex interfacial mass and momentum transfer equation "on average", or in a weak sense, across the boundary. The resulting boundary conditions are appropriate for use in the Rio Grande integrated modeling effort.

Additionally, statistics at the stream-aquifer boundary have been studied by incorporating the random nature of several parameters, including the hydraulic conductivity of the soil, the hydraulic roughness of the streambed, and the location of interfaces. In this way, expressions for the mean fluxes and pressure at the stream-aquifer interface have been derived, as well as higher order moments.

Plans for the Next Reporting Period

The designed downscaling procedures that are required for the coupling between the atmosphere and the land-surface will be further tested and fully implemented within the PAWS framework.

The theoretical developments made in the understanding of the stream-aquifer interactions will be coded and tested. The implementation of the procedures within the PAWS framework will be started.

4.3 Medium Resolution Integrated Modeling

The medium resolution effort arose as a result of the discussions for the reformulation of the integrated modeling. It will constitute an effort similar to the one being conducted at Los Alamos National Laboratory, i.e. it will also involve an atmospheric model, a land surface model, and a groundwater model, but with a coarser spatial scale. The coupling of the systems will face the same type of problems as the ones faced in the fine resolution effort. We are planning on using the knowledge developed at the fine scale to help in a speedier development of the medium resolution modeling effort.

Atmospheric Model

A decision has been made for the use of the MM5 mesoscale atmospheric model and a search for a mesoscale modeler familiar with MM5 has already started. In the mean time, we have started to work with MM5 coupled with the NOAH land surface model over the Arizona region.

Land Surface Model

We have conducted an extensive comparative evaluation of different Land Surface Models (LSMs) with different levels of complexity. The models compared were – in order of increasing complexity: Bucket, CHASM, BATS, NOAH, BATS2, and CLM. All the models were calibrated at 6 different sites, covering different climate and vegetation characteristics, in an offline fashion. The sites used were: ARM-CART SGP (in Oklahoma), BOREAS (Canada), Cabauw (Netherlands), Illinois, Ji-Parana (Brazil), and Tucson (Arizona). The results suggest, that the performance of the models was consistent throughout the sites, i.e. the range of errors was the similar at all the sites for each model. The NOAH model (NCEP) was the best in reproducing the results in the Tucson semi-arid environment.

Using BATS2 we have conducted a pilot study about the influence of model calibration in the carbon simulations using data from the Illinois and Ji-Parana sites. The results from such study show that the model performance can be improved by a factor of three, in terms of the root mean square error.

Groundwater Model

MODFLOW is the model that will be used for simulating the groundwater system within the medium resolution effort. In order to better represent the links between the subsurface and the surface in terms of the evapotranspiration over farmlands a new module is being developed, the FARM module for the MODFLOW. The structure of the model has already been fully designed and the computer coding has already started. Currently the stream-aquifer interactions are being modeled with the stream module of MODFLOW. In the future the developments from the fine resolution effort will be implemented.

Plans for the Next Reporting Period

Data from a San Pedro river riparian site has been collected and will be used for further evaluation of the LSMs in the semi-arid environments. In particular, we will be focusing on the quality of the results from the NOAH model. Based on the encouraging results of the carbon calibrations we plan on gather data from the Southwest to conduct similar studies, in order to identify proper parameters for those simulations. The inclusion of infiltration excess processes into the NOAH model will also be carried out.

The coding of the new FARM module will be completed. Testing of the module will be performed offline and coupled to the groundwater model over the Elephant Butte Irrigation District (Rio Grande Basin). The areal extent of the testing is dependent on the acquisition of GIS coverages for the area. Those coverages are to be provided by the irrigation district.

The MM5 atmospheric model will be run over the state of Arizona with the NOAH land surface coupled. Comparisons of different convective precipitation parameterization will be carried out. The effect of changing the default parameter values in the NOAH with those obtained from the offline exercises will be assessed.

4.4 Basin Scale Systems Modeling

Three different groups are responsible for these efforts. The strategy for coordinating them is still in the works and will be defined after the Thrust Area 4 workshop that took place in Albuquerque September 20-21, 2001.

Low Dimensional Catchment Modeling

Currently, the activities are being carried out as part of the TA 2 Basin Scale Hydrologic Systems – Hydroclimatic variability and low dimensional recharge-runoff models, at PSU (Chris Duffy). The details of the activities are included in the TA 2 report.

Climate Modeling

Computational models of hydrologic systems provide a conceptual framework for integrating theory with data analyses and experiments. Integrated system models typically couple atmospheric, land-surface, stream, and ground water subsystems. In the past, limited computer resources and lack of spatially distributed data at sufficient spatial and temporal scales have made it impossible to simulate coupled hydrologic systems at scales fine enough to be confident of the accuracy of underlying physical theories. Moreover, data about hydrologic systems have usually been limited to only a few samples, even though Earth systems exhibit considerable heterogeneity in both space and time. To begin to answer these questions, we have therefore developed a global to regional climate modeling system to predict short-term (synoptic) and long-term (climatological) characteristics of the Southwest. Macroscale hydroclimatology forecast and control simulations are being evaluated with available data, and modifications to the models will be made in order to increase the ability of our global and regional modeling system to predict regional climate change.

The strategy is to first use observed precipitation and temperature and eventually other observed variables along with regional simulations driven by large-scale analyses to provide the initial drivers for a macroscale hydrologic model. This is the strategy of Land Data Assimilation Systems (LDAS) being developed by NCEP and others. Besides incorporating observed variables, LDAS also provides an opportunity to eventually update soil moisture states using observational streamflow. Hydroclimatological forecasts will then use forecast precipitation, temperature and other global to regional forecast variables to drive the VIC model. As we learn how to modify the forecasts to better represent observed precipitation and other hydrologic forcings, the hydroclimatological forecasts should improve. Unfortunately, our effort was stalled due to the abrupt departure of the SAHRA funded postdoc, Yifeng Cui in April 2001. We subsequently went through an international advertisement and recruitment effort to hire a new postdoc, Ji Chen.

Dynamic Simulation Model

Another integrative modeling effort undertaken by SAHRA is the use of dynamic simulation modeling (DSM) of specific watersheds, including stretches of the Upper and Middle Rio Grande, the Verde, and the Conchos. DSM can be used for a variety of purposes, from simple mass balance models of surface and groundwater (Verde) and representations of basins that include numerous dams, reservoirs, and other control structures (Conchos), to models that incorporate salinity and other water quality parameters (Upper and Middle Rio Grande) and those that link physical water resources parameters with economic and policy variables (Middle Rio Grande).

These DSMs will be used not only to integrate research results from other SAHRA Thrust Areas and other sources, they will help to pinpoint areas of uncertainty in the hydrologic cycle and basin-scale water budgets where additional research efforts can yield the most useful results. DSMs also are potentially valuable decision support tools for investigating various what-if scenarios, and can be optimized to achieve various quantifiable objectives.

Finally, SAHRA is investigating the use of DSMs and their graphical user interfaces as educational tools, from the K-12 level to policy makers.

Plans for the Next Reporting Period

GCM and regional model climate change forecasts will also be used as boundary conditions. We (Han and Roads 2001a,b) have already developed regional simulations for current and future climates and the output from these simulations will be used to drive our Southwest hydrologic model for current as well as for future CO_2 global change experiments. Our goal is to better understand how different the climate changes might be in macro scale hydroclimatological models in comparison to those from standard coupled atmospheric land models.

The new postdoctoral Research Associate, Ji Chen, will be taking over the macroscale hydrologic effort in Sept. 2001.

Additional Activities

SAHRA Annual Integrated Catchment Modeling Workshop, September 20-21, 2001, Double Tree Hotel, Albuquerque, NM.
Organizers: Larry Winter, Luis Bastidas, Everett Springer

On September 20-21, 2001, approximately 35 participants gathered at the Double Tree Hotel in Albuquerque New Mexico for a SAHRA-sponsored workshop on integrated catchment modeling. The purpose of the workshop was to bring together SAHRA researchers doing modeling, not just from Thrust Area 4, in order to present the achievements of the different groups and to discuss the coordination of the proposed multi-resolution approach and the integration of the different modeling efforts. The multi-resolution approach was accepted and three groups of interested researchers were formed to discuss the three levels of resolution proposed: fine, medium, and basin scale. The fine resolution group decided to further pursue the Virtual Watershed Laboratory effort, and the decision to put together a proposal to the NSF IT initiative was made. The basin scale (coarse resolution) group decided that all the efforts will be carried out using the Powersim software environment. The medium resolution group decided that it will not be focusing on a common computational environment, at the moment, but areas of common use of products from other TA were identified. It was also generally agreed the use of the Rio Grande as a pilot basin for the studies.

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Figure 4. 1 Multiresolution approach and links to other Thrust Areas

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Figure 4. 2 Processes to be represented

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Figure 4. 3 Support Projects

Thrust Area 5	Sustainable Water Resources Management		
PI Name (s)	Juan Valdes, David Brookshire, Thrust Area Co-Leaders		
Participants			
	Name	Status	
1	Aparicio, Javier	Other research scientist	
2	Bowen, Sheila	Graduate student	
3	Brookshire, David	Faculty	
4	Browning-Aiken, Anne	Postdoctorate, Thrust Area Coordinator	
5	Burness, Stuart	Faculty	
6	Chermak, Janie	Faculty	
7	DeSimone, Richard	Graduate student	
8	Granillo, Cecilia	Undergraduate student	
9	Gutierrez, Maria	Undergraduate student	
10	Kim, Tae-woong	Graduate student	
11	Krause, Kate	Faculty	
12	Lansey, Kevin	Faculty	
13	Little, Joseph	Graduate student	
14	Liu, Zhongmei	Graduate student	
15	Maddock, Thomas	Faculty	
16	McCarthy, Cara	Graduate student	
17	McHugh, Kathleen	Graduate student	
18	McPhee, James	Graduate student	
19	Moote, Margaret Ann	Other research scientist	
20	Moreno, Denise	Other participant	
21	Mozumder, Pallob	Graduate student	
22	Schmid, Wolfgang	Graduate student	
23	Shepherd, Jennifer	Graduate student	
24	Stauber, Leah	Graduate student	
25	Tidwell, Vincent	Other research scientist	
26	Tom, Melissa	Undergraduate student	
27	Valdes, Juan	Faculty	
28	Varady, Robert	Faculty	
29	Varvel, Kyle	Graduate student	
30	Yeh, William	Faculty	
Funding (reporting year)			
	NSF	357,484	
	Other - University of Arizona match	30,195	

Funding (anticipated for next year)		
	NSF	366,129
	Other - University of Arizona match	30,000

Thrust Area 5 - Water as a Resource: Competition, Conflict, Planning, and Policy

The main goal of Thrust Area 5 is to examine and analyze issues related to water-resources policy, including behavioral, sociological, and economic factors, in semiarid regions of the Southwest and integrate current SAHRA modeling and physical sciences efforts with community water planning and management. Thrust Area 5 consists of four components: 1) Institutional analyses and social assessments, 2) Behavioral aspects of water markets and water banking, 3) Non-market valuation, and 4) Water resources management and operations.

Thrust Area 5 participants met May 9-10 in Albuquerque, NM, in order to assess the area's structure and title concept and to decide how TA 5 might be more closely integrated within its component parts and with other thrust areas. Much of the discussion was based on the SAHRA Integration Committee's suggestions about reformulating Thrust Areas 4 and 5. Integration included as well the concept of strengthening ties between scientists, stakeholders, and policy makers, which could be addressed through research collaboration, decision support system modeling, and surveying or measuring economic behavior demonstrated in water consumer choices.

The results of this workshop are reflected in Thrust Area 5's new title, "Water as a Resource: Competition, Conflict, Planning, and Policy," and in the focus on four conceptual areas:

- 5.1 "Institutional analyses and social assessment"
- 5.2 "Behavioral Aspects of Water Markets and Water Banking"
- 5.3 "Non-Market Valuation"
- 5.4 "Water Resources and Management Operations"

The focus area "Institutional analyses and social assessment" demonstrates how stakeholder surveys, background historic and socio-economic research can be used to assess the effectiveness of current water management organizations in addressing basin issues and to identify potential links between scientific research and stakeholder needs for more effective management tools. Similarly, the characterization and analysis of droughts are other means of addressing institutional, management, and policy issues of bi-national concern.

The focus area "Behavioral Aspects of Water Markets and Water Banking" has developed survey instruments that enable us to compare residents' actual water consumption through water bills and low-cost, high-resolution water meter loggers with their responses to changes in price, institutions, or education in an experimental setting.

The focus area "Non-Market Valuation" proposes to examine the influence of other types of valuation on stakeholders' water demands and choices. This and the previous focus area provide a scientific evaluation of stakeholders' water choices and suggest where and how policy and management changes might be more effective.

The focus area "Water Resources and Management Operations" links the research from the prior Thrust Area 5 areas with the findings from other thrust areas in modeling systems developed collaboratively with water managers. These system dynamic models act as frameworks for integrating physical and social science into decision tools for the management of scarce water resources.

In sum, at the Albuquerque workshop Thrust Area 5 participants strengthened their ability to work closely with each other in modeling efforts, in measuring residential water demand, and in selecting modeling approaches that could be used by both researchers and stakeholders. Thrust Area 5 participants perceive an equal need for integration between scientific research and water stakeholders within the other thrust areas. They also hope for increased integration in the modeling efforts of other thrust areas.

5.1. Institutional analyses and social assessment

The Upper San Pedro Basin (Varady, Moote, & Browning-Aiken)

The goals of this period were to promote the use of stakeholder surveys and the Alternative Futures model as water management tools by basin water managers and stakeholders, to provide information and other resources to encourage organizational capacity-building within Mexican and U.S. watershed groups, and to facilitate the collaboration between U.S. and Mexican watershed organizations for joint water basin management in the Upper San Pedro. Activities include:

- Provided the results of two surveys of stakeholder perceptions of water needs and issues in both Arizona and Sonora (Moote and Gutierrez 2001) to the Upper San Pedro Partnership in Sierra Vista, Arizona, and the municipal government of Cananea, Sonora. These surveys are tools that the Partnership can use in developing the water resource management plan for Cochise County and that Cananea can use in addressing municipal water problems and creating a management plan.
- Promoted the use of some variations of Maddock's (TA 4) Alternative Futures, a hydrologic model with scenarios for water resource management in the San Pedro.
- Generated and disseminated information within the basin in the *San Pedro News and Comment*, the *San Pedro Directory* and the San Pedro web site. The *News and Comment* is a weekly email digest of newspaper articles, editorials, and letters to the editor relating to water issues in the San Pedro Basin. Subscribers include nongovernmental agencies; academic researchers; federal, state, and local agency staffers; and many basin residents. The *San Pedro Directory*, available electronically, provides names and contact information about local, federal, and state agencies from both Mexico and the U.S. who have been involved in research and management efforts in the San Pedro. In January 2001 the Udall Center posted an Upper San Pedro Basin page on its Web site at http://udallcenter.arizona.edu/sanpedro/home.html. This Web site provides detailed summaries of all San Pedro activities, access to downloadable Udall Center publications on the San Pedro, and links to other San Pedro-related Web sites.
- Facilitated the development of a Mexican grassroots watershed organization in the basin. Organizational capacity-building efforts include 1) providing materials regarding the organization of other Latin American water organizations and 2) obtaining technical support from other Sonoran watershed organizations and environmental nongovernmental organizations to help this incipient watershed group. The group has selected environmental education as one of its key missions and supports the implementation of the environmental education proposal ECOSTART (TA 6) in Cananea and Naco.
- Collaborating with the Mexican National Water Commission (Comision Nacional de Agua or CNA) to organize a workshop on watershed management and organization issues in Guadalajara, Jalisco, Mexico, November 9. The principal goal of this event is to encourage national support of grassroots watershed organizations such as the one currently developing in the Mexican portion of the San Pedro. The workshop will enable Mexican hydrologists and managers to initiate innovative, basin-wide management approaches.
- Promoting the collaboration of Arizona and Sonora watershed groups in addressing shared concerns regarding water use and management in the Upper San Pedro Basin.
- Formulating a water policy paper comparing the policy issues and management strategies in the San Pedro and Verde Basins.

The Verde Basin (Varady and Browning-Aiken)

An initial scoping study of the Salt/Gila Basins earlier this year indicated that the range of issues was extensive and many Native American stakeholders were reluctant to discuss water issues because of on-going adjudication. Therefore we decided to narrow our focus to the Verde Basin, where the interest in hydrologic research and other scientific tools is regarded as an important means of resolving water issues. We have been assessing stakeholder perceptions of water issues and conflicts within the basin by conducting research and interviews with water managers and planners and by attending watershed organizational meetings. Specifically surveyed:

- Historical and contemporary groundwater and surface-water use in the Upper and Middle Verde Sub Basins
- The development of basin watershed organizations, their missions and objectives

- Policy issues affecting water use in the Verde, specifically the designation of Prescott, AZ, as an Active Management Area and adjudication regarding Native American water rights of the Apache and Yavapai in the basin.
- The findings of hydrologic research in the connections between ground and surface water and between Upper and Middle Verde groundwater.
- The nature of natural resource planning models already existing within the Verde basin and the need for additional hydrologic modeling efforts.

As a result of this assessment, we have offered water conflict mediation with major Verde Basin stakeholders.

Defining Drought and Drought Preparedness in the Conchos River: Probabilistic Assessment of Droughts in Arid Regions (Valdes, Kim and Aparicio)

The goal in the last research period was to develop drought indices such as PDSI (Palmer Drought Severity Index) and SPI (Standardized Precipitation Index) to characterize droughts in the Conchos basin. These indicators were used to develop a Drought Intensity-Area-Frequency curve that represents the spatial influence of droughts and that can be used to identify areas associated with given drought risks. As a result of this analysis, the 1990's drought was identified as one of the most severe droughts during the period of record on the Conchos basin. This has implications in the binational treaty between the U.S. and Mexico, as mentioned below. An example of the areal coverage of the drought and the associated risk is presented in Figure 5.2. The area-intensity-frequency curve is presented in Figure 5.3. The annual areal estimates of the droughts for the 1990's are also shown.

To obtain a complete probabilistic definition of the droughts, parametric and non-parametric methods were used. The traditional approach has been to use extreme value analysis to estimate the return periods of extreme hydrologic events including floods and droughts. This approach, however, deals with only one aspect of the droughts, either intensity or duration. In our research we characterized the droughts by three parameters: duration, average intensity and peak. A probability density function (PDF) for two or three of these correlated parameters was evaluated. In this research period, we applied parametric and nonparametric approaches to evaluate the joint PDF of drought indicators. Nonparametric methods for frequency analysis were examined as a substitute for traditional parametric methods since they did not need an assumption on the population distribution, but they did allow the estimation of the PDF directly from the observed data. In this study, nonparametric methods performed better than parametric approaches both for the Conchos basin and were also validated by the closest Texas climatic region, which had records for more than 100 years. The joint and conditional PDFs of drought parameters were evaluated for the Conchos.

During this period efforts were made to relate climatic precursors like ENSO to the summer rainfall that produces the largest amount of precipitation in the catchment. Preliminary results were not promissory but will be continued in the next research period.

The final goal is to develop a drought preparedness strategy for supporting, designing and managing water resources in the Conchos basin.

Extraordinary Drought Analysis for the Rio Grande/Bravo Basin (Dracup and Gutierrez)

The objectives of the drought analysis for the Rio Grande/Bravo Basin, is to: (1) assess the relative magnitude of drought events that have occurred in the basin; (2) determine the frequency of occurrence of these droughts; and (3) to reassess the hydrology used in determining the "extraordinary drought" conditions that are discussed but not quantified in the 1944 Treaty between the U.S. and Mexico. The following tasks have been completed to date:

- The Treaty of February 3, 1944 for the "Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande" has been obtained and studied.
- Streamflow data for the Rio Grande/Bravo Basin has been obtained from the USGS and from the Instituto Mexicano de Technologia del Agua (IMTA)
- Each of the stream flow sites were analyzed to determine whether or not they are unimpaired, that is, to see if there are any upstream diversions or storages.

The following tasks are currently being worked on:

- Paleoclimatological data for the Rio Grande/Bravo Basin are being gathered.

- A hydrological analysis, similar to that which was performed at the time of the 1944 Treaty, is being performed. We will verify the hydrologic analysis of the Treaty by comparing the figures and results presented in the treaty with those obtained with our analysis.

Plans for the next reporting period:

- Develop an important partnership with Northern Arizona University's Center for a Sustainable Environment (CSE), directed by Gary Nabhan, to:
  - ➢ Collaborate on water policy research impacts on the Verde Basin with Professor David Ostergren, possibly employing NAU students as policy interns
  - ➢ Share information regarding Native American natural resource management programs in the Verde Basin
  - ➢ Collaborate with Professor Ostergren and others on potential watershed conflict mediation in the Verde Basin
- Continue characterization of droughts in arid regions, particularly in the Conchos and Rio Grande.
- Develop drought-forecasting schemes for the Conchos using climatic precursors.
- Adapt hydrologic models (DSS) to the needs of Verde water managers and policy makers to improve effectiveness of decision-making. Their models will include alternate water planning scenarios linked to population growth and economic development.
- Initiate a textual analysis of Verde Basin newspaper reports, interviews and speeches to determine water stakeholders' perceptions of water policies and management strategies.
- Write a policy paper comparing the policy issues in the Verde and Upper San Pedro Basins and the management strategies watershed organizations use to address water resource planning issues.
- Perform a hydrologic drought analysis for the Rio Grande/Bravo Basin using a stream flow simulation model.
- Define "extraordinary drought" conditions that are discussed but not quantified in the 1944 Treaty.
- Perform an analysis of the effects of the El Niño-Southern Oscillation and the Pacific Decadal Oscillation on precipitation and stream flow in the Basin.
- Perform a hydrologic drought analysis for the Rio Grande/Bravo Basin using a stream-flow simulation model. We have determined from Larry Winter and Everett Springer of LANL that they do not have an operational simulation stream-flow model of the Basin. We are in the process of determining if such model is available through the USBR. If no simulation model of the Basin currently exists, we will investigate the possibility of developing our own model using Riverware.
- Define the term "extraordinary drought" condition that is discussed but not quantified in the 1944 Treaty.
- Analyze the effects of the El Niño-Southern Oscillation and the Pacific Decadal Oscillation on precipitation and stream flow in the Rio Grande/Bravo Basin.

