

# Water Resources Research Center

## Annual Technical Report

### FY 1999

## Introduction

ANNUAL REPORT Fiscal Year March 1999-February 2000 Program Report Federal Grant Number 1434-HQ-96-GR-02657, Revision 0007 Prepared By Arizona Water Resources Research Center The University of Arizona Tucson, Arizona 85721

## Research Program

### Basic Project Information

<b>Basic Project Information</b>	
<b>Category</b>	<b>Data</b>
<b>Title</b>	Decision Support System For River System Management Under Hydroclimatic Variabilty
<b>Project Number</b>	C-98-01
<b>Start Date</b>	03/01/1998
<b>End Date</b>	08/30/2000
<b>Research Category</b>	Climate and Hydrologic Processes
<b>Focus Category #1</b>	Water Supply
<b>Focus Category #2</b>	Management and Planning
<b>Focus Category #3</b>	Surface Water
<b>Lead Institution</b>	The University of Arizona

### Principal Investigators

<b>Principal Investigators</b>			
<b>Name</b>	<b>Title During Project Period</b>	<b>Affiliated Organization</b>	<b>Order</b>
Juan B. Valdes	Professor	The University of Arizona	01
Kevin Lansey	Associate Professor	The University of Arizona	02
Roy Koch	Professor	Portland State University	03
Hugo Loaiciga	Professor	University of California-Santa Barbara	04

## **Problem