***Relevance of focus area efforts to SAHRA goals**:*

Institutional analysis and social assessment in the Upper San Pedro and Verde Basins emphasize the use of stakeholder views of water issues and needs by water policy makers and water resource managers. The process of undertaking this institutional analysis and social assessment enhances stakeholders' ties to researchers and increases the potential use of hydrologic models by community planners and managers.

Establishing drought indicators for the Rio Conchos Basin and analyzing historically occurring drought in the Rio Grande/Rio Bravo Basin provides water policy makers and water managers more effective tools in long-term watershed management of water resources shared between the U.S. and Mexico.

5.2. Behavioral Aspects of Water Markets and Water Banking

Demand Side Management (Brookshire, Burness, Chermak, and Krause)

The overall goal of the demand side management (DSM) work has been to provide pricing and other options that result in efficient management of water resources. In order to provide such options, accurate modeling of water demand in semi-arid climates is necessary. This not only includes residential, but also commercial, institutional and industrial users of water. In addition to the market uses of water we must also contend with the non-market uses. In order to achieve this goal, it is necessary to reduce the data gaps that exist. This was a priority during the past year. While this is an ongoing endeavor, we have been very successful this year in acquiring data, as well as in developing protocols and instruments for acquiring additional experimental and survey data. Activities include:

- Modeling efforts have included a dynamic analysis of the interacting incentives for private versus habitat water use in the context of a mountain front recharge system such as in the Upper San Pedro river basin. A novel situation arises wherein private demands are consumptive use related while public, habitat demands, while clearly consumptive, are closely related to water stocks. This effort incorporates an optimal control framework to consider the implications of current water use vis-à-vis future water availability and the role of policy in anticipating future scenarios. A major result is that as a result of hydrological lags, policy tools must be forward looking. As such they must not only recognize the implications of current decisions on future water availability, but also evaluate alternatives in anticipation of future needs for and availability of water.
- A concurrent effort involves a hybrid modeling effort that attempts to bridge the gap between hydrologic models and economic optimization models by superimposing economic benefit functions on a finite element model of interactive groundwater/surface water use. This research effort illustrates the value of capturing the hydraulic interactions, or water supply, components together with the water demand components, in a single model, and demonstrates the need for further investigation in this area. This optimization model replicates the steady state decision process for water allocation and infrastructure investment in the Upper San Pedro Basin. In this case, there are two competing demands for a limited supply of water, public water supply and water to maintain a riparian habitat for migrating birds (The San Pedro Nature Conservation Area) and two possible investment opportunities resulting in rainfall capture and recharge and wastewater recharge.

As SAHRA is ultimately concerned with sustainable water use in semi-arid environments, we undertook an investigation into the economic implications for sustainable use and the degree to which the related considerations can be undertaken in the context of traditional policy tools. Accordingly we find that some water allocation concerns in semi-arid environments often identified as "sustainability" issues are really no more than classical economic problems involving various sorts of market failure or incompletely specified property rights and, as such, amenable to fairly straightforward policy solution. However some problems related to "sustainability" may remain, and these tend to be problematic, for while numerous authors have characterized sustainable solutions, there is a paucity of incentive-based operational mechanisms capable of implementing these solutions. Additionally, the problems often marshaled under the rubric of sustainability do not admit costless answers. The quantification of attendant remediation costs comprises an important element of policy concern.

Consumer demand: Experimental setting

Economic research efforts have focused on experiment design and collection of field data. Specific to comments received at the annual meeting last February, we have worked on experimental designs that parallel real world conditions. Furthermore, a sampling methodology is being designed so that the sample is consistent with the population. Fortunately, as described below, we have been able to collect data from one population of urban water users that will allow us to compare distributions of traits within the experiment participant sample with distributions within the population. Activities include:

- Pilot experiments conducted this year to determine the feasibility of computerizing established common pool resource experiments. On the basis of those pilots we decided that the remaining experiments would have to be programmed by professional programmers. Programmers have now written and installed programs that will enhance the networking capabilities in the experiment lab. They have also begun programming some specific experiments. Their approach is to construct flexible, module-based designs that will allow us to conduct experiments and to change the parameters of those experiments as additional information becomes available, or as the protocol evolves. These enhancements are necessary to make the computerized experiments useable by members of the community, many of whom have minimal computer skills/experience.
- An important element of experimental economic research is to construct the experiment so that participants face real incentives that parallel the incentives present in the situation being studied. This poses a problem for experiments on water use, as we cannot directly affect a participant's actual water consumption in the lab. Therefore, one of our primary tasks has been to devise a protocol that credibly

links the incentives of the experiment to actual water use. We have decided to address this issue by linking participants' payoffs in the lab to their actual water use as reflected in their water bills and on their surveys. As economists, we assume that a person's actual consumption decisions reflect their underlying preferences. Therefore, we should be able to categorize participants' preference, or utility, for water based on observed consumption. The way that we will use that logic in our protocol design will be to structure experiment payoffs to reflect participants' revealed preferences for water use. That is, a participant whose water bill and survey responses suggest that he or she tends to conserve water will be rewarded for "play" that tends toward conservation; a participant whose water bill and survey reveal a taste or preference for copious water use will be rewarded for "play" that tends toward high consumption.

Survey of disaggregated demand

Economic research also focused on the design of a water use survey instrument. Activities include:

- Pilot surveys were administered to participants in the pilot experiments. The surveys were intended to provide parallel information regarding participants' actual water consumption, allowing us to compare lab/experiment responses to actual use.
- Based on what we learned from the pilot surveys, new survey instruments were developed to better capture water use and to distinguish among different types of water use. Goals of the survey are to determine uses that can quickly change in response to changes in price, institutions, or education (for example, showering or car washing habits) and to learn more about when and how consumers make structural changes that result in lower water consumption over a longer time horizon. Examples of these kinds of capital investments include changing landscaping from lawn to native plants and installation of low-water use appliances. These surveys will be administered to the same people who participate in the lab experiments, allowing within-subject comparisons between the two methods of data collection.
- In addition to the experimental and survey data, we collected a data set from the City of Albuquerque. These data consist of monthly observations over a five-year period for the approximately 133,000 residential, commercial, industrial, and institutional accounts in the Albuquerque metropolitan area for which the City provides water. The data consist of usage, charges, and service location from 1994-2000. The type of service and meter size as well as other potentially informative characteristics such as neighborhood association further distinguishes the data. The acquisition of this data set is important for several reasons. First, the data are sufficiently rich to give us distributional information concerning city water use that will be helpful in projecting future use patterns. Second, the detail allows us to gain additional insights into use patterns across the city by linking these data to census tract data. While the experimental data cover a wider range of prices than we see in the historical data, the city WaterWise Program data set will allow us to test the validity of the experimental data against historical use. Do we see consistency in statistically significant characteristics across the experimental and the historical? Do we see consistent movements in both the experimental and the historical data in response to specific factors? Third, the data will allow us to model water demand across institutional, industrial, and commercial users. This is an area that we were severely lacking in information about use, or distinguishable characteristics. The data for these users appear to be of sufficient detail to estimate demand and test for significant differences across firm type. The data lack the range of prices that we would like, but they give us baseline information about use under existing institutions. Furthermore, the information that we gain from these data can help in the design of experiments specific to industrial, institutional, and commercial users in the future.

Factors Affecting Residential Water Demand (Gary Woodard)

Studies over the past several years have failed to produce a clear, detailed understanding of domestic water uses, and how various socio-economic factors including price and conservation programs influence domestic demand. For example, we understand in general that higher prices reduce demand, but not how. Do people cut back more in outdoor uses than indoor? Do they irrigate less frequently, or for shorter periods of time? Are clothes washers and dishwashers run less often, with fuller loads? Do they take shorter showers, or fewer showers? Or do people install low-flow showerheads? Are they more likely to repair water leaks? Our understanding is particularly fuzzy for some important, rapidly growing categories of domestic demand, including “ranchettes” (residences in rural areas on several acre lots, with their own well and septic system) and new suburban residences.

This project is developing and deploying low-cost high-resolution water meter loggers to identify and quantify specific domestic water demands within individual households over extended periods of time. By measuring domestic water flow at the 0.1-gallon, 0.5-second resolution, water use traces are generated which reveal particular water uses and details such as frequency of toilet flushing, length of showers, gallons of water used per load of laundry, and frequency and duration of outdoor irrigation. System leaks, and sometimes their origin, also can be identified and quantified. When meter logging extends for periods of months and years, impacts of seasonal weather and climatic fluctuations (El Niño, La Niña) on irrigation can be measured, and the impacts of price increases and other economic factors on overall water demand can be directly observed. Also, household reactions to various water conservation programs can be observed.

***Plans for next reporting period*:**

- We have submitted a grant proposal to the Turner Foundation (with Woodard) to fund a three-year study of type of water use at the individual household level. The available technology, coupled with traditional survey tools, will allow us to model water demand at the most micro-level possible.
- Albuquerque water use data set: We will conduct a complete analysis of existing data. This will provide an accurate picture of water use in the City during the five-year period. It will also provide the basis for a survey design to supplement the industrial, commercial, and institutional data. Data from all three sources (surveys, experiment participation, and water bills) will be combined to describe patterns of water consumption under existing conditions (water bills) and under conditions of scarcity or prices that we simulate in the lab.
- Scarcity modeling: A behavior model of residential and urban water use is being constructed towards the end of determining the true scarcity value of water in scenarios where extant water rates are much below true scarcity values and representative only of delivery and system maintenance costs. The goal here is not only to quantify this relationship, but also to provide working estimates of water scarcity values in order that demand relationships might be specified over ranges where water price-quantify observations are non-existent. This study will be initiated in the context of Albuquerque water use-data but has applications to other scenarios as well.
- Pricing for scarcity value of water: We will incorporate estimated demand functions into dynamic optimal control models to estimate the range of water prices necessary to include the scarcity value of water. The range of prices from this work will be incorporated into the experimental design to ensure adequate coverage of future prices.
- Willingness to pay and willingness to accept: Valuation estimates require a clear understanding of responses to valuation questions. One robust finding in the empirical literature is that consumers tend to report different valuations depending on whether they are asked to price commodity that they own (e.g., willingness to accept, or WTA, as payment for existing water rights) or are asked to price a commodity that they do not own (e.g. willingness to pay, or WTP, to acquire additional water rights). These problems are particularly evident when survey respondents are asked to value a commodity for which standard markets do not exist, as is often the case for water. Therefore we are in the process of designing experiments that investigate the WTP/WTA disparity in the specific context of sustainability.
- Salinity: Modeling of salinity in agricultural groundwater use in the lower Rio Grande is being undertaken with the ultimate goal being to incorporate this into a model of conjunctive groundwater/surface water use.
- Unanticipated drought: We will be modeling the effects of unanticipated drought on traditional policy and water use priorities.
- SAHRA resources have been used to develop and prove the concept, produce, and field test data logging equipment, develop and test the necessary software, and compare various battery options and data storage and retrieval mechanisms. The Bureau of Reclamation (BuRec) support will allow for the purchase and assembly of at least 50 meter/logger/sensor systems. Audubon Society support is being used to install meters and sensors in middle-and upper-class ranchettes in the Sonoita/Elgin region of Arizona as well as to gather and analyze the data for two years. Support from Cochise County is allowing another 20 low-income ranchettes along the Upper San Pedro River to be logged. BuRec and Proposition 301 funds will support logging of newly constructed homes in three different price ranges in

the metropolitan Tucson area. Coordination is being planned with the UNM researchers, particularly Krause, on their work involving consumer demand experiments.

Relevance of focus area to SAHRA goals:

The overall goal of the demand side management (DSM) is to provide understanding of individual water demand behavior for consumers, within a private good setting. In addition, there needs to be an understanding of public good type demands for water. These are essential elements of any overall integrated demand management framework. A related issue is the context of the demand management modeling that draws upon the hydrologic cycle and other physical modeling information. Linking an experimental setting with a historical data set and surveys at the individual level is crucial to the demand side modeling and the eventual overall modeling framework. This addresses the private demands. For the public demands, the derived demand for water as it is related to the hydrologic cycle, riparian health, and the diversity of birds also provides a critical component of the demand side modeling, draws upon multiple disciplines, and allows the incorporation of factors into demand management which have not traditionally been carried out.

5.3 Survey to Value Non-Market Water Users

Economic Valuation of Flyways (Brookshire, Chermak and Burness)

A meeting was held to with several non-SAHRA researchers to design the overall structure of an interdisciplinary proposal on the economic valuation of flyways. The goal of this research is to link the understanding of the science of the relationship between water availability, habitat health, and the valuation of both birds and water as resources. An interdisciplinary team has been organized to write a proposal to seek funding, with SAHRA's support in kind, to addresses the non-market valuation of water and the associated value of the diversity of birds in the San Pedro area. The teams consists of Arianna Brand (CSU), Julie Stromberg (ASU), Bonnie Colby and Tom Maddock (UA), David Goodrich (USDA-ARS), Holly Richter (The Nature Conservancy), and Janie Chermak, Stu Burnesss David Brookshire and Philip Ganderton (UNM). The team will meet for the first time in Tucson, AZ, September 21 to share research interests and design the overall structure of an inter-disciplinary proposal. This represents a parallel effort to the market demand efforts discussed in this progress report. The essential goal is to link the understanding of the science of the relationship between water availability, and habitat health and the valuation of the resources both birds and water. Our intent is to submit the proposal in the early part of 2002.

Plans for next reporting period:

- Complete and submit proposal writing for Economic Valuation of Flyways and the Non-Market Value for Water

Relevance of focus area efforts to SAHRA goals:

This proposal addresses SAHRA's goals to integrate research across a broad range of disciplines and to develop scientific knowledge that can aid public and private water management agencies. The focus is on the derived demand for the non-market value of water.

5.4 Water Resources Management and Operations:

Development of a Drought Preparedness Plan for the Conchos Basin (Valdes, Aparicio, Kim)

The Conchos River Basin has an area of 26,400 square miles entirely in Mexico, but its flows are part of a bi-national treaty between the U.S. and Mexico regarding the allocations of water of the Rio Grande/Rio Bravo signed in 1944. As part of this plan Mexico is required to maintain a total flow from these Mexican tributaries (of which the Conchos is by far the most important). This total flow cannot average less than 350,000 acre-feet/year over a five-year cycle without Mexico being in "violation" of the treaty unless there is a situation of "extraordinary drought." The treaty requires that Mexico make up the deficit in the subsequent five-year cycle. The 1990's have been years of significant deficits in rainfall and thus Mexico is in deficit. The main goal of this task is to use drought characterization in conjunction with the other tributaries of the Rio Grande/Rio Bravo on the Mexican side. Activities include:

- A probabilistic definition of drought.

- Continue with characterization of water resources (supply and demand) in the Rio Grande/Bravo catchment: major reservoirs (7), major irrigation districts, cities and towns, etc. This would include contacts (directly and with our IMTA partners) with Mexico's CNA, IBWC, irrigation districts and other major water users in the basin.

Decision-Support Systems (DSS) for Sustainable Water Resources Management
Modeling of Rio Grande, N.M. (Lansey and Varvel)

In coordination with a group of agencies in New Mexico we are extending the Upper Rio Grande Water Operations Model (URGWOM) to include water quality. URGWOM is used on a daily basis to model the hydraulics of the Upper Rio Grande. More importantly, it provides water accounting for the reservoirs in total and for individual water owners. To date, it only considers water quantity using an object-oriented software known as Riverware.

The URG Water operations group, however, has objectives that are being considered by different subgroups. Water quality in terms of dissolved oxygen, arsenic, algae, and total sediment load is an issue in northern New Mexico and salinity concerns have been voiced in the southern portion of the state. Riverware, at present, does not have the capability to model water quality. We have elected to use Powersim for this purpose. As the modeling approaches are the same, the developed and calibrated relationships in Powersim should be easily transferable to Riverware in the future. We are incorporating the water balance relationships used in URGWOM to our model as necessary. A significant difference will be the time step for the water quality that is being considered at a one-week time step due to limited field data for calibration. Activities include:

- Complete the water balance model in Powersim and initiate calibration of the water quality model by December 2001. The water quality portion of the model will be completed in spring 2002.
- Future steps will be defined in collaboration with URGWOM. Several avenues are possible: extending the water quality element to other constituents and time steps, linking geographic information systems to account spatial variations and land use decisions to the water quantity and quality portions of URGWOM, and including groundwater resources in URGWOM (as URGWOM presently only considers surface water).

Decision-Support Systems (DSS) for Sustainable Water Resources Management: Modeling of Verde River Basin (Lansey and Bowen)

The Gila River basin scoping study identified the Verde River as a critical basin in terms of need for planning and conflict resolution. A final summary of the hydrology of the Gila Basin was completed that identified major water supplies, demands, and water resources facilities. The emphasis shifted to the Verde basin with Sheila Bowen, a part time Master's student, becoming involved from Civil Engineering. Understanding this complex system and the constraints on water use and demands is critical. The effort to develop that understanding has been undertaken by Anne Browning, TA5 research scientist. Ms. Bowen is responsible for identifying the range of options and initial scenarios that can be input to a lumped model (e.g., Powersim structure). The intent is that these scenarios will be reviewed by interested parties in an open meeting or individually and feedback to refining the acceptable options. The outcomes for different decisions will then be presented in the noted water balance model. Melissa Tom, a freshman Civil Engineering student and supported by a SAHRA REU, is assisting with model development. Activities include:

- Until Fall 2001, only Sheila Bowen was involved in Verde River Basin modeling. As a part-time student she is slowly making progress by understanding the political structure in the region and the hydrologic system.
- Through this year, Anne Browning-Aiken has been building stakeholder confidence, which has led to further interactions and definition of stakeholder needs.

Alternative Futures (Maddock)

Research involves the development and study of mathematical models for the conjunctive management or allocation of ground and surface waters. Dr. Maddock has been writing proposals for auxiliary funding for SAHRA. A proposal for $194,000 was submitted to the U.S. Army for the continuation of work on the Alternative Futures Project as joint Harvard, Desert Research Institute and SAHRA study. The ultimate goal is to produce a unified hydrological, ecological, and landscape architectural model that acts as the cornerstone of a decision-support system for the San Pedro Basin. Another proposal was to expand the

Alternative futures groundwater model from Redington, AZ, to the confluence of the Gila River and Winkleman, AZ. This would be a joint SAHRA and The Nature Conservancy (TNC) project. The purpose of this model expansion project is to aid the TNC in determining lands for purchase and water rights retirement and in restoring the riparian habitat along the lower San Pedro River.

Models Used by Western States to Determine Permitting and Compliance of Rules Governing Ground and Surface Interactions (Maddock and McHugh)

This research was only recently initiated. It will develop a synopsis and evaluation of western water laws to determine their scientific credibility and utility in court.

Water Resource Management Modeling using System Dynamics (Vincent Tidwell)

There is an urgent need to find the water to meet our growing demand, which has more than tripled since 1950. Technological solutions, although necessary, will be costly and take time to develop and implement. On a more immediate basis, efficient water management practices must be pursued. The difficulty is that responsibility for water is highly dispersed resulting in a piecemeal approach to resource management. Additionally, management practices must full appreciate the interconnection, feedback, and time delays among watershed subsystems (e.g., precipitation, runoff, groundwater discharge, evapotranspiration, recharge) that operate over a range of spatial and temporal scales.

To this problem we are adopting a holistic, systems-level approach. Specifically, systems dynamics is adopted as a decision support framework in which we integrate the natural system with other systems like economics, demographics, and ecology. The resulting decision models are couched in the context of the legal, political, and social constraints that limit the decision process. Activities include:

- Developed a prototype decision support model for the Middle Rio Grande Basin. This model incorporates the basic components of water supply (basin inflow, recharge, evaporative losses, etc.) and water demand (municipal, agricultural, and industrial).
- Established a cooperative relationship with the US Bureau of Reclamation, US Army Corps of Engineers, New Mexico Interstate Stream Commission, and City of Albuquerque.
- Calibrated model against historical data for basin outflows and groundwater depletion.
- Integrated user-friendly interfaces to allow real-time analysis of alternative water management practices in the basin.

Decision Support Systems for Sustainable Water Resources Management (Yeh and McPhee)

The goal is to create a Decision Support Environment easy to operate by decision-makers with basic computing skills and with a minimum of training. We believe this is a key requirement to ensure the usefulness of any management tool. During the next reporting period we plan to have meetings with decision-makers and stakeholders, in order to obtain feedback on this topic and to tailor the model to meet their requirements the best possible way.

The multi-objective optimization model is a management model, which is capable of generating trade-off relationships among the various conflicting objectives. For the development of the multi-objective optimization model, quantification of the conflicting objectives within the San Pedro River Basin must be achieved. The objectives considered include the following: 1. Meeting the water demand in the Basin, 2. Maximizing the extent of the riparian area that can be sustained, 3. Protecting groundwater quality in the Basin, and 4. Mitigating negative water quality impacts in the riparian habit. Noninferior solutions will be sought to identify the trade-offs among the various objectives. We have chosen the constraint method to develop the trade-offs among the various conflicting objectives.

The developed simulation model will be linked with the optimization model by the response matrix method. In this approach, the simulation model along with the initial and boundary conditions are used to determine the influence of pumping and/or recharge at selected locations in the flow region. These influence coefficients form the response matrix that replaces the governing equation in the optimization model. Therefore, a considerable amount of computer time and storage can be saved in the optimization. Another advantage of the response matrix approach is that the simulation model can be treated as an independent subroutine and called to generate the influence coefficients. However, an iterative solution of the optimization problem is generally required because the response surface of the governing equation is not necessarily linear. In principle, at each new iteration in the optimization, the response matrix should be updated using the optimized values of the decision variables from the previous iteration. Convergence takes place if the updated policy remains the same as the previous policy. We will use the parameter perturbation method to generate the influence coefficients. Activities include:

- Completed an initial stage of model analysis and study of the Alternative Futures Model, which is the groundwater flow model to be used to evaluate the San Pedro Basin system influence coefficients (and hence the Jacobian Matrix) so to fully understand the model conceptualization, assumptions, main hydrologic features and input/output structure.
- Finish a computer subroutine to get the influence coefficients. The management model and its associated subroutines are being built with emphasis on input flexibility, so to be able to modify on a user-friendly fashion the set of state variables included in the objectives cluster, and eventually the objective definition itself.

Plans for next reporting period:

- Develop a forecasting model for drought indexes using climatic precursors
- Develop a systems-based model of the Rio Grande/Bravo basin using Powersim at two temporal aggregation levels, annual and monthly, to simulate the current operating policies of the basin under current and future conditions of water demand.
- Develop alternative operating procedures taking into account long-term forecasts of droughts, institutional and legal constraints.
- Build links with local stakeholders in the San Pedro Basin, Mexican portion.
- Work with Mexican researchers at IMADES on groundwater simulation model for the Upper San Pedro River Basin..
- Build the Verde River Basin model with alternate scenarios in the fall of 2001. We anticipate initial model demonstrations in the spring of 2002 with significant user feedback for improvements. The primary difficult anticipated in this effort is understanding of the hydrologic system and the interaction of surface waters in the Verde River with groundwater decisions in the Prescott Valley.
- Integrate economics into the Middle Rio Grande (MRG) System Dynamics model.
- Extend the spatial extent of the MRG model and implement Rio Grande Compact constraints on the system.
- Couch the MRG model in a fully stochastic framework for sensitivity and uncertainty analysis.
- Research studies on western water laws will be divided into two parts. The first part will be a synopsis of current water law in the west. The basic guidelines of the prior appropriation doctrine will be outlined. In addition, specific states will be given special attention due to their more progressive approach in dealing with the surface/ground water relation. These states include Arizona, New Mexico, California, Oregon, Colorado, and Washington. Other states, such as Nebraska, Oklahoma, Texas, Kansas, Nevada, North Dakota, Utah, Wyoming, and Idaho will be given a brief description of their approach to surface/ground water interaction. Descriptions will include the status quo for each state's approach to dealing with the groundwater/surface water dilemma, specific legal cases which illustrate these approaches, strengths and weaknesses of these approaches, and current trends in each state.
- The second part of the water laws research will examine the models used to determine compliance of groundwater/surface water rules. These models include, but are not limited to, the Bright Line tests used by Oregon and Colorado, the Washington Yakima River Basin model, and Texas' Water Rights Analysis Package (WRAP). Models will be examined for both scientific credibility, their ability to be used and understood in court, and their strengths and weaknesses.

Relevance of thrust area efforts to SAHRA goals:

The Upper Rio Grande (URG) water quality model and the Middle Rio Grande System Dynamics model will provide the basis for water management decisions. The collaboration with multiple users demonstrates SAHRA outreach to solving water management issues. As we learn more about the water quality relationships, collaboration with other thrust areas, particularly TA 2, may be advisable to look at long-term salinity. Like the URG effort, Verde basin modeling is intended to improve water management decisions and overall planning of the Prescott valley. This region must develop an overall water management plan to meet Arizona safe yield requirements with an understanding of the impacts of their decisions on Verde River flows and the associated environmental concerns. Sustainable water supply is the overarching goal of SAHRA. To understand the hydrologic system, other TA's may be requested for support. In addition, the drought research activities promote bi-national management of shared water resources in the U.S. and Mexico. Finally, western water law research will aid water policy makers and managers in addressing the dilemma of ground water/surface water legal inconsistencies.

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Figure 5.1 Integration scheme for Thrust Area 5.

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Figure 5.2. Drought areal extent for 1996

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Figure 5.3. Area-Intensity-Frequency Curve for the Conchos Basin

III. EDUCATION

Education Objectives

Our broad educational objectives or goals remain unchanged. The three overarching and cross-cutting goals in TA6 are to 1) improve hydrologic literacy at all levels, 2) integrate research and education, and 3) move beyond business as usual. While these goals seem self-evident, these statements will be described in greater detail below. First, by improving hydrologic literacy we mean the ability and actual practice of applying sound hydrologic principles to problems ranging from basin-scale water management, policy debate and substance, environmental protection, and finally to public participation in terms of both individual action (like conservation) and public participation in water-related issues (like growth). Second, by integrating research and education we want to recognize and promote the bi-directional incorporation of SAHRA research into all our educational programs, which necessitates broad science personnel participation in these efforts both within and beyond the university, as well as wide-spread opportunities for teachers, students and the public to participate in and appreciate Center activities. Finally, by moving beyond business as usual we want to acknowledge the difficulty in moving from our traditional roles toward ones that require boldness, innovation, collaboration, and public service. Obviously, these goals are self-reinforcing, as are the projects that are describe below.

Stakeholders

The audience or primary stakeholders that SAHRA's TA6 recognizes include the traditional ranks of the postdoctoral and graduate student. Undergraduate students are recognized as being critical future leaders and opinion makers who have much to gain in terms of basic hydrologic literacy skills. More technically able students are the prime recruits for future graduate study, whether their interests lie in science, policy or education. Where possible, it is advantageous to work with those individuals who have the greatest lifetime impact. Certainly, our classroom teachers have this huge multiplier effect so they are critical SAHRA stakeholders. Their students, likewise, are important to our mission of widespread hydrologic literacy and the subtle influence children can have on adults around them. Needless to say, water management professionals are important users of SAHRA research products and services and require advanced and rather specific training to transform our academic and research ideas into new operational standards. The public is the final major stakeholder. It is important to reach them because not all water policy is based on technical detail. Thus without an educated public, SAHRA's mission can never fully be satisfied. There are many overlaps between TA6 and TA7 stakeholders, particularly within these last two categories. One group of stakeholders who are critically important but implicitly involved in all these activities are SAHRA research scientists.

III. Table 1: Education Matrix

What \ Who	Graduates	Undergraduates	Teachers	K-12 Students	Professional +
New Courses	Grad Seminar	Water Issues	Water Science	WISE	SAHRA Seminar
Career Paths	MSE	CEA-CREST		Project WET	Watershed
Research Opportunities	RA's	REU		HS Interns, GLOBE	
Extended Learning	Community Service		EEOP ITEP	Biosphere II	Partners Roundtable

Management and Organization

An education matrix (Table 1) provides a convenient framework for relating the various education stakeholders to generic program objectives. In general, SAHRA seeks to advance its educational goals by developing new courses targeted to various stakeholder constituencies and by supporting career pathways from one level of educational engagement to the next. Further, SAHRA seeks to promote an array of research opportunities to foster an authentic and deeply in-grained appreciation and knowledge of its activities. More informal outreach activities might be termed extended learning or community service opportunities. These will typically engage university students in short duration, Center-supported and coordinated outreach efforts into the community to both further the students' community needs and to give them experience communicating their knowledge to a radically different, but highly receptive group. We will seek to leverage SAHRA funds wherever possible and actively solicit non-SAHRA funding to support these activities.

Performance Assessment
These programs can judged to be successful by their persistence and gradual growth in numbers served and quality of product. Successful programs will be offered at multiple locations and will be shared with diverse audiences through publications and presentations. Successful programs will garner positive participant reviews. The most successful activities are likely to attract outside financial support.

Problems
Participation has been low for many pilot projects. This is expected to change next year as development accelerates and we have the whole year to market these opportunities. Some external activities are poorly linked with our core personnel and research objectives. This was partially by design, the initial emphasis being to focus simply on improving hydrologic literacy. Our revised strategy is to forge much stronger links between education activities and research or researchers. Education activities away from Tucson remain challenging to organize and to encourage broad Center participation.

Integration of Research and Education
In terms of Center integration, our four broad objectives can be placed around the core educational resources of the Center, which includes Center personnel, research findings and foci, simulation models and motivational scenarios or primary science justification. In short, the educational mission is dependent upon these interactions. Achievement of these objectives leads to success meeting our overarching goals of improving hydrologic literacy, integrating research and education and moving beyond business as usual.

Significant Changes
A significant portion of the public outreach component of our efforts has been run through Biosphere 2 Center. This relationship has not been very effective or collaborative and is under review. In the short-term, we are working closely with the Biosphere to complete the current middle school level curriculum development effort. In the longer-term we want to explore new opportunities, such as collaborating with other regional science Centers and to participate in the development of interpretive material for a large groundwater model at Biosphere 2 Center. The underlying shift in emphasis here is away from supporting generic hydrologic literacy towards a greater emphasis in more active promotion of fundamental SAHRA science concepts and themes.

Internal Education Activities
A significant amount of resources have gone into course development. We have done this only after a careful needs assessment. Our overall goals in course development are to improve hydrologic literacy, integrate state-of-the-art research findings and venues into basic course material and to provide inspiration and motivation to the student.

- *Title: Graduate Seminar (HWR696)*

Led by: Bales & Washburne
Intended Audience: SAHRA graduate students
Impact: 12 UA students/yr; Center focused curriculum
Narrative: This one unit seminar class is taught every spring to help assimilate new graduate students into the interdisciplinary focus of SAHRA. Postdocs contribute by reviewing the innovative science and relevant water management issues within their areas of expertise. Participating students get to know how their own thrust areas by making presentations to the rest of the class covering a topic of particular interest. SAHRA scientists lead discussions of fundamental research, management and policy issues that the students will face during their tenure with the Center.

- *Title: Undergraduate Water Issues course (HWR203)*

Led by: Washburne
Intended Audience: Non-science undergraduates
Impact: 100 UA students/yr; new general education program with some Center content
Narrative: This is a mid-size (50 students) Tier 2 general education (required natural science) course at the University of Arizona that we teach every semester. The class is mostly non-science majors. The class goals are to improve the students' hydrologic and scientific literacy, instill life-long learning and job skills and prepare the students for dealing with as yet undefined water issues in their future. The class is relatively unstructured, from the students' perspective, although the course is broken into two week modules which concentrate on issues related to the major themes of: water quantity, watersheds, water quality, water law, ground water, water conflicts and water sustainability. Class reading is drawn from industry and government fact-sheets and reflective essays about current regional water issues. A variety of activities are integrated into the 75 minute class time. Most classes begin with a focus image think-pair-share activity, which is used to introduce new concepts and terminology. A variety of in-class activities engage the students in data collection, analysis and group simulations. The students' math skills are stimulated by the basic calculations and conversions required within these activities. In many cases, SAHRA science plans can be used to explain the historical development or current needs of various water management applications. We have just begun to encourage the further development of or graduate TA teaching skill by sharing the lecture duties for this lively class.

- *Title: SAHRA Seminar Series*

Led by: Woodard
Intended Audience: University water research community
Impact: approximately 8 seminars/yr x 30 in audience; Impacts both internal and external communities
Narrative: No professional or academic education experience is complete without a forum for the intellectual exchange and debate about current developments and controversies in the field. This need is particularly acute for a large interdisciplinary group such as our own. In conjunction with the Department of Hydrology and Water Resources (HWR) and the Assistant Director for Knowledge Transfer, we are promoting the collegial exchange of professional views in a regular seminar series. Many of these lectures will be video taped for distribution within our Center.

- *Title: MS in Water Resource Engineering (MSE) Professional Degree Program*

Led by: Valdes
Intended Audience: mid career water professionals
Impact goal: 2 new participants/year; New graduate degree program
Narrative: This degree program was set up last year in collaboration with all three Arizona state universities (UA, ASU, NAU) to facilitate mid-career academic and professional advancement. An academic program was forged from offerings (particularly distance learning courses) from the three universities and an intensive one-year on-campus stay to pick-up key specialty courses and develop rapport with a faculty advisor. In place of a traditional thesis, a professional report related to the students work situation would serve as the capstone project. While interest in this route is expected to be light, it will greatly facilitate the career advancement for a few mid-level water resource managers.

- *Title: Graduate Research Assistantships / Community Service*

Led by: Washburne
Intended Audience: SAHRA graduate students
Impact: 40 RA/TA's/yr, 100 hours of community service; external mentoring and leadership
Narrative: SAHRA funds over 40 graduate RA's and TA's to provide the research support and scientific innovation necessary for such a large and diverse Center. Because their specific activities and accomplishments are chronicled elsewhere, the focus here is on some of the unique opportunities this group enjoys. To promote interdisciplinary understanding and friendships, most SAHRA graduate students are seated in two large office spaces. Most students are required to take one core course that covers the philosophy and an overview of the goals and objectives of the Center (HWR696), co-taught by the Deputy Director. Graduate students are further encouraged to take part in some extracurricular community service project or something that extends their learning outside of class. Examples of some current opportunities are helping to mentor undergraduate interns, staffing the SAHRA public display at professional or professional

development meetings, becoming involved with inquiry and research development programs in surrounding school districts, and helping to support special water-related activities (such as Sabino Canyon Days) with cooperating schools.

- *Title: Research Experiences for Undergraduates*

Led by: various researchers
Intended Audience: undergraduates at SAHRA-related institutions or affiliates
Impact: 8-14 undergraduates/yr; Center-related career/research experience
Narrative: NSF has provided supplemental funding for 14 separate summer or semester-long REU's over the current fiscal period. These programs have been aimed at attracting highly motivated undergraduates to experience our research environment. We intend to offer a significant fraction of these next year to under-represented students, particularly to specifically recruited Native Americans. This past summer saw the completion of several successful REU experiences, with valued research coming from the solute, riparian and vadose zone research efforts. We are currently developing REU support to improve mentoring, assessment and follow-up.

- *Title: High School Intern Program*

Led by: Woodard
Intended Audience: High school students headed to UA
Impact: 8 interns/yr; Center-related career/research experience
Narrative: Eight outstanding high school juniors and seniors were recruited from local schools to participate in various field and database support roles this past summer. The program was a great success, particularly in terms of a project that had several of the interns programming and debugging a data collection system using hand-held personal data assistants (PDA's). Several of the interns who worked for us this summer have entered the University and continue working with us as undergraduate assistants, thus supporting our career pathways objectives.

- *Title: Environmental Hydrology (FOR/GGG 340)*

Led by: Aregai Tecle (NAU)
Intended Audience: undergraduate environmental studies majors
Impact: 20 students/yr; New course with some Center content
Narrative: Aregai Tecle is developing an undergraduate emphasis area in rural water and watershed management. The courses and the emphasis area are meant to promote the objectives of SAHRA and meet student needs. Environmental Hydrology was developed and approved in 2001 as a forestry, geography and honors course. The course consists of a 3-credit hour lecture and 1 credit-hour laboratory/field experience. The course is being taught this fall (2001) as a web-enhanced course, and there is plan to develop as web-based course in the near future.

External Education Activities

- *Title: High School Teacher Water Science Workshop (HWR599L)*

Led by: Madden & Uyeda (Local HS teachers/trainers)
Intended Audience: High School science teachers in the SW
Impact: 8 trained this year in Tucson and Socorro; goal of reaching 26 next year
Narrative: This past summer we piloted a new two-week workshop for high school teachers aimed not only at increasing their hydrologic literacy, but also to give them much needed experience engaging in inquiry themselves, developing authentic research skills and analyzing complex (interdisciplinary) information. We were able to hold small workshops both in Tucson, AZ and in Socorro, NM with the help of two master teachers and many hours of preparation. The regular class sequence is to review some basic concepts, have them read about several on-going issues or conflicts, introduce the Seek/Solve/ Create/Share methodology in the context of a water quality problem and finally to work through a week-long problem-based learning (PBL) module constructed around a regional water management plan developed by a small group. Again, SAHRA science and policy work is being integrated into this workshop. We hope to use SAHRA's distributed network of researchers to stay in contact and support these teachers implementing what they have learned. This has been a successful joint effort between the SAHRA core office and the UA College of Education.

- *Title: High School Water in Science and the Environment Course (HWR101C)*

Led by: Woodard & Washburne
Intended Audience: High school teachers interested in providing integrative science alternatives to students at the AP level
Impact: under development; 8 teachers and 80 students next year
Narrative: Most water education materials are developed at the K-9 grade level. With the growth of charter schools, systemic science education reform, integrated and inquiry-based environmental science curricula, there is greater demand for a year-long, AP-level water science course that qualifies for basic university science credit and promotes early recruitment into undergraduate hydrology major programs. This course builds on our other course development and knowledge transfer efforts, particularly our web site. The first pilot program in 3-4 schools will be in place for the 2002 fall semester. The development of this course is a collaborative and jointly funded endeavor between four water Centers at the University of Arizona: SAHRA STC, Center for the Benign Manufacture of Semiconductors (CBMS) ERC, the Arizona Water Resources Research Center (WRRC), and the Water Quality Center (WQC). The course will integrate state-of-the-art water science, technology-rich and inquiry-based activities and regional field trips. There are many opportunities for graduate student support and community service learning. We hope to expand this program to other SAHRA cities within three years. Obviously this effort satisfies our developing career pathways objective.

- *Title: SAHRA/GLOBE Collaboration*

Led by: Washburne & Ferre
Intended Audience: K12 science students in SAHRA areas of interest
Impact: under-development; possibly 30 schools by next year
Narrative: This major new initiative ties together several previous strands of our education effort. The goal of the collaboration is to leverage the resources and abilities of both partners to more effectively sample environmental phenomena at wide space and time scales in SAHRA's areas of interest. Essentially, this partnership requires significant buy-in and participation at all levels throughout SAHRA as well as in the schools located in our areas of interest. Global Learning and Observations to Benefit the Environment (GLOBE) students will be tasked with regular and special sample collection while SAHRA scientists and students will work with the schools to show how the student measurements can be integrated with their scientific datasets for a more complete physical picture of the water balance and water quality. The initial focus areas are the Rio Grande, San Pedro and Four Corners areas. A salinity and water solute sampling program is being set-up this Fall along the Rio Grande. Native American schools throughout the Four Corners region, where we have existing teacher training and support efforts, will be tasked to evaluate their regional hydroclimatology within the constraints of GLOBE and SAHRA.

- *Title: Passport to Learning – Water sustainability module*

Led by: Steve Russell (Biosphere 2 Center)
Intended Audience: middle school students
Impact: Possibly 5-10,000 students on class tours per year
Narrative: SAHRA has supplied curriculum development funds to enhance an existing water cycle component in their standard middle school tour. These extensions will address selected aspects of hydrology and water use in southern Arizona. In particular, the relationships between water and other ecosystem processes will be examined. This supplement is computer-based, which should enhance its impact. The enhanced module will be introduced over the coming year.

- *Title: Environmental Education Outreach & Institute for Tribal Environmental Professionals (EEOP/ITEP)*

Led by: Mansel Nelson (NAU)
Intended Audience: Native American K-12 Teachers
Impact: 8 jointly funded workshops
Narrative: SAHRA provides travel and participant support matching funds to two pre-existing programs based at NAU to develop, demonstrate and support K-12 water resources and water quality education throughout the Four Corners region. Eight workshops and many on-site demonstrations were given to K-12 teachers and students. The purpose of this partnership is to train teachers who will incorporate the teaching of water and

water quality in their science curriculum, and to stimulate students to learn about water and water quality problems that affect their tribal areas. Additionally, we believe this early exposure to water issues and science is crucial to recruiting more college-bound students into our degree program. A brief summary of workshops and outreach supported, in-part by SAHRA, over the last year are:

1. GLOBE - Native American Network II (GLOBE-NAN II) Follow-up Workshop. This entailed working with 42 K-12 educators from Navajo Nation to implement the GLOBE program. It was done in collaboration with Northern Arizona University (NAU)'s Science and Mathematics Learning Center (SMLC). The EEOP staff did a follow-up on the GLOBE teacher workshops to help educators with implementing the GLOBE program The Workshop took place on 04/28/01 at Window Rock High School in Ft Defiance, Arizona.
2. GLOBE – SMLC - Native American Network III (GLOBE-NAN III) Summer Institute from 06/11/01 to 06/15/01. The five-day workshop involved 18 educators from the Havasupai, Navajo and Hopi tribes.
3. GLOBE Train-the-Trainer workshop. The EEOP staff planned and conducted this workshop in collaboration with GLOBE Headquarters for 30 educators from 18 Tribal Colleges and organizations. The Workshop was held at the Northern Arizona University main campus in August 2001. The objective of this training was to encourage representatives from the Tribal Colleges to work with K-12 schools in their region to implement the GLOBE program.
4. Tribal Schools Ecological Monitoring Program (TSEMP) workshop involving a three-day long education program organized and given in cooperation with The Nature Conservancy (TNC) and Navajo Nation Environmental Protection Agency (NNEPA). However, only three educators from the Navajo Nation took the workshop. Participants learned the GLOBE hydrology protocols, macroinvertebrate sampling, and stream ecology. Schools currently involved in the TSEMP program include Tse Ho Tso Middle School (3 teachers), Chinle High School (2 teachers), Navajo Pine High School (1 teacher), St Michaels Elementary School (1 teacher), and Tsaile Elementary School (1 teacher).
5. Summer Scholars program (6/03/01 to 06/30/01). This program was organized in collaboration with four school districts and it provided Middle School students with an emphasis in environmental science, mathematics, and technology a one-week on-campus, residential experience. The Summer Scholars program involved four one-week sessions and reached 140 students as follows:
   i. 06/03/01 Shonto Preparatory School (24 students)
   ii. 06/10/01 Sacaton-Gila River (30 students)
   iii. 06/17/01 Tuba City Junior High (36 students)
   iv. 06/24/01 San Juan County (Utah) School District (50 students).
6. A one-day Summer Institute on Youth Opportunity Program was given to 24 students from the Navajo Nation. During the workshop students participated in a panel discussion concerning the current status of Navajo Nation's surface and ground water systems. The discussion included the importance of the role of the community in water protection and why it is important to protect the existing water supplies.
7. Protective Circle. In this program, the EEOP staff visited 15 schools on Navajo Nation to provide classroom presentations and teacher workshops. During the visits, the EEOP staff gave presentations on solid waste and water contamination issues. The EEOP staff also used ground water models to teach students and educators about the importance of proper handling household hazardous wastes in order to keep contaminants off ground water.
8. Uranium and Radiation Outreach Education (UREO). The EEOP staff conducted three two-day workshops for 25 educators on uranium issues in the Navajo Nation. One issue that was specifically addressed is the contamination of ground water from uranium mining and milling operations on the Navajo Nation. The intention is to develop some understanding of the nature of this type of contaminant, its seriousness, effects on humans and how to avoid or protect oneself from it.

Professional Development Activities

Several workshops were organized to plan, coordinate and discuss early progress between SAHRA researchers and their stakeholders. These are discussed under Knowledge Transfer and the appropriate Thrust Area headings. Below, a few of the professional development activities carried out in collaboration with the SAHRA education program are highlighted.

- *Title: Tribal Watershed Analysis & Management Workshop (NAU/FOR499)*

Led by: Laurel Lacher & Johnathan Long (White Mountain Apache Tribe)
Intended Audience: Tribal watershed managers and technicians
Impact: 8 this year; 12-15 next year
Narrative: SAHRA provided key participant support (scholarships) to an affiliated group (White River Apache Tribal Environmental Affairs Office), which developed and piloted an invigorating two-week summer workshop devoted to improving tribal environmental watershed management practices. The course received further institutional support from our colleagues at NAU. One goal of the program was to provide professional development to tribal members in their own environment. Another goal was to encourage career development through a college degree credit in watershed and water resources management. The workshop was run from a White River Apache elk camp near Cibecue, AZ. Eight participants from five different tribal organizations helped pilot his year's course. They represented a wide-range of hydrologic literacy and watershed management experience, which clearly underlined the value and need for this type of professional development effort. They also discussed their unique needs with regard to tribal sovereignty, custody and control of environmental data and management

- *Title: Northern Arizona Watershed Collaborations*

Led by: Aregai Tecle (NAU)
Intended Audience: Tribal and agency watershed managers
Impact: A presence and working relationship with tribal and other local watershed activists
Narrative: We have developed a strong collaboration to study soil and water salinity as well as the nutrient content and the productive capability of Hopi tribal lands. The Hopi Tribe provides in kind contributions in the form of a hydrologist and soil and water sampling equipment. We are working to develop collaborations with NAU's Center for Environmental Sustainability and the Navajo Nation to study land management impacts on water and water quality in the Coconino Plateau and the Navajo Reservation, respectively. Further, we are developing a partnership with the USDA Forest Service to study the relationship between forest management and wildland hydrology and water quality. We also have funds from the Bureau of Land Management and the Arizona State Prop 301 to study related problems. In addition, we are developing partnerships with local, regional and national environmental groups such as the Nature Conservancy, the Grant Canyon Trust, the Grand Canyon forest partnership, the Sierra Club and other groups. This will help us to view and address our water resources-related educational and research activities in a holistic framework.

IV. KNOWLEDGE TRANSFER

Knowledge Transfer Objectives

SAHRA's knowledge transfer (KT) objectives have not changed substantially from a year ago. They remain as follows:

- developing working relationships with various stakeholders so as to learn their information needs and solicit ideas and suggestions to guide SAHRA's research efforts;
- communicating research findings and making available to water resources managers and policy makers in semi-arid areas the decision support models, data sets, and tools that result from our research; and
- improving water resources management and furthering hydrologic literacy by identifying, sorting, validating, and making available in useful formats existing information.

What *has* changed is our emphasis. Internal knowledge transfer among the 10 universities and seven labs and federal agencies that make up our partners remains critical; however, many internal KT mechanisms and tools are now in place. At the same time, we are starting to see the generation of significant research results. Thus, our emphasis has become more externally focused.

Initially, we limited international activities as well. Now we have identified key issues and partners, and have begun to more aggressively pursue international opportunities. Major emphasis currently is placed in three areas:

- studying the impacts of privatization and decentralization of water and land resources in developing countries;
- looking at trans-boundary water issues, which include international borders, state borders, and Indian reservations; and
- studying water management issues in northern Mexico, including the Conchos and upper San Pedro basins.

Perhaps most significantly, we have identified areas of critical water information that lack effective dissemination mechanisms, and are beginning to provide this in specific areas. These information clearinghouses will serve not only Southwestern water resources professionals, but water professionals around the world. Our Web-based News Watch service is an example, providing a single source for global coverage of stories, press releases, and significant reports that impact water resources. News sources reviewed and items summarized span the globe, with English-language summaries provided for articles written in English, Spanish, Italian, and French.

Performance and knowledge indicators will be based primarily on quantifying demand for the information produced. Thus, we will monitor the number of people, and their institutional affiliations, that access various types of information made available via workshops, through our Web site, and in print.

Problems

SAHRA continues to grow, with new partners such as Sandia National Labs and The Nature Conservancy, an NSF "glue" grant with Cal. State – L.A., new funds from the State of Arizona for additional programs, and grants from a variety of groups, including the Audubon Society, Bureau of Reclamation, and local governments. This has necessitated continued work on mechanisms for efficient and effective internal knowledge transfer. At the same time, research and education efforts begun a year ago are starting to bear fruit, necessitating greater external knowledge transfer efforts. Human resources are stretched thin.

The situation should improve over the next year, both because some major start-up tasks will be largely accomplished, and because we will have greater human resources. Our recently revamped Web site will need only maintenance and additions rather than wholesale development. The same is true of our static displays, electronic kiosks, and printed materials. We have gone from having no editor to employing a part-time editor, and plan to have an additional full-time editor on board next year. We currently are recruiting for a data base specialist, who will facilitate internal sharing of raw data and processed results. Supplemental funds from NSF are expected to fund videoconferencing facilities at three partner institutions. A post-doctoral research associate will be added in the education/knowledge transfer areas.

Organizations

Knowledge Transfer Activity	Professional Development
Led by	Gary Woodard
Participants	

	Name and Organization
1	Bonnie Colby, Agricultural and Resource Economics, U of Arizona
2	John Thorson, Special Master, Gila River Adjudication, retired

SAHRA has hosted and co-sponsored a number of short courses and symposia, including:

- Short course on of ModFlow 2000;
- North American Monsoon Experiment Meeting

SAHRA hosted an Annual Recharge Workshop, March 22-23, 2001, at New Mexico Tech, Socorro, NM. Leaders: Fred Phillips, James Hogan. On March 22-23, 2001, ~30 participants gathered at New Mexico Tech in Socorro New Mexico for a SAHRA-sponsored workshop on recharge in semiarid regions. The purpose of the workshop was to bring together SAHRA researchers investigating recharge in order to present recent advances in the understanding of groundwater recharge and vadose-zone processes in semiarid regions and foster cross-thrust area integration to develop a unified approach to understanding this key parameter

SAHRA has helped develop, with the Dept. of Civil Engineering, a Masters program for practicing professionals in the hydrology and water resources area.

SAHRA has begun a seminar series, bringing two distinguished speakers to the University of Arizona each semester to not only present a seminar on a topic of wide-spread interest, but also to spend a couple days talking with SAHRA researchers and visiting labs and field sites.

SAHRA is jointly funding and contributing to publication of the 2nd ed. of Indian Water Rights: Negotiating the Future, by Bonnie Colby and John Thorson. The book, to be published in Spring 2002, will form the basis for SAHRA's first Executive Training Program, in fall of 2002.

SAHRA has developed static displays, electronic kiosks, and printed materials for use in professional conferences. The purpose of participating in these events is to spread word about SAHRA, develop new partnerships, and recruit students. Conferences and meetings where SAHRA has had major displays include:

- Arizona Hydrologic Society (2000 and 2001);
- New Mexico Annual Water Conference (Jan 2001)
- Annual AGU meeting (Fall 2000)
- National Climate Meeting, Annual AMS meeting, Albuquerque (Jan 2001)
- Arizona Science Teachers Convention, Phoenix (Oct 2000 and 2001)

Knowledge Transfer Activity	International Activities
Led by	Diana Liverman
Participants	

	Name and Organization
1	Paul Wilson, Agricultural and Resource Economics, U of Arizona
2	Juan Valdes, Civil Engineering, U of Arizona
3	Bob Varady, Udall Center, U of Arizona
4	Margaret Wilder, U of Arizona
5	Tereza Cavazos, U of Arizona

6	Nicolas Pineda, Colegio de Sonora
7	Jose Luis Moreno, Colegio de Sonora

Tereza Cavazos (postdoctoral fellow with ISPE/CLIMAS) completed a project on Climate and Climate Variability of the Conchos Basin, Chihuahua, Mexico. The abstract of the paper, that soon will be submitted for publication is as follows:

- The Rio Conchos basin lies in the arid/semiarid part of the Mexican state of Chihuahua, where major cities such as Ojinaga, Chihuahua, Camargo, Jimenez, Delicias, and Parral are growing rapidly due to increasing industrialization. Water supply management creates great challenges at the binational level, especially during times of extended droughts such as those of the 1950s and 1994-1998. Thus, understanding the climate of the basin, its variability and the possibilities for seasonal predictability are fundamental for water management and planning in the basin. In this paper we present the climatology and precipitation variability of the Conchos River basin and the Bolson de Mapimí referred here to as the Conchos-Mapimi region. Special attention is given to the possible atmospheric and oceanic factors responsible for extended droughts. It is found that the current atmospheric and oceanic anomalies are typical of those of extreme drought years over the study area.

SAHRA has worked closely with the Texas Center for Policy Studies (TCPS) to publicize their report on the Conchos http://www.texascenter.org/borderwater/rioconchos.htm and to provide input into follow up studies with TCPS and the World Wildlife Fund.

Paul Wilson has translated a thesis, "Irrigation Management Transfer in Mexico: A Preliminary Economic Analysis," by his graduate student, Sergio Mario Arredondo Salas, on economic impacts of privatization in selected irrigation districts in northern Mexico. It will be distributed by SAHRA as a bilingual publication.

SAHRA organized a panel and poster session on water at the Annual Conference on the US-Mexico Border environment in Tijuana in April 2001 that included several researchers connected with the SAHRA project including Nicolas Pineda of the Colegio de Sonora. Other speakers included Suzanne Michel from San Diego State University, Patricia Romero from the Autonomous University of Mexico, and Michael Choen from the Pacific Institute. The panel discussion focused on the impacts of the restructuring of water management in Mexico, the water crisis in the Rio Conchos watershed, the response of Sonoran municipios to new water institutions, and the prospects for binational river basin management councils. More than 400 representatives of non-governmental organizations, government agencies and universities from both sides of the border attended this conference.

SAHRA researchers Margaret Wilder, Nicolas Pineda, Jose Luis Moreno and Diana Liverman currently are revising a paper on the restructuring of water management in Mexico. This paper describes recent changes in Mexican water management and their impacts on local agricultural and municipal areas in Sonora, Mexico.

Margaret Wilder has completed a draft of her PhD dissertation on water in Sonora and has published two related articles:

- Margaret Wilder, 2000. The "New Water Culture" and Ejidal producers in the Yaqui Valley, Sonora. Estudios Sociales. Revista De Investigación Del Noroeste 10, no. 19.
- Margaret Wilder, 2000. Border Farmers, Water Contamination, and the NAAEC Environmental Side Accord to NAFTA.Natural Resources Journal, Fall2000, Vol. 40 Issue 4, p873

Soroosh Sorooshian, Juan Valdes and Gary Woodard presented three invited talks on March 30, 2001 at Universidad de Sonora, Dept. of Civil Engineering

- Opportunities in Professional Development: The New Master of Engineering Degree in Water Resources, Juan Valdes, Dept. Head, Civil Engineering
- Water Resource Issues in Semi-Arid Areas: Opportunities and Challenges of an Integrative Research Approach, Soroosh Sorooshian, Director, SAHRA

- Closing the Researcher - Stake-Holder Loop: Outreach, Technology Transfer, and Hydrologic Literacy, Gary Woodard, Ass't. Director, SAHRA

They also met with researchers to pursue joint research opportunities and to discuss a possible program for sending their faculty to the University of Arizona to pursue advanced degrees.

Diana Liverman has worked to broaden the international outreach component of SAHRA. She and Bob Varady will offer a one-day seminar to the Mexican National Water Commission in November 2001. In addition, she:

- Helped the UA Center for Latin American Studies establish a collaboration with Johns Hopkins University (Professor Margaret Keck) and several Brazilian Universities to investigate water management in Brazil. The UA effort is led by Dr Maria Carmen Lemos (assistant professor of Latin American Studies) and the overall project is likely to receive major support from the Hewlett and MacArthur Foundations.
- Worked closely with the IAI and the University of Miami to plan the 2001 Summer Institute for young scholars in the Americas which this year focused on "Water and Society". SAHRA was represented through an invitation to Professor Soroosh Sorooshian to be a guest lecturer. We have obtained a mailing list of participants to include on SAHRA databases and as a source of future contacts in Latin America.
- Chaired a search committee for the Department of Geography and Regional Development that was able to recruit an outstanding young scholar who focuses on environmental issues in Africa, including water. Dr. Simon Batterbury has just arrived at UofA from the London School of Economics and is willing to help us with any appropriate activities in Africa.

Knowledge Transfer Activity	Internal Information Sharing
Led by	Kyle Carpenter
Participants	

	Name and Organization
1	Jill Gibson, SAHRA
2	James Hogan, SAHRA
3	Gary Woodard, SAHRA

A number of searchable databases have been developed on the administrative (private) side of SAHRA's Web site to meet information-sharing and integration objectives. These include:

- a database of people associated with SAHRA;
- a projects database on all discrete research, education, and knowledge transfer efforts;
- a bibliography on the hydrology literature of the Rio Grande;
- digitized "classic" reference works;
- glossary of all terminology used in the various disciplines within SAHRA;
- annotated photo collections; and
- a calendar of SAHRA activities.

We also have developed a lending library of equipment to record digital photos, video, and audio of SAHRA-related activities.

Knowledge Transfer Activity	Web-based Information Clearinghouses
Led by	Kyle Carpenter, Gary Woodard
Participants	

	Name and Organization
1	James Hogan, SAHRA
2	Louise Shaler, SAHRA
3	Moji Agha, SAHRA
4	Brad James, SAHRA

SAHRA is developing comprehensive searchable databases of useful information for water managers, educators, and the general public. These include:

News Watch Service This Web site allows users to search for news items on water issues in semi-arid and arid areas by topic, date, and geographic area. Items are culled from over 100 Web sites, as well as press releases and reports being solicited from major water policy and research organizations. The items are summarized in English from their original languages (English, French, Spanish, Italian). The Web site highlights major breaking stories and offers shortcuts to the most recent stories in several topic areas.

Conservation Information A Web site aimed at both homeowners and water conservation professionals is being developed, with roll-out scheduled for the end of 2001.

K-12 curriculum Clearinghouse A searchable database on hundreds of K-12 water-related curriculum materials has been created. The user interface allows users to search for materials based on subject, media type, grade level, cost, and other factors. Intended for use by school teachers, the database also is being used to determine where SAHRA should focus new curriculum development efforts.

Rio Grande Bibliography The development of a bibliography for the Rio Grande has been recognized as an important resource for SAHRA researchers. We have begun compiling a bibliography using several existing bibliographies developed for sections of the Rio Grande basin. We have ~1000 references currently stored in the Endnote bibliographic program. We are making this database available over the website, and plan to add Web-based forms so researchers can both search and add to this valuable resource.

Rio Grande Historic Reports An outgrowth of our Rio Grande bibliography effort was the recognition of many historic reports on the Rio Grande. These reports provide a wealth of information about the past conditions (hydrologic, geochemical, and socio-economic) within the basin. These reports are difficult to obtain but are potentially very useful to many SAHRA and non-SAHRA researchers. In order to make these reports publicly available we have begun to scan, convert to pdf and post on our website these reports. Our initial effort focused on a 1938 report on Regional Planning of the Upper Rio Grande by the National Resources Council. In addition to scanning the entire report and converting it to PDF files, the associated maps were scanned, digitized and reproduced as well. Also, a searchable database on the 500+ tables, charts, photos, and other figures was compiled. All this information has been burned onto CDs and will soon be posted on the Web. We will post additional reports as they become known and available to us.

Isotopes and Hydrology We have begun an effort to develop an isotope hydrology information resource on the SAHRA website. This resource will consist of a clickable periodic table. When an element of interest is selected – say carbon – it would then link to a web page which would provide the basic information about that isotopic system as well as important hydrologic applications. For carbon it would have information about ^{12}C, ^{13}C and ^{14}C, how these isotopes are measured, how much it cost for an analysis and details about the major applications of these isotopes is in hydrology. We hope that this information will provide background information to complement isotopic research within SAHRA. The web page content is being developed by students in Brenda Ekwurzel's Isotope Hydrology class at the University of Arizona.

Virtual Field Trips At the USGS, Tucson, Stan Leake and Chris Duffy have collaborated on developing "virtual field trips" in the southwest for scientific, stakeholder and public use. The website for the Rio Grande: http://cataractis.cee.psu.edu/riogrande/, is a result of this effort.

Knowledge Transfer Activity	Recruiting the Next Generation
Led by	Gary Woodard, Jim Washburne, Julie Luft

Participants	
	Name and Organization
1	Alison Charney, Tucson High
2	Warren Grantham, Mountain View High, now UA College of Engineering
3	Jessica Jensen, Moutain View High, now UA College of Engineering
4	Chelsi Remme, Amphi High, now UA College of Engineering
5	Pavla Senkyrikova, Amphi High, now UA College of Engineering
6	June Sherlock, Dept. of Hydrology & Water Resources, UA College of Engineering
7	Grant Shreve, Amphi High
8	Melissa Tom, Tucson High, now UA College of Engineering

Very few young people enter college planning on a career in some water resources field. Rather, hydrologists, watershed scientists and others generally come to the field indirectly, from such disciplines as geology or environmental science. A related phenomenon is the dearth of challenging earth sciences courses at the high school level, and little enthusiasm by high school science teachers for integrating water resources-related curriculum materials in their existing classes.

SAHRA has targeted high school teachers and promising science students in an effort to increase the potential number and quality of young people entering water resources fields. These efforts include development of a K-12 water curriculum clearinghouse (discussed elsewhere), maintaining a listserv for K-12 science teachers in Arizona that are interested in water-related topics, beginning the development of a high school course on Water in Semi-arid Environments, and selected outreach activities to high schools with diverse populations.

The most fully developed effort to date is the Summer Program for Learning About Semi-arid Hydrology (SPLASH). This program recruited seven outstanding high school seniors and juniors from three high schools with diverse populations and exposed them to a summer of field work, lab work, and knowledge transfer activities.

The result of this program was an understanding of how diverse and challenging the fields of hydrology and water resource management are, and an appreciation of how "real" scientific research is planned and conducted. A significant side benefit of the program was the significant amount of assistance provided by the summer interns to our researchers in the field and in the labs.

All five graduating high school seniors are now freshmen in the University of Arizona's College of Engineering and are working as REU students on specific research projects. Four of them are women. The initial success of the SPLASH program has resulted in plans to repeat it next summer at a larger scale, and has provided insights on developing a challenging class in the science of water resources for the high school level.

Outcomes or Impacts

SAHRA is barely 20 months old, with many research activities begun just a year ago. Evaluating our activities in terms of significant impacts on water resource management is probably premature. Much of the scientific knowledge that results from our research is reflected in new or improved models of portions of the hydrologic cycle; these in turn will be integrated in basin-scale models. Education and knowledge transfer, including professional development, will then help turn these models into key elements of decision support systems and policy analysis tools.

To date, we see some signs that this strategy is feasible. The Nature Conservancy has expressed a desire to base future land purchases on SAHRA-provided groundwater/surface water models that predict the degree to which river flows and riparian vegetation will be protected or restored by changes in water uses. The New Mexico State Engineer's Office has asked that we enhance their URGWOM model through development of compatible dynamic simulation models that provide information on water quality variables, including salinity and dissolved oxygen . Other areas where DSMs are being developed or planned are the Verde River in

Arizona, the Conchos Basin in northern Mexico, and additional reaches of the Rio Grande in New Mexico and west Texas. These models not only integrate a variety of existing knowledge and new research findings, they also help to identify pieces of the hydrologic cycle or water budgets where future research is needed.

Plans

We will continue aggressively pursuing the goal of making SAHRA's Web site an information clearinghouse for several types of information critical to water resources managers in arid and semi-arid areas. Our water curriculum clearinghouse is a searchable database for K-12 educators. It will be modified so that it aligns with the NSF-funded digital library system, DLESE, and will be enhanced by adding critical reviews written by classroom teachers. Our K-12 focus is on high school science teachers and their most promising students, using summer internships, a high school water resources course that confers college credit, and targeted outreach to prime the pipeline that produces the next generation of water resource managers.

We will post for public use our conservation site, currently under development. The user interface has been designed to appeal to homeowners with only a casual, or passing interest in saving water, by being both visually appealing and entertaining, as well as useful and informative.

SAHRA will begin its Executive Training Program in Fall 2002 with a short course on Indian Water Rights. We also will begin policy briefings on selected topics.

We will seek creative ways to expand and leverage our new News Watch service. We hope to summarize Arabic and Farsi news stories, in addition to the current English, French, Spanish, and Greek. We will make more readily available the current knowledge base in the basins where our field research currently is concentrated by expanding our new bibliography of research materials on the Rio Grande, and identifying, digitally preserving and enhancing more key historical documents.

Internal KT will be enhanced by establishing identical videoconferencing facilities at the University of Arizona and three partner universities. These facilities will be made even more useful by our new on-line conferencing software, developed in-house. Both external and internal knowledge transfer will be enhanced by completion of our "projects" database.

V. PARTNERSHIPS

Partnership Objectives

Our partnership objectives are to form lasting relationships with universities, government research labs and agencies, commercial labs and consulting firms, state and local agencies with water management responsibilities, as well as NGOs and Irrigation Districts, to produce mutually beneficial interchanges of data, information, and human and capital resources and further our goal of improving the science of hydrology and water resources in ways that are useful. This includes giving stakeholders a key role in defining the scenarios that are coming to drive our research agenda. It also involves leveraging our resources through various creative arrangements with a variety of partners and cooperators.

Our overall objectives and plans have not changed significantly from a year ago.

Performance and management indicators are semi-quantitative at this point. We have observed a steady increase in the number of institutions who are approaching us with proposals for joint activities. A growing percentage of our projects are based on specific needs and interests of stakeholders. In the near future, we will be able to judge whether the outputs of our scientific and knowledge transfer efforts are producing decision support and policy analysis tools that are being used by water resources managers.

Problems

SAHRA has had numerous opportunities to partner with many diverse organizations. The challenge has been to manage the rate of growth, and bring new partners into SAHRA in a controlled way that leverages our resources, creates synergies for all concerned and contributes to integrating our activities.

Activities

Summary of SAHRA Activities with Other Institutions		
Institution	Relation[1]	Joint Activities, Shared Resources, Objectives
Arizona Hydrologic Society	Cooperator	This professional society for hydrologists co-sponsored a teacher hydrology workshop during its annual meeting in Sept. 2001.
Arizona Project WET (Water Education for Teachers)	Participant	We collaborate on hydrologic literacy efforts. WET has received SAHRA funds to catalog and enhance cooperative extension programs in Arizona and New Mexico. We will be sharing an education outreach coordinator and program manager with AZ Project WET.
Arizona State Univ, Biology Dept.	Partner	ASU researchers are heavily involved in TA3, the study of water, energy and nutrient fluxes in riparian systems.
Arizona Dept of Water Resources (ADWR)	Partner, Stakeholder	ADWR provided funding on the San Pedro Water Needs study; it is interested in most of our TA3 research results, as well as the TA5 rural domestic water demand work.
Audubon Society	Partner, Stakeholder	They are providing financial support and assistance for research on the water demand characteristics and conservation potential of rural "ranchettes", low-density housing with individual wells and septic systems.
Cal. State - L.A. CEA-CREST	Partner	TA2 has initiated a joint research effort with Dr. Hibbs with the goal of understanding the causes of groundwater and surface water salinization in the region around El Paso, Texas. A low-level scintillation spectrometer has been purchased with supplemental funds for joint use.
Canadian Natl. Water Research Institute	Cooperator	Dr Marsh has shared continuous high resolution micrometeorological data collected at his research sites. This provides additional case studies of the dynamics surrounding energy partitioning during snowmelt.
Canadian National Research Council	Cooperator	Provides SAHRA with spatial database for energy balance before, during and after snow melt season.
City of Taos	Cooperator, Stakeholder	Taos is cooperating in the effort to extend Up-per Rio Grande Water Operations Model (URGWOM).
City of Albuquerque	Cooperator,	Albuquerque is involved in the effort to extend Upper Rio Grande Water Operations

	Stakeholder	Model (URGWOM); GIS, Econ/Census
Cochise County, AZ Planning Dept.	Partner, Stakeholder	Cochise County is providing financial and technical support for a study of the water demand characteristics of domestic well owners in the upper San Pedro Basin.
Columbia University's Biosphere 2 Center	Partner	Our joint goal is to improve the hydrologic literacy of visitors through collaborative efforts to develop display and tour materials that contrast the unique hydrologic aspects of Biosphere 2's and Southern Arizona's environment. This is a non-profit science and nature center.
GLOBE Program	Participant	We promote authentic science and research through support and encouragement of GLOBE teachers and training in our area of interest, and share some staff support. GLOBE is an International K-12 environmental monitoring and science education program.
Grayhawk Ranch Nature Center	Cooperator	The Ranch has allowed us to perform TA3 research on its privately owned ranch along the San Pedro River.
Harvard University, School of Design	Partner	We have jointly produced a unified hydrological, ecological and landscape architectural model (Alternative Futures) that acts as a cornerstone for a DSS for San Pedro Basin.
Instituto del Medio Ambiente y el Desarrollo Sustentable (IMADES)	Partner, Stakeholder	We are jointly working to refine a groundwater simulation model of the Mexican potion of San Pedro River Basin. Twice a year we meet with a representative of IMADES (Mexican Environmental Agency) in Cananea, Sonora, to conduct fieldwork in northern Sonora. Through IMADES, access was gained to sections of our field area inside Mexico.
Instituto Mexicano de Tecnologia del Agua (IMTA)	Partner, Stakeholder	We are jointly analyzing and modeling the frequency and areal extent of drought in the Conchos Basin of northern Mexico. We just started development of a dynamic simulation model of the basin's system of reservoirs. IMTA, the Mexican equivalent to USGS, has provided data, reviews, and expertise on the topic of hydrologic technology. They are interested in impacts of privatization of irrigation districts.
International Atomic Energy Agency (IAEA)	Partner	Our main points of collaboration currently are through participation in a working group on "Isotopic indicators of sustainability in groundwater systems" and through incorporating the Rio Grande basin study into the IAEA river basin program. This program is aimed at using isotopic mass balance techniques for studying basin scale water and solute balances.
International Boundary and Water Commission (IBWC)	Stakeholder	Previous U.S. commissioner serves on SAHRA's Advisory Board. IBWC is interested in research involving border waters, including the middle and lower Rio Grande, the Conchos Basin, and the upper San Pedro River.
Korea University, Dept. of Environ. Engineering	Cooperator	Dr. Chulsang Yoo has collaborated in the area of drought characterization and is one of the co-authors of a paper in preparation.
Los Alamos National Laboratory (LANL)	Partner	LANL is heavily involved in TA4 activities, modeling basins as appropriate scales, and provides SAHRA with supercomputing capabilities and expertise. Development of a virtual watershed model linking climatic, surface runoff, and groundwater models, is a top priority.
Middle Rio Grande and Estancia Water Assemblies	Stakeholder	These water resource managers are interested in our TA2 research.
NASA/GSFC GLDAS	Cooperator, Stakeholder	They provide precipitation data in the land surface data assimilation.
NASA Regional Earth Science Application Center (RESAC)	Partner	This NASA Center, also located at UA-HWR, works closely with TA1 and provides snow coverage data and other in-kind services to SAHRA.
NASA	Cooperator, Stakeholder	Instantaneous satellite imagery and instantaneous rainfall data for TA1 model simulation. The generated precipitation data will be used in the data assimilation into numerical weather prediction model. Provided funds to SAHRA.
National Park Service (NPS)	Partner, Stakeholder	NPS has provided partial funding for lab supplies, sample collection, and postdoc salary.

New Mexico Office of State Engineer	Partner	This office has provided us with funding to conduct supporting soil hydrological research for an ongoing ET study as part of TA2.
New Mexico Dept of Environ. Protection	Cooperator, Stakeholder	They assisted effort to extend the Upper Rio Grande Water Operations Model (URGWOM). Effort to model dissolved oxygen, dissolved solids in Upper Rio Grande.
New Mexico Master of Science Teaching Program	Participant	They hosted a summer workshop for teachers in hydrology and are helping to coordinate a High School Rio Grande sampling network. They are a state-wide science teacher professional development, training and support organization. SAHRA paid two trainers for the summer workshop and is supplying participant support for Rio Grande monitoring effort.
New Mexico Bureau of Mines and Mineral Resources	Cooperator	Their ion chromatograph has been used for aqueous geochemical analyses in support of TA2 research.
New Mexico Institute of Technology (NMT)	Partner	NMT is a major contributor to solute and salinity balance studies in TA2. They are measuring stable Cl isotopes in vadose zone chloride, and investigating climatic effects of grassland conversion to scrubland. They are starting study to quantify mountain block recharge rates and processes.
New Mexico Interstate Stream Commission (NM-ISC)	Participant, Stakeholder	NM-ISC is interested in collaborating with TA2 researchers on Rio Grande salinity issues, as well as on other riparian issues through researchers in TA3. Drilling of well transects is to begin this November. We anticipate active collaboration by next summer. NM-ISC recently funded a study to investigate groundwater – surface water interactions in the riparian corridor of Socorro reach of the Rio Grande to improve understanding of water flowpaths and mass balance within this reach. The goal is better management of river flow to sustain the endangered Silvery Minnow.
NOAA Atmospheric Turbulence and Diffusion Div (ATDD)	Cooperator	ATDD participated in the a set of reconnaissance field trips to potential study sites for the TA1 EC tower. ATDD has also provided, through the NOAA lab, the soil temperature probes deployed at each of the micrometeorological stations and the EC tower site on Mt. Bigelow.
Northern Arizona Univ.- Forestry Dept.	Partner	This partner is doing pilot projects looking at salinity issues with Hopi and monitoring Verde River watershed.
Northern Arizona Univ./ITEP/EEOP (NAU)	Partner	This environmental outreach program affiliated with NAU trains, supports and mentors Native American teachers in the Four Corners region. Training has been through GLOBE and Project WET. Received SAHRA funds, assistance.
Oregon State Univ. - Atmospheric Sci.	Participant	Dr Mahrt is installing a network of thermistors at the Mt Bigelow study site to measure soil temperature.
Penn State Univ.	Partner	Chris Duffy is involved in TA2 efforts to model the genesis of groundwater. Also has developed educational “virtual field trips” of middle Rio Grande.
Salt River Project - Hydrology Off (SRP)	Partner, Stakeholder	SRP provides an internship and operational expertise to SAHRA. It benefits from TA1 snow products that provide operational guidance in its watershed.
Sandia National Labs Geohydrology Division (SNL)	Partner, Stakeholder	SNL is funding a SAHRA fellowship and is working jointly with us on a dynamic simulation model of the Albuquerque basin in the middle Rio Grande. Other areas of possible joint work are being explored, including sensor technology.
Scripps Institution of Oceanography	Partner	Scripps consulted on 32Si method development, and has been a valuable resource for answering questions that have arisen during the adaptation of the extensive chemical separations to extract 32Si from water and soil samples.
Sevilleta LTER	Partner	Sevilleta LTER researcher William Pockman (UNM) contributed one month of time to the drought plot study, and will continue in this capacity in the future. LTER also provided additional financial support for infrastructure design and construction; and two summer REU students and support.
State of Arizona	Partner, Stakeholder	Through a sales tax initiative, the State of Arizona has new education funds, some of which are provided to the University of Arizona to enhance critical areas. One area receiving additional funds is water resources. SAHRA is directly receiving funds to increase research and knowledge transfer, and is managing other shared funds for a joint water education program.

The Nature Conservancy (TNC)	Partner, Stakeholder	TNC has granted us access to sections of land in our TA3 field area in Arizona. They also provided our project with maps detailing land ownership is the San Pedro River Basin. In September 2001, they committed funds to develop a groundwater/surface water model for the middle and lower San Pedro. These models help TNC select lands for purchase and water rights retirement and aid in restoration of riparian habitat in the lower San Pedro.
U.S. Army Corps of Engineers - CREL	Partner, Stakeholder	CREL provided funds to SAHRA for TA3 research. Interested in SAHRA's Alternative Futures modeling efforts.
U.S. Bureau of Reclamation (USBR)	Partner, Stakeholder	USBR has provided us with funding for the detection of salinity sources in the Mesilla Valley. Another USBR office has provided funding for development of low-cost data logger and sensor technology for disaggregating and quantifying domestic water demand. A third USBR office has provided partial support, through Yuma County Cooperative Extension, for development of a water conservation Web site.
U.S. Geological Survey - Water Resources Division	Partner	SAHRA has received office space, research equipment, transportation, and other needs for several science questions within TA 3. The USGS has instrumented several vegetation study sites with continuously recording ground water monitoring wells and stream stage recorders. USGS is also conducting a critical review of San Pedro River basin aquifers we will use. Also has provided soil cores for ^{32}Si project.
U.S. Geological Survey	Stakeholder	SAHRA provides daily precipitation data over Africa, Middle East, and South Asia for flood and drought assessment. Joint MMS/PRMS modeling efforts with TA1.
U.S. Army - Ft. Huachuca	Collaborator, Stakeholder	Collaborating on a vegetation and stream reach mapping project of the Upper San Pedro Basin located in the San Pedro National Riparian Conservation Area. Providing 2 ecological study sites on their base.
U.S. Bureau of Land Management	Stakeholder, Cooperator	Cooperation with the BLM has allowed our project access to land in the San Pedro River National Conservation Area (SPRNCA). This has greatly benefited TA3 work.
UA Dept. of Hydrology and Water Resources (HWR)	Partner	SAHRA and HWR have split funding of various infrastructure, faculty, and students.
UA Geosciences - Isotopic Lab	Partner	Joint effort to measure stable Cl isotopes in vadose zone chloride; to measure stable Cl isotopes in cores from the San Pedro valley, with the aim of distinguishing diffusive from advective movement of solutes. Also, Eastoe is contributing time and partial analytical costs to Wirt's project on the origin of groundwater in Chino Valley, near Prescott, where urban use of groundwater is being challenged by other interests. As part of the project, we are making seasonal tritium measurements on rain.
UA NASA/Raytheon HYDIS	Stakeholder	HyDIS provides global precipitation data to the research groups, especially TA1, and public users.
UA Physical Research Lab, Dept. of Space	Cooperator	Consultation for 32Si method development. Has been a valuable resource for answering questions that have arisen during the adaptation of the extensive chemical separations to extract 32Si from water and soil samples.
University of California - Riverside Environmental Sci.	Partner	Soil cores taken at the four micrometeorological stations and the EC tower on Mt Bigelow will be analyzed at the Riverside Salinity Lab, providing us with information necessary for estimating the runoff/infiltration portion of the water balance. Other sharing of equipment and data resources.
University of Nevada – Desert Research Institute (DRI)	Partner	DRI researchers Joe McConnel and Doug Boyle are involved in TA1 snowpack research.
University of New Mexico, Econ. Dept.	Partner	Researchers at UNM are involved in several Thrust Area 5 projects, including estimation of non-market values of water, experimental economic approaches to revealing demand curves, and value of instream water uses.
University of New Mexico - Earth Data Analysis Ctr (EDAC)	Partner	Together with the EDAC we work on the use of remote sensing images for determination of regional distribution of actual evapotranspiration and soil moisture contents using the SEBAL algorithm. In-kind data support.
University of California – San	Partner	John Roads leads the Experimental Climate Prediction Center and lends his expertise to TA1 and TA4. Improved mesoscale climate modeling for the southwest

Diego Atmos. Sci.		is a high priority.
University of California – Los Angeles CEE	Partner	Bill Yeh is involved in TA5 development of decision support tools for water system operators.
Upper San Pedro Partnership[2]	Partner, Stakeholder	The USPP is leveraging funds, resources, and expertise for research activities. They represent the principal stakeholders involved with activities in TA3 work along the Upper San Pedro River.
US Environmental Protection Agency - Water Office (EPA)	Participant, Stakeholder	An EPA STAR grant sponsored the investigation of the effects of water table declines on sap flow in riparian habitat. We shared equipment, provided student assistance for field work. Experiment allowed for simultaneous and complementary research to occur.
USDA Agricultural Research Service	Partner, Stakeholder	ARS personnel are heavily involved in TA3. We provide ARS with information on vegetation structure at sites they are measuring for rates of riparian evapotranspiration. They also are interested in the relationship between ecological site characteristics and the hydrologic response, part of the research agenda of TA1. There is considerable sharing of equipment, and joint field work.
USDA - Natl. Forest Service, Catalina Ranger District	Cooperator, Stakeholder	The micrometeorological installations on Mt. Bigelow will provide the Forest Service fire management department with spatially distributed temperature and humidity data needed to predict forest fire risk. Jointly developing interactive educational kiosk at recreational center.
USDA/NRCS	Partner	They are modifying Rosetta to predict drainable porosity from data in NRCS databases with neural network models, in support of TA1 work.
White River Apache Tribe	Partner	Laurel Lacher, Tribal hydrologist, has developed outside funding through EPA and other sources to coordinate and operate a two-week summer workshop for the professional development of tribal environmental specialists. A significant amount of this training is watershed based. SAHRA funded five watershed workshop scholarships in 2001.

[1] Definitions of relationships:

Partners	have a contractual agreement with SAHRA (with cash or in-kind financial support).
Participants	have a level of involvement with SAHRA activities and events that exceeds 160 hours per year, but have no contractual relationship.
Cooperators	have a level of involvement with SAHRA activities and events that does not exceed 160 hours per year.
Stakeholders	are interested in, and benefit tangibly from SAHRA activities.

[2] Upper San Pedro Partnership consists of the following members:

Arizona Dept. of Environmental Quality
Arizona Dept. of Water Resources
Audubon Society
Bureau of Land Management
City of Bisbee
City of Sierra Vista
Cochise County
Hereford NRCD
Huachuca City
The Nature Conservancy
U.S. Army - Ft. Huachuca
USDA-ARS-SWRC
US Forest Service

Outcomes or Impacts

Not enough time and experience has accrued to be able to draw many conclusions about overall impacts of our diverse partnership activities.

Plans

There are no plans or goals to continue expanding partnerships indefinitely. The rapid growth phase in which we currently find ourselves may level off after another year or so. We expect that some of our partnerships will grow and intensify, while others will wane, depending on the benefits derived by each party.

VI. DIVERSITY

Many of SAHRA's objectives are aimed at improving the current state of water management and operations throughout our areas of interest, which are focused on the southwestern U.S. and Mexico. Our efforts are directed at improving the state of the science as well as the practice of science. As a result, a key group of our stakeholders consists of water managers and officials responsible for water operations or policies. While no firm statistics are available, we believe that the key diversity needs in these positions will most likely be filled by women, Hispanics and Native Americans.

Objectives

SAHRA's primary diversity objective is to improve the hydrologic literacy and technical ability of tribal members and agencies. This is because of the importance of the developing tribal sovereignty, and control over many critical water supply and water quality issues, that confront the tribes throughout the southwest. Our strategy is to focus on career pathway development from the K-12 level to the University system through teacher workshops, summer programs, undergraduate internships, support networks and graduate study.

Similar programs are in place in the area around our centers of research for local high school students, which have the potential to recruit into our program the predominately Hispanic student population that characterizes these schools. Recent departmental and SAHRA statistics reveal a significant number of women are naturally attracted to this field (35% and 25%, respectively). We will monitor this participation rate and try to increase SAHRA's percentage of women graduates.

A third and newest diversity initiative is related to a collaborative GLUE supplementary grant between SAHRA and CEA-CREST, centered on the campus of Cal. State – LA. We expect this collaborative effort will give our projects greater visibility and recruiting potential from this diverse and similarly focused junior college.

Performance and Management Indicators

All of our programs will attempt to gauge the level of participation from under-represented communities. Many of our educational efforts are focused on particular interest groups or have a high potential to benefit the diversity targets identified above. Every effort will be made to encourage the recruitment of a diverse student and intern population from each partner. Most of our programs are too new to provide specific diversity statistics, except for the information collected from graduate students and researchers, which certainly reflects a significant percentage of women in these positions.

Problems

Native American students have many demands placed on them and face significant social and cultural barriers to completing a formal graduate degree in a natural science, such as hydrology. While we do not have any simple solutions to these well-documented issues, we plan to work closely with the small number of students we have to provide the support and encouragement to continue in this field.

Contributions

It should be obvious how all the education and knowledge transfer programs described in earlier sections relate to our diversity objectives. The most prominent efforts are outlined below:

- K-12: We begin with focused teacher workshops on reservations (EEOP/ITEP outreach) and in largely Hispanic communities (Biosphere 2's Passport to Learning about water sustainability, the SAHRA/GLOBE collaboration and Community Service opportunities) to bring basic hydrologic literacy and to build life-long interest in water issues. This is facilitated through our coordination of the Water Educators Roundtable of Southern Arizona.
- Pre-college: Our focus is on AP-level college-credit hydrology courses (HWR101C), water and science research training for teachers (HWR599L) and pre-college summer internships for high school seniors (HS Intern program). These programs attract many Hispanics and women.
- Undergraduate: We are building basic hydrologic literacy among the diverse body of non-science undergraduates (HWR203). Further, we are encouraging more technically competent students (honors

intern program) and students specifically interested in hydrologic sciences (REU, FOR340). We will try to recruit native American students into some REU positions next summer.

- Graduate: Our graduate program draws students from around the world but we pay particular attention to underrepresented students with strong academic and related experiences. We expect our collaboration with Cal State LA (CEA-CREST) will be particularly useful in this regard. Although NSF does not place a great emphasis on the professional education of non-US students, SAHRA believes part of our mandate is to help meet this critical future need, particularly for students from less-developed, semi-arid countries. To help meet this need, we have a significant fellowship program funded by the World Lab. We expect to work closely with our diverse student body to progress through their degree programs.
- Professional Development: We are just starting to focus professional development efforts on specific communities (Tribal Watershed workshop). Our research workshops are also likely to attract a diverse number of working professionals and other stakeholders.
- Web Site: Our web site does not target specific audiences but is certainly available to a every member of the community. Significant portions of the site are available in both English and Spanish.

Plans

Our plans for the next year are to better assess how the array of programs described above are functioning and work on developing better contacts, particularly at the community and junior college level.

Impact

The following table summarizes the diversity of SAHRA participants:

	Gender		Race/Ethnicity				Citizenship			
	Male	Female	Hispanic	Asian	Native American	African American	Non U.S	Perm. Resident	Total	
Faculty	29	12	2	4	0	0	3	0	41	21%
Staff	6	6	1	0	0	0	0	0	12	6%
Grads / PD	80	35	7	21	2	1	36	7	115	60%
UG / HS	9	16	3	1	0	1	1	2	25	13%
Total	124	69	13	26	2	2	40	9	193	
	64%	36%	7%	14%	1%	1%	21%	5%		

VII. MANAGEMENT

Organizational Strategy & Structure

Overall SAHRA planning is conducted by the Executive Committee (EC) consisting of 13 members (see below), including the leaders of the individual thrust areas. The EC is responsible for setting the vision and goals of SAHRA and for overseeing the planning and coordination of the science, education and outreach activities. The executive committee meets once a month by phone conference, with every third meeting being held in-person at the University of Arizona. Decision making is by consensus with ultimate authority and responsibility carried by the Director and Deputy Director. Coordination and integration within and across the Thrust Area science activities is carried out by the TA leaders mentioned above with the major assistance of the TA postdoctoral research associates (PDRAs). The group of PDRAs constitutes a kind of “shadow” executive committee which is extremely important to achieving the goals of planning, critical self-review, cross-disciplinary integration, and coordination with other non-SAHRA funded projects and activities. The postdoctoral research associates meet as a group with Gupta, Woodard and Washburne approximately 1-2 times per month, and weekly when major issues come up. Major ideas and initiatives that emerge are presented before EC for discussion and approval. External advice and oversight is provided by the (currently) eight member External Advisory Board. The EAB meets at least once per year to provide feedback to the executive committee. Administrative affairs are managed primarily by Associate Director with assistance from the two Assistant Directors and the (currently) 6 person administrative support staff. The administrative staff meet weekly. These meetings are also attended by one or more postdoctoral research associates. The individual TA activities are coordinated by the relevant TA leader and postdoctoral research associate via email and regular TA meetings.

In addition, several SAHRA wide “issue” workshops and meetings are held each year to bring researchers together across disciplines. Finally, all SAHRA scientists, students and stakeholders gather once a year at the annual meeting (held each spring) to meet and get to know each other, share and discuss scientific results, and conduct center-wide discussion and planning.

The major change in the Center organization during the past year is mainly one of evolution. The concept of having a science coordination group of PDRAs had already been developed during year one, but the recruitment of the young scientists to fill those roles was only accomplished during the past 12 months.

Executive Committee: Soroosh Sorooshian (UA, Director), Roger Bales (UA, Deputy Director, Leader TA1), Hoshin Gupta (UA, Associate Director, Science and Administration), Gary Woodard (UA, Assistant Director, Knowledge Transfer and Outreach), James Washburne (UA, Assistant Director, Education), Fred Phillips (NMT, Leader TA2), David Goodrich (UA/USDA-ARS, Leader TA3), Larry Winter (LANL, Leader TA4), Juan Valdes (UA, Co-leader TA5), David Brookshire (UNM, Co-leader TA5), Julie Luft (UA, Leader TA6/Education), Diana Liverman (UA, International Cooperation), and Stan Leake (USGS).

Post-Doctoral Research Associates: Constance Brown (TA1), James Hogan (TA2), John Villinski (TA3), Luis Bastidas (TA4), and Anne Browning (TA5). Coordination and integration assistance is also provided by postdoctoral researcher (at large) Martha Whitaker.

External Advisory Board (see also section 3 below): Kenneth Schmidt (Ken Schmidt and Associates, EAB Chair), Susan Avery (CIRES), John Bernal (Pima County Public Works Dept.), Peter Eagleson (Massachusetts Institute of Technology), Charles Howe (University of Colorado), Devendra Lal (Scripps Institute of Oceanography), Harold Mooney (Stanford University), and Peggy Woods (Amphitheatre High School).

Center Administrative Staff: Rannie Fox (administrative assistant), Jill Gibson (business manager), Kyle Carpenter (communications specialist), Gabriel Lopez (accountant associate), John Petti (research specialist), and Steven Schroeder (systems support analyst), and several work-study student helpers. Additional administrative support is provided by Corrie Theis (Administrative Associate to Sorooshian), and Cas Sprout (Administrative Assistant to Bales).

Organizational & Management Problems

We have experienced five major organizational/management challenges during the first two years of existence of the Center. These problems and how we have successfully tackled them are discussed below.

A) Tight Schedule - Balancing Responses to NSF With Setting up a Center:

This can be described as the problem of the four R's - recruiting, rooms, research, and reports. Recruiting of scientific, technical and administrative staff took considerably longer than anticipated. As a result, several Center-based activities have been late in getting off the ground. Some of the PDRA's were not identified and hired until the second year, thereby delaying implementation of the science coordination activities. However, since these personnel have been put in place, considerable progress has been made. An editor has yet to be recruited, and as a result the SAHRA newsletter has yet to be published. We anticipate resolving this issue within the next three months. The issue of space took considerable time to resolve. Because of the need to renovate and furnish the facilities for SAHRA postdocs, students and technical staff, we were only able to move in towards the end of the first reporting period.

The issues of research and reports are closely related. For the first six months, much of the management team's time was devoted to establishing SAHRA as an entity and putting appropriate infrastructure support in place, while also responding to NSFs requests for reports and information. The latter was responsible for serious challenges to staff morale. As a result, it was not until after submitting the first annual report on August 1, 2000 that the executive committee was able to seriously begin to address the important issues of science planning and coordination. With the hiring of PDRA's this reporting burden can now be spread among more people.

[Recommendation to NSF: A minimum 12 month moratorium on NSF requests for information and reports be implemented at the time of funding of a new center, to enable the fledgling center to find its feet].

B) Communication & Coordination:

Although the executive committee had been meeting fairly often during the first six months, it was not until after about October 1, 2000 that we were able to settle down to a regular schedule of meetings and discussion of matters other than administrative or responding to NSF concerns (see item A above). The lack of a proper conferencing facility (due to University renovation delays) aggravated the problem. However, this problem has been largely resolved during this past 12 month period and communication and coordination is now functioning well.

C) Financial Management & Budgeting:

The primary problem we encountered was the lack of compatibility of the financial reporting structure provided by the University with that required to properly manage the Center. Book-keeping is complicated by multiple sources of funding in addition to NSF. We therefore had to design and implement our own shadow book-keeping system which took almost 6 months and is still being refined. However, we are now able to provide the executive committee with monthly expenditure reports broken out by thrust area, and have the structure required to enable the annual budget projections required. Of course, further budgeting complications are caused by expanding science interests and increasing salary rates that could not have been properly anticipated during writing of the proposal. We have therefore already been forced to explore additional sources of funding including proposal writing and from the state.

One additional problem should be mentioned - several investigators reported experiencing problems with other funding proposals being apparently jeopardized by their association with the NSF STC. Some investigators expressed this fear as a reason for choosing to not becoming closely associated with the Center.

[Recommendation to NSF: Financial computing software appropriate to the STC organizational structure – multiple thrust areas, multiple investigators & multiple funding sources – should be designed and made available to new STC business offices, along with training].

D) Over-commitment:

In the beginning, it took some time for both senior personnel and individual investigators to adjust to the new "Center" way of doing business. Key Center personnel, namely the members of the executive committee, were already over-committed and the financial rewards of Center involvement are not considerable when weighed against the responsibilities. Because of the effort required for start-up activities, it took some time for the benefits of working with the Center to be realized, for camaraderie to be established, and for the excitement that comes from being part of something "new and bigger" to set in. Fortunately this problem was recognized at an early stage, and the plan was established to hire young and energetic postdoctoral research associates to help with science coordination, as well as the more mundane tasks of soliciting information and preparing reports. Now that the major PDRA positions have been filled, the workload for the executive committee seems to have become manageable.

[Recommendation to NSF: Ensure that the problem of over committed investigators and plans for addressing the problem be discussed with PIs during review of the proposal].

E) Integration & Coordination:

Almost from the time that the award was announced, and before the Center had a chance to become organizationally and structurally established, considerable pressure was placed on the executive committee by the NSF oversight team to respond with plans for "integration" of Center activities. This expectation by NSF was premature, given the work that had to be done to set in place the main structural components of the Center, and the time needed by scientists to adapt to the "Center way" of doing science.

It was not until early this year, and in particular after the first annual meeting in (February 2001) that it became feasible to give serious formal consideration to planning of integration and coordination activities. A committee on integration was formed to review the overall structure of science activities (see Section 2 below). The committee met weekly over a period of about three months and prepared a draft report which recommended some structural changes within each TA. Based on the recommendations of this report, several meetings were held to work on coordination issues within TA4 and TA5. As a result, most of the major thrust area coordination and communication issues appear to have been resolved. Further, the committee identified areas of development and planning that need to be addressed by the executive committee and the administrative staff – namely development of an integrated knowledge base, and development of a scenario model to more closely link SAHRA activities to regional policy and decision making concerns.

As far as the next reporting period is concerned, we do not anticipate any major management problems. As mentioned above, the main challenges will be to a) establish the knowledge base as a strong foundation linking the research, education and knowledge transfer efforts, b) continue work on the scenario and integration models, using this process to bring about even greater cohesion and direction within SAHRAs activities, and c) implement a process of project review to phase out some activities and bring in new ones.

Management and Communication Systems to Bring about Integration

During the first reporting period, efforts to bring about integration were mainly handled by the Executive Committee and the central administrative staff. Integration of SAHRA physical science activities has always been good, due to the fact that the proposal preparation process was done from the "ground up", using large numbers of meetings and consensus building procedures. Further, more than 50% of the scientists had already been working together in multi-disciplinary fashion on issues related to the San Pedro basin under the NASA EOS and SALSA projects. In addition, it had already been decided to actively recruit a group of young and energetic postdoctoral research associates to assist the TA leaders in management and coordination of each TA. These PDRAs were placed together in a specially constructed office suite to facilitate close working relationships and coordination of activities.

Feedback provided to SAHRA at the first annual meeting by the EAB and NSF oversight team suggested that a more formal procedure to foster integration was required and, in particular, that special attention was required in the aspects of integrated modeling (TA4), and integration of the physical and behavioral sciences (TA5). In response, a special *committee on integration* was formed, led by the Associate Director, Hoshin Gupta, and consisting primarily of the five thrust area PDRAs, selected members of the EC, and postdoctoral research associate Martha Whitaker (committee coordinator and secretary), to review the overall structure of science activities. The committee met weekly over a period of about three months, reviewed the critiques provided by the EAB and NSF, developed a conceptual model for integration of SAHRA activities, and prepared a draft report (to the executive committee) which recommended some structural changes within each TA. Based on the recommendations of this report, several meetings were held to work on coordination issues within TA4 and TA5.

The EAB/NSF critique of TA4 had to do primarily with the (over) emphasis on only high performance computing, while the critique of TA5 had to do primarily with the poor coordination and communication between the physical and behavioral scientists. The TA5 coordination and communication issues were largely resolved at a pivotal TA5 workshop hosted May 9-10, 2001 by the University of New Mexico, and the new structure and objectives of TA5 are reflected in this annual report. The TA4 issues were largely resolved at a

TA4 workshop hosted September 20-21, 2001 in Albuquerque by Los Alamos National Laboratory, and the new structure and objectives are also reflected in this annual report.

It should be mentioned that the linking of a senior researcher with a junior scientist (PDRA) to lead and coordinate the activities of each TA, and the incorporation of the PDRAs into the analysis and planning activities of the Center has been an unqualified success, resulting in extremely high morale and enthusiasm for participation. In particular it has had the synergistic impact of bringing together the experience and perspective of senior scientists with the creative energy of younger scientists in a way that is creating considerable enthusiasm for SAHRA as an enterprise dedicated to the public good.

In addition to the structural TA changes, the committee identified two important points that need immediate and ongoing attention. One is the need for development of a coordinated “knowledge-base” to support and inform SAHRA science, modeling, education, and knowledge transfer activities. The knowledge base will consist of data, models, documents, histories, graphics etc. collected or developed by SAHRA researchers, as well as other data, documents models etc., needed to support SAHRA science and modeling activities. This is a bigger task than had been previously imagined (it had not even been budgeted for) and we have begun to design a proper strategy to handle it. The decision has been made to have our Communications Specialist, Kyle Carpenter, oversee this effort, and to hire two additional database support staff. One position will be filled by diverting our systems support analyst, Steven Schroeder, to this task and we are recruiting a new person to replace him as computer support. The second database person will be recruited later as the system is developed. The design and development of the knowledge-base will be a major component of our activities over the next two years.

The second important point identified by the committee on integration, is the need for dialog within SAHRA and with stakeholders and policy makers, to develop a clear set of scenarios that will drive the integrated science and modeling activities from the “top-down”. This dialog has been initiated at the executive committee level and has given rise to a preliminary scenario model that complements the conceptual integration model mentioned earlier. The Deputy Director, Roger Bales will be leading further development of the scenario model during the next several months. The immediate goal is have the details of the integration and scenario models fully worked out in time to be presented at the second annual meeting in February 2002.

External Advisory Board (EAB)

	Name	Affiliation
1	Susan Avery	CIRES
2	John Bernal	Pima County Public Works
3	Peter Eagleson	Massachusetts Institute of Technology
4	William Harris	University of South Carolina
5	Charles Howe	University of Colorado at Boulder
6	Devendra Lal	Scripps Institute of Oceanography
7	Harold Mooney	Stanford University
8	Kenneth Schmidt	Kenneth D. Schmidt & Associates
9	Peggy Woods	Amphitheater High School

Changes to Centers’ Strategic Plan

There have been no major changes to the SAHRA strategic plan during this reporting period. There have been small evolutionary changes to the organizational structure (as described above) emerging mostly in response to people learning how to work together in the “Center” context.

VIII. CENTER-WIDE OUTPUTS AND ISSUES

PUBLICATIONS

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Washburne, J., Woodard, G., Carpenter, K. and Luft, J., Improving hydrologic literacy and the web, Presented at: 81st AMS annual meeting, 10th symp. on Edu., Albuquerque, NM, Mon. Jan. 15, 2001.

Williams, D.G., Response of desert riparian ecosystems to potential changes in climate, presented at the USGS workshop: Predicting hydrologic, geologic, and biologic responses to a drier and warmer climate in the desert Southwest, Tucson, AZ, 2001.

Wilson, J., Hydrology Research at New Mexico Tech (SAHRA research featured). Presentation to New Mexico Legislative Finance Committee staff. July, 2001.

Woolslayer J., P.R.H. Neville, C.K. Bales, L. Winter, E. Small, J.B.J. Harrison, and J.M.H. Hendrickx, Monitoring regional soil moisture and evaporation using remote sensing, Soil Science Society of America, Annual Meeting, Minneapolis MN, 2000.

Awards and Honors

	Recipient	Award Name	Awarded By	Date
1	Noah Molotch	J.E. Church Memorial Award, Best student paper	Western Snow Conference	April 2001
2	Patrick Ellsworth	Beckman Scholar		2000-2001
3	Fred Phillips	O. E. Meinzer Award	Hydrogeology Division of the Geological Society of America	2001
4	Kevin Dressler	Best Student Poster Presentation	El Dia del Agua, University of Arizona	April 2001
5	Tim Bardsley	2-yr EPA STAR Graduate Fellowship	EPA	June 2001
6	Juan Valdes	Honorary member	Italian Association for Hydrotechniques	2001
7	Juan Valdes	Fellow	American Geophysical Union	2000
8	Roger Bales	Fellow	American Geophysical Union	2001
9	Hoshin Gupta	Keynote Speaker, Penman Lecturer	British Hydrological Society	Sept. 2000
10	SALSA team; Goodrich, Sorooshian, Maddock, etc.	USDA Secretary of Agriculture Honors Award	U.S. Department of Agriculture	2001
11	SAHRA staff	Staff -TEAM Award for excellence	College of Engineering and Mines, Univ of Arizona	2001

Center Graduates

	Student Name	Degree(s)	Years to Degree	Placement
1	Savyasachi Srinivas	MS	2	Lockhheed Martin

Patents, Licenses, and Start-Up Companies
It is too early to report significant accomplishments in the area of intellectual property rights and spin-off economic activity. Furthermore, the kinds of products that SAHRA is working to produce – data sets, integrative models, and other decision support tools – are more in the nature of public goods, and not patentable. Our goal is to have these outputs be used by agencies and other water resource management institutions, and we will report success in these areas in future reports.

We have developed two software applications that allow PDAs to be used as data loggers for "event" sensors, including tipping rain gauges, anemometers with reed switches, some stream flow meters, and high-accuracy water meters. These are protected by copyright and may be offered via license, but this has not yet occurred.

Participants

	Participant	Category	Gender	Disability	Ethnicity	Race	Citizenship
1	Ackroyd, Stephen	Graduate student	M	None	Non-Hispanic	White	other non-US Citizen
2	Adeli, Roya	Undergraduate student	F	None	Non-Hispanic	Asian American / Pacific Islander	Permanent Resident
3	Agha, Moji	Other participant	M	None	Non-Hispanic	Asian American / Pacific Islander	US Citizen
4	Akporiaye, Alero	Undergraduate student	F	None	Non-Hispanic	African American	other non-US Citizen
5	Aparicio, Javier	Other research scientist	M	None	Hispanic	Hispanic	other non-US Citizen
6	Austin, Barb	Graduate student	F	None	Non-Hispanic	White	US Citizen
7	Bagstad, Ken	Graduate student	M	None	Non-Hispanic	White	US Citizen
8	Bales, Roger	Faculty	M	None	Non-Hispanic	White	US Citizen
9	Bardsley, Tim	Graduate student	M	None	Non-Hispanic	White	US Citizen
10	Bastidas, Luis	Postdoctorate	M	None	Hispanic	Hispanic	other non-US Citizen
11	Blattstein, Ayelet	Undergraduate student	F	None	Non-Hispanic	White	US Citizen
12	Blumenfeld, Hana	Graduate student	F	None	Non-Hispanic	White	US Citizen
13	Bowen, Sheila	Graduate student	F	None	Non-Hispanic	White	US Citizen
14	Boyle, Doug	Postdoctorate	M	None	Non-Hispanic	White	US Citizen
15	Brigham, Lindy	Faculty	F	None	Non-Hispanic	White	US Citizen
16	Brooks, Paul	Faculty	M	None	Non-Hispanic	White	US Citizen
17	Brookshire, David	Faculty	M	None	Non-Hispanic	White	US Citizen
18	Brown, Constance	Postdoctorate	F	None	Non-Hispanic	African American	other non-US Citizen

19	Browning-Aiken, Anne	Postdoctorate	F	None	Non-Hispanic	White	US Citizen
20	Burness, Stuart	Faculty	M	None	Non-Hispanic	White	US Citizen
21	Cable, William	Other research scientist	M	None	Non-Hispanic	White	US Citizen
22	Carpenter, Kyle	Support staff	M	None	Non-Hispanic	White	US Citizen
23	Charney, Alison	Pre-college students	F	None	Non-Hispanic	White	US Citizen
24	Chen, Ji	Postdoctorate	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
25	Chermak, Janie	Faculty	F	None	Non-Hispanic	White	US Citizen
26	Chief, Karletta	Graduate student	F	None	Non-Hispanic	American Indian / Alaskan Native	US Citizen
27	Colby, Bonnie	Faculty	F	None	Non-Hispanic	White	US Citizen
28	Conklin, Martha	Faculty	M	None	Non-Hispanic	White	US Citizen
29	Costigan, Kelly	Other research scientist	F	None	Non-Hispanic	White	US Citizen
30	Cui, Yifeng	Postdoctorate	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
31	DeSimone, Richard	Graduate student	M	None	Non-Hispanic	White	US Citizen
32	Dody, Avraham	Visiting faculty	M	None	Non-Hispanic	White	other non-US Citizen
33	Dolmar, Dan	Graduate student	M	None	Non-Hispanic	White	US Citizen
34	Dracup, John	Faculty	M	None	Non-Hispanic	White	US Citizen
35	Dressler, Kevin	Graduate student	M	None	Non-Hispanic	White	US Citizen
36	Duffy, Chris	Faculty	M	None	Non-Hispanic	White	US Citizen
37	Eastoe, Christopher	Other research scientist	M	None	Non-Hispanic	White	Permanent Resident
38	Edwards, Eric	Graduate student	M	None	Non-Hispanic	White	US Citizen
39	Einloth, Sharon	Graduate student	F	None	Non-Hispanic	White	US Citizen
40	Ekwurzel, Brenda	Faculty	F	None	Non-Hispanic	White	US Citizen
41	Elliott, James	Undergraduate student	M	None	Non-Hispanic	White	US Citizen
42	Ellsworth, Patrick	Undergraduate student	M	None	Non-Hispanic	White	US Citizen
43	Fan, Quanfu	Graduate student	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
44	Fasel, Patricia	Other research scientist	F	None	Non-Hispanic	White	US Citizen
45	Fassnacht, Steven	Postdoctorate	M	None	Non-Hispanic	White	other non-US Citizen
46	Ferre, Paul	Faculty	M	None	Non-	White	US Citizen

					Hispanic		
47	Flores, Tracy	Support staff	F	None	Non-Hispanic	White	US Citizen
48	Fox, Rannie	Support staff	F	None	Non-Hispanic	White	US Citizen
49	Furman, Alexander	Graduate student	M	None	Non-Hispanic	White	other non-US Citizen
50	Gao, Xiaogang	Postdoctorate	M	None	Non-Hispanic	Asian American / Pacific Islander	Permanent Resident
51	Garatuza, Jaime	Faculty	M	None	Hispanic	Hispanic	other non-US Citizen
52	Gibson, Jill	Support staff	F	None	Non-Hispanic	White	US Citizen
53	Goodrich, David	Other research scientist	M	None	Non-Hispanic	White	US Citizen
54	Granillo, Cecilia	Undergraduate student	F	None	Non-Hispanic	Asian American / Pacific Islander	US Citizen
55	Grantham, Warren	Undergraduate student	M	None	Non-Hispanic	White	US Citizen
56	Grimm, Nancy	Faculty	F	None	Non-Hispanic	White	US Citizen
57	Gu, Ailiang	Graduate student	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
58	Guan, Huade	Graduate student	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
59	Gupta, Hoshin	Faculty	M	None	Non-Hispanic	Asian American / Pacific Islander	US Citizen
60	Gutierrez, Maria	Undergraduate student	F	None	Hispanic	Hispanic	US Citizen
61	Haas, Peter	Graduate student	M	None	Non-Hispanic	White	US Citizen
62	Hamblen, Jennifer	Graduate student	F	None	Non-Hispanic	White	US Citizen
63	Hinnell, Andrew	Graduate student	M	None	Non-Hispanic	White	other non-US Citizen
64	Hogan, James	Postdoctorate	M	None	Non-Hispanic	White	US Citizen
65	Hong, Yang	Graduate student	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
66	Hong, Sung-ho	Graduate student	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
67	Hsu, Kuo-lin	Postdoctorate	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
68	Hultine, Kevin	Graduate student	M	None	Non-Hispanic	White	US Citizen
69	Huth, Anne	Graduate student	F	None	Non-Hispanic	White	US Citizen
70	Ip, Filipe	Graduate student	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
71	James, Brad	Undergraduate student	M	None	Non-Hispanic	White	US Citizen
72	Jensen, Jessica	Pre-college students	F	None	Non-Hispanic	White	US Citizen
73	Jin, Jiming	Postdoctorate	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen

74	Khodatalab, Neusha	Graduate student	F	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
75	Kim, Tae-woong	Graduate student	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
76	Krause, Kate	Faculty	F	None	Non-Hispanic	White	US Citizen
77	Kurc, Shirley	Graduate student	F	None	Non-Hispanic	White	US Citizen
78	Lal, Devendra	Faculty	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
79	Lansey, Kevin	Faculty	M	None	Non-Hispanic	White	US Citizen
80	Lawler, David	Graduate student	M	None	Non-Hispanic	White	US Citizen
81	Leake, Stan	Other research scientist	M	None	Non-Hispanic	White	US Citizen
82	Leavesley, George	Other research scientist	M	None	Non-Hispanic	White	US Citizen
83	Lee, Dennis	Graduate student	M	None	Non-Hispanic	White	US Citizen
84	Leij, Feike	Other research scientist	M	None	Non-Hispanic	White	Permanent Resident
85	Lewis, David	Postdoctorate	M	None	Non-Hispanic	White	US Citizen
86	Lin, Guanghui	Faculty	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
87	Lite, Sharon	Graduate student	F	None	Non-Hispanic	White	US Citizen
88	Little, Joseph	Graduate student	M	None	Non-Hispanic	White	US Citizen
89	Liu, Zhongmei	Graduate student	F	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
90	Liverman, Diana	Faculty	F	None	Non-Hispanic	White	US Citizen
91	Long, Austin	Faculty	M	None	Non-Hispanic	White	US Citizen
92	Lopez, Gabriel	Support staff	M	None	Hispanic	Hispanic	US Citizen
93	Lopez, Melissa	Undergraduate student	F	None	Hispanic	Hispanic	US Citizen
94	Lopez-Coreas, Marcela	Undergraduate student	F	None	Hispanic	Hispanic	US Citizen
95	Luft, Julie	Faculty	F	None	Non-Hispanic	White	US Citizen
96	Madden, John	Support staff	M	None	Non-Hispanic	White	US Citizen
97	Maddock, Thomas	Faculty	M	None	Non-Hispanic	White	US Citizen
98	Mahani, Shayesteh	Postdoctorate	F	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
99	Markstrom, Steve	Other research scientist	M	None	Non-Hispanic	White	US Citizen
100	Martens, Dean	Other research scientist	M	None	Non-Hispanic	White	US Citizen
101	McCarthy, Cara	Graduate student	F	None	Non-Hispanic	White	US Citizen

102	McConnell, Joe	Faculty	M	None	Non-Hispanic	White	US Citizen
103	McGhee, Douglas	Graduate student	M	None	Non-Hispanic	White	US Citizen
104	McHugh, Kathleen	Graduate student	F	None	Non-Hispanic	White	US Citizen
105	McPhee, James	Graduate student	M	None	Non-Hispanic	White	other non-US Citizen
106	Mills, Suzanne	Graduate student	F	None	Non-Hispanic	White	US Citizen
107	Mniszewski, Susan	Other research scientist	F	None	Non-Hispanic	White	US Citizen
108	Moayyad, Ben	Graduate student	M	None	Hispanic	Hispanic	US Citizen
109	Mohanty, Binayak	Other research scientist	M	None	Non-Hispanic	Asian American / Pacific Islander	Permanent Resident
110	Molotch, Noah	Graduate student	M	None	Non-Hispanic	White	US Citizen
111	Moote, Margaret Ann	Other research scientist	F	None	Non-Hispanic	White	US Citizen
112	Moradkhani, Hamid	Graduate student	M	None	Non-Hispanic	N/A	other non-US Citizen
113	Moreno, Denise	Other participant	F	None	Hispanic	Hispanic	US Citizen
114	Mozumder, Pallob	Graduate student	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
115	Murray, Reagan	Postdoctorate	F	None	Non-Hispanic	White	US Citizen
116	Neville, Paul	Other research scientist	M	None	Non-Hispanic	White	US Citizen
117	O'Reilly, Catherine	Graduate student	F	None	Non-Hispanic	White	Permanent Resident
118	Paige, Ginger	Postdoctorate	F	None	Non-Hispanic	White	US Citizen
119	Pailzote, Cheryl	Graduate student	F	None	Non-Hispanic	American Indian / Alaskan Native	US Citizen
120	Paradzick, Charles	Graduate student	M	None	Non-Hispanic	White	US Citizen
121	Parsons, Amy	Undergraduate student	F	None	Non-Hispanic	White	US Citizen
122	Petti, Jonathan	Support staff	M	None	Non-Hispanic	White	US Citizen
123	Phillips, Fred	Faculty	M	None	Non-Hispanic	White	US Citizen
124	Phillips, Patrick	Graduate student	M	None	Non-Hispanic	White	US Citizen
125	Pierce, Danielle	Other research scientist	F	None	Non-Hispanic	White	US Citizen
126	Pockman, Will	Faculty	M	None	Non-Hispanic	White	US Citizen
127	Poff, Boris	Graduate student	M	None	Non-Hispanic	White	US Citizen
128	Qu, Yizhong	Graduate student	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
129	Raghava, Srinivasa	Graduate student	M	None	Non-	Asian American /	other non-US Citizen

					Hispanic	Pacific Islander	
130	Remme, Chelsi	Pre-college students	F	None	Non-Hispanic	White	US Citizen
131	Rene, Palafox	Undergraduate student	M	None	Hispanic	Hispanic	US Citizen
132	Rivenburgh, Reid	Other research scientist	M	None	Non-Hispanic	White	US Citizen
133	Roads, John	Other research scientist	M	None	Non-Hispanic	White	US Citizen
134	Rodrigeuz-Marin, Graciela	Graduate student	F	None	Hispanic	Hispanic	other non-US Citizen
135	Rosenau, Naomi	Graduate student	F	None	Non-Hispanic	White	US Citizen
136	Schaap, Marcel	Other research scientist	M	None	Non-Hispanic	White	Permanent Resident
137	Schade, John	Postdoctorate	M	None	Non-Hispanic	White	US Citizen
138	Schmid, Wolfgang	Graduate student	M	None	Non-Hispanic	White	other non-US Citizen
139	Schroeder, Steve	Staff	M	None	Non-Hispanic	White	US Citizen
140	Schwartz, Kerry	Support staff	F	None	Non-Hispanic	White	US Citizen
141	Scott, Russell	Postdoctorate	M	None	Non-Hispanic	White	US Citizen
142	Sedmera, Kris	Graduate student	M	None	Non-Hispanic	White	US Citizen
143	Senkyrikova, Pavla	Pre-college students	F	None	Non-Hispanic	White	Permanent Resident
144	Shaler, Louise	Support staff	F	None	Non-Hispanic	White	US Citizen
145	Shanahan, Timothy	Graduate student	M	None	Non-Hispanic	White	US Citizen
146	Shepherd, Jennifer	Graduate student	F	None	Non-Hispanic	White	US Citizen
147	Sherlock, June	Undergraduate student	F	None	Non-Hispanic	White	US Citizen
148	Shouse, Pete	Other research scientist	M	None	Non-Hispanic	White	US Citizen
149	Shreve, Grant	Pre-college students	M	None	Non-Hispanic	White	US Citizen
150	Shuttleworth, Jim	Faculty	M	None	Non-Hispanic	White	US Citizen
151	Simunek, Jirka	Other research scientist	M	None	Non-Hispanic	White	Permanent Resident
152	Small, Eric	Faculty	M	None	Non-Hispanic	White	US Citizen
153	Sorooshian, Soroosh	Faculty	M	None	Non-Hispanic	Asian American / Pacific Islander	US Citizen
154	Springer, Everett	Other research scientist	M	None	Non-Hispanic	White	US Citizen
155	Stauber, Leah	Graduate student	F	None	Non-Hispanic	White	US Citizen
156	Stone, Jeff	Other research scientist	M	None	Non-Hispanic	White	US Citizen

157	Stromberg, Juliet	Faculty	F	None	Non-Hispanic	White	US Citizen
158	Thedinga, Thomas	Undergraduate student	M	None	Non-Hispanic	White	US Citizen
159	Thies, Corrie	Support staff	F	None	Non-Hispanic	White	US Citizen
160	Thorson, John	Other participant	M	None	Non-Hispanic	White	US Citizen
161	Tidwell, Vincent	Support staff	M	None	Non-Hispanic	White	US Citizen
162	Tom, Melissa	Undergraduate student	F	None	Non-Hispanic	White	US Citizen
163	Tomkins, Claire	Undergraduate student	F	None	Non-Hispanic	White	US Citizen
164	Tseng, Peng-Hsiang	Other research scientist	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
165	Uyeda, Steven	Graduate student	M	None	Non-Hispanic	Asian American / Pacific Islander	US Citizen
166	Valdes, Juan	Faculty	M	None	Hispanic	Hispanic	US Citizen
167	Varady, Robert	Faculty	M	None	Non-Hispanic	White	US Citizen
168	Varvel, Kyle	Graduate student	M	None	Non-Hispanic	White	US Citizen
169	Viger, Roland	Other research scientist	M	None	Non-Hispanic	White	US Citizen
170	Villinski, John	Postdoctorate		None	Non-Hispanic	White	US Citizen
171	Wagber, Tracy	Undergraduate student	F	None	Non-Hispanic	White	US Citizen
172	Walvoord, Michelle	Graduate student	F	None	Non-Hispanic	White	US Citizen
173	Wang, Bei	Graduate student	F	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
174	Warrick, Arthur	Faculty	M	None	Non-Hispanic	White	US Citizen
175	Washburne, James	Faculty	M	None	Non-Hispanic	White	US Citizen
176	Watts, Chris	Other research scientist	M	None	Non-Hispanic	White	other non-US Citizen
177	Welsch, Ada	Undergraduate student	F	None	Non-Hispanic	White	US Citizen
178	Wilder, Margaret	Faculty	F	None	Non-Hispanic	White	US Citizen
179	Williams, David	Faculty	M	None	Non-Hispanic	White	US Citizen
180	Wilson, John	Faculty	M	None	Non-Hispanic	White	US Citizen
181	Wilson, Paul	Faculty	M	None	Non-Hispanic	White	US Citizen
182	Winter, Larry	Other research scientist	M	None	Non-Hispanic	White	US Citizen
183	Woodard, Gary	Support staff	M	None	Non-Hispanic	White	US Citizen
184	Yeh, William	Faculty	M	None	Non-	Asian American /	US Citizen

					Hispanic	Pacific Islander	
185	Yepez, Enrico	Graduate student	M	None	Hispanic	Hispanic	other non-US Citizen
186	Yilmaz, Koray	Graduate student	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
187	Young, Deborah	Faculty	F	None	Non-Hispanic	White	US Citizen
188	Zahraie, Banafsheh	Postdoctorate	F	None	Non-Hispanic	N/A	other non-US Citizen
189	Zhu, Julian	Postdoctorate	M	None	Non-Hispanic	Asian American / Pacific Islander	other non-US Citizen
190	van Genuchten, Rien	Other research scientist		None	Non-Hispanic	White	US Citizen
191	vanHaren, Joost	Postdoctorate	M	None	Non-Hispanic	White	other non-US Citizen
192	von Glinski, Gerd	Graduate student	M	None	Non-Hispanic	White	US Citizen

1	the number of participating institutions (all academic institutions that participate in activities at the Center)	18
2	the number of institutional partners (total number of non-academic participants, including industry, states, and other federal agencies, at the Center)	34
3	the total leveraged support (sum of funding for the Center from all sources *other* than NSF)	$314,000
4	the number of participants (total number of people who utilize Center facilities; not just persons directly supported by NSF)	192

Media / Publicity
Newspaper Article: Tucson Citizen newspaper, “Against the Flow: Water-saving toilets’ benefits go down drain,” November 2, 2000, quoting Gary Woodard, SAHRA Assistant Director for Knowledge Transfer. (See Appendix D)

Newspaper Article: Arizona Daily Star, “Study: Low-flow toilets waste water,” November 2, 2000, quoting Gary Woodard, SAHRA Assistant Director for Knowledge Transfer. (See Appendix D)

University Newspaper Article: Arizona Daily Wildcat, “Low-flow toilets save Tucson money, UA researchers say,” November 3, 2000, quoting Gary Woodard, SAHRA Assistant Director for Knowledge Transfer. (See Appendix D)

University Staff and Faculty Weekly Newspaper: Lo Que Pasa, “Study shows leaks in conservation theory behind low-flow toilets,” November 16, 2000, quoting Gary Woodard, SAHRA Assistant Director for Knowledge Transfer. (See Appendix D)

Web Site www.emagazine.com: In Brief, “The Low Flow’s False Flush,” March-April, 2000, quoting Gary Woodard, SAHRA Assistant Director for Knowledge Transfer. (See Appendix D)

University Staff and Faculty Weekly Newspaper: Lo Que Pasa, “UA could get $16 million in Prop 301 funds,” February 1, 2001. A portion of those funds will go to SAHRA Education efforts. (See Appendix D)

University of Arizona College of Engineering and Mines newsletter: HWR Report, “HWR hosts STC directors meeting: They share experiences related to running STCs,” Spring 2001. (See Appendix D)

Web site www.uswaternews.com: U.S. Water News, Conservation/Reuse, “Study questions water savings from low-flow toilets,” April 2001, quoting Gary Woodard, SAHRA Assistant Director for Knowledge Transfer. (See Appendix D)

Web site www.azstarnet.com: Arizona Daily Star, “Unending water fight,” April 30, 2001. Quotes Gary Woodard, SAHRA Assistant Director for Knowledge Transfer, in this article, part of a week-long series on Tucson water issues. (See Appendix D)

Newspaper article: Arizona Daily Star, “Try to revive San Pedro: Nature Conservancy buys farm with aim of halting water pumps, restoring river’s flow,” quoting Tom Maddock III and the assistant director, Gary Woodard. (See Appendix D)

Television news report: The “tree torture” experiment and related activities, including the summer internship program, were covered by KUAT-4 June 6, 2001. The station interviewed four students.

Television news report: The summer internship program, along with the Greenland ice core work, was covered by KUAT-6, on Friday, July 27, 2001. The station interviewed four individuals including the deputy director, Roger Bales and two students.

Television news report: Assistant Director, Gary Woodard was featured in a story on the impacts of water prices and climate fluctuations on municipal water demand, by KUAT-6. On Feb. 21, 2001.

Newspaper, TV and Radio Interviews: Assistant Director Gary Woodard was interviewed by six newspapers, five TV stations, and three radio stations regarding research on ultra-low flush toilets.

IX. BUDGET

University of Arizona	Total Award	Actual Expenditure	Estimates of Projected Expenditures
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR			
Sorooshian,			
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates			
List each separately with name and title. (A.7. Show number in brackets)			
1.Sorooshian	14727	19254	0
2.Bales, Roger	11103	13920	0
3.Gupta, H	71400	51778	30351
4.Washburne	63000	31994	21994
5.Woodard	68933	53322	27927
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	99979	134136	12916
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	329142	304404	93188
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)			
1. ( ) POSTDOCTORAL ASSOCIATES	203864	140966	170779
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	148136	46261	53138
3. ( ) GRADUATE STUDENTS	235119	162605	97285
4. ( ) UNDERGRADUATE STUDENTS	48480	18702	8886
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)	54384	36377	31444
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. ( ) TOTAL OTHER PERSONNEL (1-6)			
TOTAL SALARIES AND WAGES (A + B)	1019125		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)	162201		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)	1181326	709315	454720
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)			
Computer	21306	17574	12200
Laptop	5000	5000	0
Equipment		31693	77273
TOTAL EQUIPMENT	26306	54267	89473
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)	53000	39154	33229
2. FOREIGN	20000	7564	12875
F. PARTICIPANT SUPPORT			
1. STIPENDS			
2. TRAVEL			
3. SUBSISTENCE			
4. OTHER	45000	22168	0
G. OTHER DIRECT COSTS			
1. MATERIALS AND SUPPLIES	74000	82882	4303
2. PUBLICATION/DOCUMENTATION/DISSEMINATION	38666	4822	0
3. CONSULTANT SERVICES	12000	3900	8600
4. COMPUTER SERVICES			
5. SUBAWARDS	900453	191348	743058
6. OTHER	15000	0	0
TOTAL OTHER DIRECT COSTS	1040119	406105	891538
H. TOTAL DIRECT COSTS (A THROUGH G)	2365751	1,115,420	1,346,258
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)			
TOTAL INDIRECT COSTS (F&A)	721510	482267	239243
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	3087261	1,597,687	1,585,501
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)			
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			
M. COST SHARING: PROPOSED LEVEL $	1693000		

Unobligated funds and plans for use

The amount received from NSF for this (second) award year is $3,087,261 while the actual amount spent and encumbered is $3,183,188 resulting in a $95,927 shortfall. However, the funds rolled over from the end of year one were $851,077. Therefore the total NSF funds remaining unexpensed at the end of years one and two are $755,150. This amount is projected to be spent during year three as explained below.

The amount requested from NSF for the next (third) award year is $3,204,870 while our projected expenditure for the period is estimated to be $3,938,859. This increase in projected spending reflects projected increases in salaries, increased recruitment of students, and necessary expansion of our research activities, as described in this progress report. In particular, our science activities require the recruitment of a mesoscale modeler, public policy expert, and three additional technical staff in the areas of computer support and knowledge base development. In addition, a change in university policy regarding minimum spending for capital expenditures requires us to reallocate funds from capital to operations, resulting in larger expenditure in the indirect cost category.

Therefore, at the end of the next (third) award year, we anticipate (after accounting for the year two rollover funds) a budget shortfall of $21,161. This amount is small enough that we will be able to cover it by other sources of support.

Also, as with year three, the fourth and fifth year expenditures will likely exceed the amounts budgeted by NSF. As described in the table of other sources of support, we have already begun to successfully solicit and obtain additional sources of funding to help cover these projected expenditures.

Arizona State University	Total Award	Actual Expenditure	Estimates of Projected Expenditures
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR			
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates			
List each separately with name and title. (A.7. Show number in brackets)			
1. Nancy Grimm Faculty	7072	3754	3754
2.			
3.			
4.			
5.			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	7072	3754	3754
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)			
1. ( ) POSTDOCTORAL ASSOCIATES	7500	4485	3203
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	7280	4451	3180
3. ( ) GRADUATE STUDENTS	9867	0	0
4. ( ) UNDERGRADUATE STUDENTS			
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	4000	5382	5055
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	28647	14318	7394
TOTAL SALARIES AND WAGES (A + B)	35719	18072	15192
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)	7422	3308	2279
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)	43141	21380	15192
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)			
TOTAL EQUIPMENT			
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)	2000	283	1081
2. FOREIGN			
F. PARTICIPANT SUPPORT			
1. STIPENDS			
2. TRAVEL			
3. SUBSISTENCE			
4. OTHER			
G. OTHER DIRECT COSTS			
1. MATERIALS AND SUPPLIES	2000	9127	3000
2. PUBLICATION/DOCUMENTATION/DISSEMINATION	500	0	0
3. CONSULTANT SERVICES			
4. COMPUTER SERVICES			
5. SUBAWARDS			
6. OTHER	4000	0	0
TOTAL OTHER DIRECT COSTS	6500	9127	3000
H. TOTAL DIRECT COSTS (A THROUGH G)	51640	30790	21551
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)	13685	8160	5711
TOTAL INDIRECT COSTS (F&A)	13685	8160	5711
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	65325	38950	27262
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)			
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			
M. COST SHARING: PROPOSED LEVEL $			

Columbia Biosphere 2	Total Award	Actual Expenditure	Estimates of Projected Expenditures
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR			
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates			
List each separately with name and title. (A.7. Show number in brackets)			
1. Len Fine Adj. Prof.	N/C	N/C	N/C
2.			
3.			
4.			
5.			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. (1) TOTAL SENIOR PERSONNEL (1-6)			
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)			
1. ( ) POSTDOCTORAL ASSOCIATES			
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	1417	1403	14
3. ( ) GRADUATE STUDENTS			
4. ( ) UNDERGRADUATE STUDENTS			
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. (1) TOTAL SENIOR PERSONNEL (1-6)			
TOTAL SALARIES AND WAGES (A + B)	1417	1403	14
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)	212	285.56	-73.56
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)	1629	1688.56	-59.56
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)			
TOTAL EQUIPMENT			
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)			
2. FOREIGN			
F. PARTICIPANT SUPPORT			
1. STIPENDS			
2. TRAVEL			
3. SUBSISTENCE			
4. OTHER			
G. OTHER DIRECT COSTS			
1. MATERIALS AND SUPPLIES	788	238.64	549.36
2. PUBLICATION/DOCUMENTATION/DISSEMINATION			
3. CONSULTANT SERVICES	12000	0	12000
4. COMPUTER SERVICES			
5. SUBAWARDS			
6. OTHER	0	1.18	-1.18
TOTAL OTHER DIRECT COSTS	12788	239.82	12548.18
H. TOTAL DIRECT COSTS (A THROUGH G)	14417	1928.38	12488.62
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)			
@24.85% = 3583	3583	479.2	3103.8
TOTAL INDIRECT COSTS (F&A)	3583	479.2	3103.8
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	18000	2407.58	15592.42
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)			
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			
M. COST SHARING: PROPOSED LEVEL $			

New Mexico Tech	Total Award	Actual Expenditure	Estimates of Projected Expenditures
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR			
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates			
List each separately with name and title. (A.7. Show number in brackets)			
1. FM Phillips	15,200		
2. JL Wilson	9,443		
3.JM Hendrickx	6,540		
4. EE Small	5,500		
5.			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	36, 683	33,987	10,020
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)			
1. ( ) POSTDOCTORAL ASSOCIATES			
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	3,000	13,386	
3. ( ) GRADUATE STUDENTS	48,000	43,650	18,400
4. ( ) UNDERGRADUATE STUDENTS			
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)	7,000	7,000	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. ( ) TOTAL SENIOR PERSONNEL (1-6)			
TOTAL SALARIES AND WAGES (A + B)	87.683	98,023	28,420
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)	12,597	5,204	1,800
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)	100,280	103,227	30,220
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)			
TOTAL EQUIPMENT	5,000	3,554	3,000
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)	16,000	14,945	3,000
2. FOREIGN			
F. PARTICIPANT SUPPORT			
1. STIPENDS			
2. TRAVEL	1,000		
3. SUBSISTENCE			
4. OTHER	1,400		
G. OTHER DIRECT COSTS			
1. MATERIALS AND SUPPLIES	53,587	49,527	15,000
2. PUBLICATION/DOCUMENTATION/DISSEMINATION			
3. CONSULTANT SERVICES			
4. COMPUTER SERVICES			
5. SUBAWARDS			
6. OTHER	5,000	0	0
TOTAL OTHER DIRECT COSTS	58,587	49,527	15,000
H. TOTAL DIRECT COSTS (A THROUGH G)	182,267	171,253	51,220
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)	84,734	81,710	23,049
TOTAL INDIRECT COSTS (F&A)	84,734	81,710	23,049
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	267,010	252,963	74,269
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE		121,998	47,729
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			
M. COST SHARING: PROPOSED LEVEL $			

Northern Arizona University	Total Award	Actual Expenditure	Estimates of Projected Expenditures
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR			
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates			
List each separately with name and title. (A.7. Show number in brackets)			
1.Aregai Tecle	**28,938**	**16,303.66**	
2.Mansel Nelson	**0.00**	**0.00**	
3.			
4.			
5.			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. (1) TOTAL SENIOR PERSONNEL (1-6)	**28,938**	**16,303.66**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)			
1. ( ) POSTDOCTORAL ASSOCIATES			
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)			
3. ( ) GRADUATE STUDENTS			**9,500.00**
4. ( ) UNDERGRADUATE STUDENTS			
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. (1) TOTAL SENIOR PERSONNEL (1-6)	**28,938**	**16,303.66**	**9,500.00**
TOTAL SALARIES AND WAGES (A + B)	**28,938**	**16,303.66**	**0.00**
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)	**2,321**	**2,783.78**	**285.00**
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)	**31,259**	**19,087.44**	**9,785.00**
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)			
TOTAL EQUIPMENT			
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)	**7,973**	**2,717.15**	**5,633.00**
2. FOREIGN			
F. PARTICIPANT SUPPORT	**9,000**	**11,109.14**	**1,440.00**
1. STIPENDS			
2. TRAVEL			
3. SUBSISTENCE			
4. OTHER			
G. OTHER DIRECT COSTS			
1. MATERIALS AND SUPPLIES	**13,138**	**2,460.94**	**10,650.00**
2. PUBLICATION/DOCUMENTATION/DISSEMINATION			
3. CONSULTANT SERVICES			
4. COMPUTER SERVICES			
5. SUBAWARDS			
6. OTHER			
TOTAL OTHER DIRECT COSTS	**61,370**	**35,374.67**	**27,508.00**
H. TOTAL DIRECT COSTS (A THROUGH G)			
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)			
TOTAL INDIRECT COSTS (F&A)	**13,976**	**7,874.67**	**4,589.00**
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	**75,346**	**43,249.34**	**32,097.00**
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)			
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			
M. COST SHARING: PROPOSED LEVEL **$ 8,776.00**			

Penn State University	Total Award	Actual Expenditure	Estimates of Projected Expenditures
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR			
Duffy, C. J.			
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates			
List each separately with name and title. (A.7. Show number in brackets)			
1. Duffy, C. J.	7,753	9,451	-
2.			
3.			
4.			
5.			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	7,753	9,451	-
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)			
1. ( ) POSTDOCTORAL ASSOCIATES			
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)			
3. (1) GRADUATE STUDENTS	17,242	16,675	8,431
4. (2) UNDERGRADUATE STUDENTS	15,062	1,200	-
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. (3) TOTAL OTHER PERSONNEL (1-6)	32,304	17,857	8,431
TOTAL SALARIES AND WAGES (A + B)	40,057	27,308	8,431
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)	5,320	3,203	363
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)	45,377	30,511	8,794
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)			
TOTAL EQUIPMENT			
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)	8,250	11,778	-
2. FOREIGN			
F. PARTICIPANT SUPPORT			
1. STIPENDS			
2. TRAVEL			
3. SUBSISTENCE			
4. OTHER			
G. OTHER DIRECT COSTS			
1. MATERIALS AND SUPPLIES	1,000	891	-
2. PUBLICATION/DOCUMENTATION/DISSEMINATION	500	-	-
3. CONSULTANT SERVICES	0	-	-
4. COMPUTER SERVICES	0	-	-
5. SUBAWARDS	0	-	-
6. OTHER	8,613	21,564	-
TOTAL OTHER DIRECT COSTS	10,113	22,455	-
H. TOTAL DIRECT COSTS (A THROUGH G)	63,740	64,744	8,794
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)			
40.3% of MTDC	22,780	9,437	3,545
TOTAL INDIRECT COSTS (F&A)	22,780	9,437	3,545
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	86,520	74,181	12,339
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)	0	0	0
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)	86,520	74,181	-
M. COST SHARING: PROPOSED LEVEL $	28,840	28,840	0

University of California, Los Angeles				Total Award	Actual Expenditure	Estimates of Projected Expenditures
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR						
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates						
List each separately with name and title. (A.7. Show number in brackets)						
1.William W-G Yeh PI						
2.John A. Dracup CO-PI						
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)						
7. (2) TOTAL SENIOR PERSONNEL (1-6)				13,190		11,474
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. ( ) POSTDOCTORAL ASSOCIATES						
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)						
3. (2) GRADUATE STUDENTS						
4. ( ) UNDERGRADUATE STUDENTS				31,048	16,870	14,566
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)						
7. ( ) TOTAL SENIOR PERSONNEL (1-6)						
TOTAL SALARIES AND WAGES (A + B)				44,608	16,870	26,040
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				8,919	1,673	2,208
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				53,527	18,543	28,248
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT						
E. TRAVEL	1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)					
	2. FOREIGN					
F. PARTICIPANT SUPPORT						
1. STIPENDS						
2. TRAVEL				1,204	2,381	2,000
3. SUBSISTENCE						
4. OTHER						
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES					684	807
2. PUBLICATION/DOCUMENTATION/DISSEMINATION						
3. CONSULTANT SERVICES						
4. COMPUTER SERVICES						
5. SUBAWARDS						
6. OTHER						
TOTAL OTHER DIRECT COSTS						
H. TOTAL DIRECT COSTS (A THROUGH G)				54,731	21,608	31,055
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)				25,250	11,346	15,991
Rate 53% base 47,679						
TOTAL INDIRECT COSTS (F&A)				80,000	32,954	47,046
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)						
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)						
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)						
M. COST SHARING: PROPOSED LEVEL $						

University of California, Riverside	Total Award	Actual Expenditure (thru 7/2001)	Estimates of Projected Expenditures
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Feike J. Leij			
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates			
List each separately with name and title. (A.7. Show number in brackets)			
1. Feike J. Leij	5,740	3,038	2,702
2. Binayak P.Mohanty	4,659	4,761	(102)
3.			
4.			
5.			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. (2) TOTAL SENIOR PERSONNEL (1-6)			
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)			
1. (1) POSTDOCTORAL ASSOCIATES	31,587	5,510	26,077
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)			
3. ( ) GRADUATE STUDENTS			
4. ( ) UNDERGRADUATE STUDENTS			
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. ( ) TOTAL SENIOR PERSONNEL (1-6)			
TOTAL SALARIES AND WAGES (A + B)			
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)	9,136	1,638	7,498
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)			
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)			
TOTAL EQUIPMENT			
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)	1,500		1,500
2. FOREIGN			
F. PARTICIPANT SUPPORT			
1. STIPENDS			
2. TRAVEL			
3. SUBSISTENCE			
4. OTHER			
G. OTHER DIRECT COSTS			
1. MATERIALS AND SUPPLIES	2,790		2,790
2. PUBLICATION/DOCUMENTATION/DISSEMINATION	1,000		1,000
3. CONSULTANT SERVICES			
4. COMPUTER SERVICES			
5. SUBAWARDS			
6. OTHER			
TOTAL OTHER DIRECT COSTS	56,412	14947	41,465
H. TOTAL DIRECT COSTS (A THROUGH G)			
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) (@25,4%)	14,329	14,329	-
TOTAL INDIRECT COSTS (F&A)			
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)			
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)			
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			
M. COST SHARING: PROPOSED LEVEL $			

University of California, San Diego	Total Award	Actual Expenditure as of 9/6/01	Estimates of Projected Expenditures
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR			
John O. Roads, Research Meteorologist			
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates			
List each separately with name and title. (A.7. Show number in brackets)			
****ALL Salaries listed incl udes fringe be nefits**			
1.			
2.			
3.			
4.			
5.			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. ( ) TOTAL SENIOR PERSONNEL (1-6)			
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)			
1. (1) POSTDOCTORAL ASSOCIATES	36,342	17,198	12,640
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)			
3. ( ) GRADUATE STUDENTS			
4. ( ) UNDERGRADUATE STUDENTS			
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)			
6. (1) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			2.147
7. ( ) TOTAL SENIOR PERSONNEL (1-6)			
TOTAL SALARIES AND WAGES (A + B)	**36,342**	**17,198**	**17,787**
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)			
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)	**36,342**	**17,198**	**17,787**
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)			
Hard Disks	5,000		5,000
TOTAL EQUIPMENT	**5,000**		**5,000**
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)	**3,390**	**6,411**	**1,550**
2. FOREIGN			
F. PARTICIPANT SUPPORT			
1. STIPENDS			
2. TRAVEL			
3. SUBSISTENCE			
4. OTHER			
G. OTHER DIRECT COSTS			
1. MATERIALS AND SUPPLIES	756	196	2000
2. PUBLICATION/DOCUMENTATION/DISSEMINATION			
3. CONSULTANT SERVICES			
4. COMPUTER SERVICES	4,456	1,235	1,000
5. SUBAWARDS			
6. OTHER	1,260	1,842	
TOTAL OTHER DIRECT COSTS	**6,472**	**3,273**	**3,000**
H. TOTAL DIRECT COSTS (A THROUGH G)	51,204	26,882	24,337
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)	23,796	13,844	9,959
TOTAL INDIRECT COSTS (F&A)	75,000	40,726	34,296
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)			
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)			(22)
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			
M. COST SHARING: PROPOSED LEVEL $ 6,960 ***			

University Of New Mexico	Total Award	Actual Expenditure	Estimates of Projected Expenditures
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR			
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates			
List each separately with name and title. (A.7. Show number in brackets)			
1. Brookshire, David S.		11,391.70	
2. Burness, H. Stuart		8,431.29	
3. Chermak, Janie		6,305.60	
4. Krause, Kate		5,749.77	
5.			
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. (4) TOTAL SENIOR PERSONNEL (1-6)	32,212.00	31,878.36	333.64
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)			
1. ( ) POSTDOCTORAL ASSOCIATES			
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)			
3. (5) GRADUATE STUDENTS	15,492.00	2,701.26	13,884.75
4. ( ) UNDERGRADUATE STUDENTS			
5. (1) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)	6,615.00	644.00	5,971.00
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)			
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	22,107.00	3,345.26	19,855.75
TOTAL SALARIES AND WAGES (A + B)	54,319.00	35,223.62	20,189.39
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)	9,846.00	5,937.60	2,814.39
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)	64,165.00	41,161.22	23,003.78
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)			
TOTAL EQUIPMENT			
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)	7,500.00	3,339.35	4,160.65
2. FOREIGN			
F. PARTICIPANT SUPPORT			
1. STIPENDS	13,700.00		13,700.00
2. TRAVEL			
3. SUBSISTENCE			
4. OTHER			
G. OTHER DIRECT COSTS			
1. MATERIALS AND SUPPLIES	6,472.00	4,097.56	2,374.44
2. PUBLICATION/DOCUMENTATION/DISSEMINATION			
3. CONSULTANT SERVICES			
4. COMPUTER SERVICES			
5. SUBAWARDS			
6. OTHER			
TOTAL OTHER DIRECT COSTS	6,472.00	4,097.56	2,374.44
H. TOTAL DIRECT COSTS (A THROUGH G)	91,837.00	48,598.13	43,238.87
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) 47%	43,163.00	22,841.12	20,321.88
TOTAL INDIRECT COSTS (F&A)	43,163.00	22,841.12	20,321.88
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	135,000.00	71,439.25	63,560.75
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)			
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			
M. COST SHARING: PROPOSED LEVEL $11,472.00			

*** THE SUMMARY BUDGET PROPOSAL IMAGES HAVE BEEN REMOVED TO DECREASE THE FILE SIZE OF THE ANNUAL REPORT. THEY ARE INLUDED IN THE FULL VERISION OF THE ANNUAL REPORT

1. Support from All Sources.

STC - SAHRA (in thousands)

Matching / Cost Sharing	Year 2 Actual	Year 2 In Kind	Year 3 Actual	Year 3 In Kind
University of Arizona	412	958	412	958
University of California - UCLA		44		45
University of California - San Diego		9		9
University of California - Riverside		12		12
Pennsylvania State University		29		30
University of New Mexico		36		37
New Mexico Tech		92		94
Columbia University Biosphere 2		0		0
Arizona State University		5		5
Northern Arizona University		4		3
Desert Research Institute		32		33
Industry (Current SRP*)	60		90	
Total	472	1,221	502	1,226
Total matching and cost sharing	1,693		1,728	

Other sources of support	Year 2	Year 3
NSF - REU (one time)	54,000	
NSF - Teleconference equipment (one time)	33,000	
NSF - Glue Grant ($517K over 3 years)	192,102	164,954
State of Arizona - Prop 301 SAHRA Grant (annual)	96,000	96,000
State of Arizona - Prop 301 SAHRA Education Consortium Grant (annual) shared between 4 University of Arizona centers	96,000	96,000
World Lab Fellowship	54,000	54,000
Sandia National Laboratories ($90K over 2.5 years)	23,000	35,000
Bureau Of Reclamation ($55K over 2 years)	25,000	30,000
Nature Conservancy ($20K over 2 years)	20,000	
	593,102	475,954

Appendix A: Biographical Information of New Faculty (3 bio's)

PAUL D. BROOKS

Hydrology and Water Resources
1133 E. North Campus Drive
University of Arizona
Tucson, AZ 85721

brooks@hwr.arizona.edu
Phone: (520) 621-3424

RESEARCH INTERESTS

Watershed-Scale Elemental Cycling; Terrestrial-Aquatic Interactions;
Carbon and Nutrient Biogeochemistry; Ecosystem Ecology;
Response to Disturbance; Biogeochemistry of Snow-Covered Systems.

EDUCATION

1995	Ph.D. Biogeochemistry/ Hydrology, University of Colorado, Boulder.
1991	M.B.S. Ecological Hydrology, University of Colorado, Boulder CO.
1982	B.S. Biological Science, Florida State University, Tallahassee, FL.

EMPLOYMENT

2000-present	Assistant Professor, Hydrology and Water Resources, University of Arizona
1998-2000	Research Associate, Institute of Arctic and Alpine Research, CU-Boulder
1995-1998	National Academy of Science -National Research Council Research Associate, U.S.Geological Survey - Water Resources Division, Boulder, CO.
1991-1995	Teaching Assistant, EPO Biology, University of Colorado, Boulder, CO.
1991-1995	Research Assistant, Institute of Arctic and Alpine Research, CU-Boulder
1986-1990	Research Associate, Center for Biomedical, Toxicological, and Hazardous Waste Research, Florida State University, Tallahassee, FL.
1985-1986	Biochemist, Institute for Applied Microbiology, ORNL, Oak Ridge TN.
1984-1985	Biochemist, Florida State University, Tallahassee, FL.
1983	Biologist, Department of Environmental Regulation, Tallahassee, FL.

TEACHING EXPERIENCE

Limnology, Global Biogeochemical Cycles, Watershed Biogeochemistry, Stream Ecology, Ecosystem Ecology, General Microbiology, Natural Science, General Biology.

HONORS AND AWARDS

1995-1997	National Academy of Sciences/National Research Council Fellowship.
1994-1995	University of Colorado, Arts and Sciences Research Fellowship.
1993-1994	University of Colorado, EPO Biology Graduate Fellowship.
1978-1982	National Merit/Achievement Scholarship, Florida State University.

Abbreviated Vitae
Brenda Ekwurzel

Education

Ph.D., Isotope Geochemistry, Lamont-Doherty Earth Observatory of Columbia Univ., New York, 1998
M.S. Geology, Rutgers University, New Jersey, 1988
B.A. Geology, *cum laude*, Dean's List, Smith College, Massachusetts, 1985

Appointments

Assistant Professor, Department of Hydrology & Water Resources, University of Arizona, 2000-present
Joint Faculty, Department of Geosciences, University of Arizona, 2001-present
Directorate Post Doctoral Researcher at Lawrence Livermore National Laboratory, California, 1998-2000
Graduate Research and Teaching Assistant, Columbia University, 1990-1997
Hydrogeologist at the Connecticut Department of Environmental Protection, 1988-1990

Honors And Awards

Lawrence Livermore National Laboratory, Science Directorate Achievement Award for Leadership, 2000
Arctic Research Consortium of the United States (ARCUS) Award for Arctic Research Excellence, 1998
Invited participant, Dissertations Symposium on Chemical Oceanography (DISCO XIV), 1997
Elected to Sigma Xi scientific research society, 1995
Elected to Phi Beta Kappa national honor society, 1985

Curriculum Vitae

Bart Nijssen

Address

Departments of Civil Engineering and Engineering Mechanics /
Hydrology and Water Resources
JW Harshbarger 216
PO Box 210011
The University of Arizona
Tucson, AZ 85721-0011
Tel: 520 626 1277
Fax: 520 621 1422
E-mail: nijssen@u.arizona.edu

Education

Ph.D. 2000: Civil and Environmental Engineering, University of Washington, Seattle
Aspects of boreal forest hydrology: from stand to watershed.

M.Sc. 1991: Tropical Land and Water Management, Wageningen Agricultural University, Wageningen, The Netherlands.
Sampling and modeling of transport processes in the vadose zone.

Positions Held

August 2001 - Present: Assistant Professor
Departments of Civil Engineering and Engineering Mechanics / Hydrology and Water Resources, University of Arizona, Tucson, Arizona

April 2001 - August 2001: Project Scientist
Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington

December 2000 - April 2001: Software Engineer
Ursus Technologies, Seattle, Washington

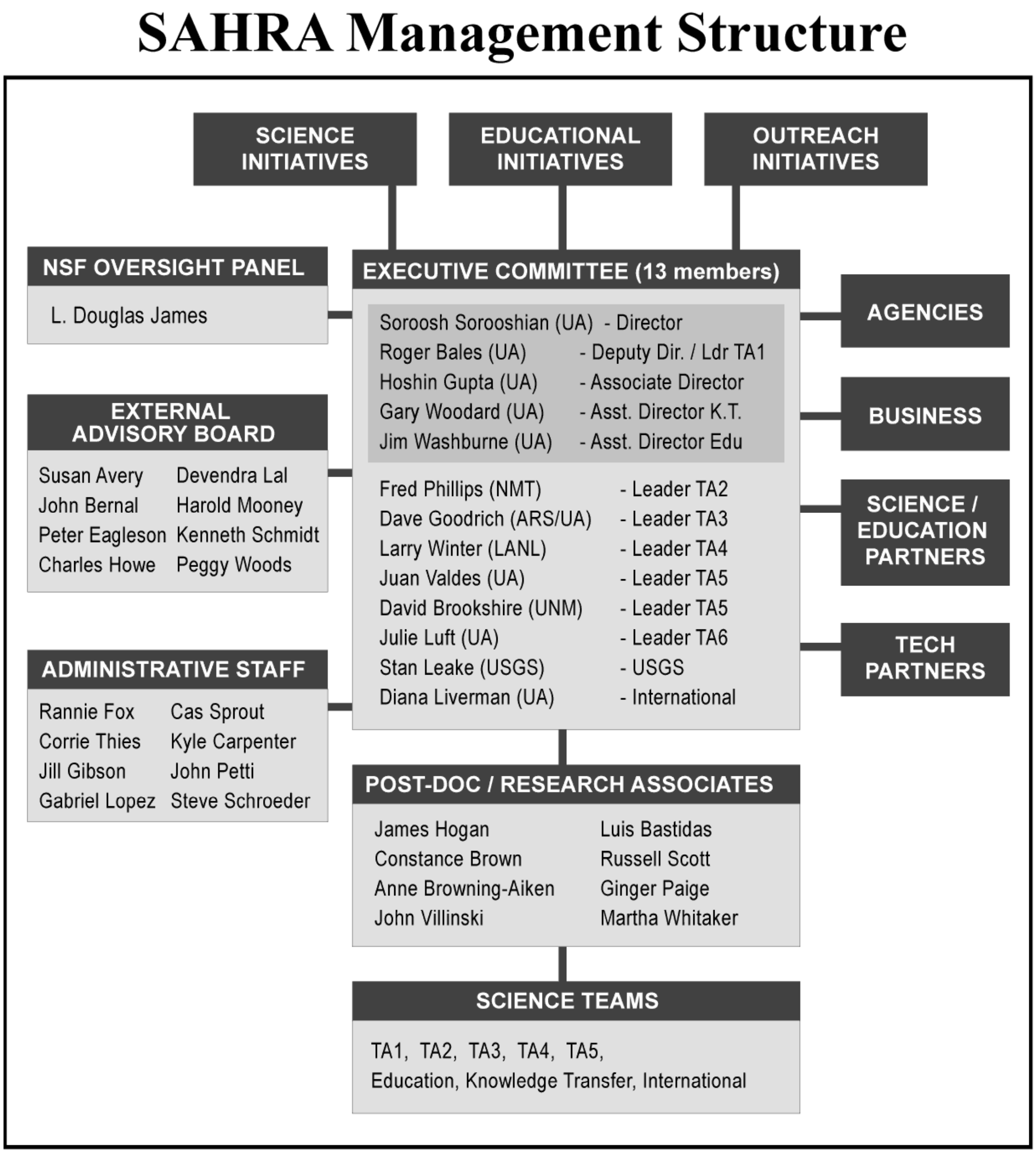
April 1994 - October 2000: Research Assistant
Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington

April 1992 - October 1992: Irrigation and Drainage Engineer
Irrigation System of the Lower Limpopo, Xai-Xai, Mozambique

September 1991 - Mar 1992: Program Officer
Save The Children Federation, Xai-Xai, Mozambique

September 1990 - June 1991: Research Assistant
Wageningen Agricultural University, Wageningen, The Netherlands

Appendix B: Center Organizational Chart



Memo

TO: Soroosh Sorooshian

FROM: Ken Schmidt, Chairman SAHRA Advisory Board

TOPIC: Advisory Board Comments & Recommendations

DATE: April 30, 2001

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1. We recommend holding the annual meeting of the Advisory Board at the same time as the Annual SAHRA meeting.
2. A "road map" that shows the relation of this program to other previously ongoing programs, and to any other related programs, would be most useful.
3. A contingency plan should be developed in case the NASA HyDis program is discontinued at some point. Also, exactly how the HyDis program work products will be applied to the SAHRA program should be explained.
4. Thrust Area V appears to be the thrust area needing the most improvement.
5. Each thrust area leader needs to clearly highlight what they accomplished last year, and note any problems preventing planned items being accomplished.
6. Meeting submittals should be provided to the Advisory Board at least 10 days before the beginning of the annual meeting.
7. If usable outreach to the non-academic community is to be made, the work products should be in English units. At the annual meeting, several non-academic presenters gave values in English units at the meeting, but virtually all academic presenters used metric units.

Appendix D: Media Publicity Materials (if any) ***

*** the Media Publicity Materials have been removed to decrease file size of Annual Report the full version of the report contains these images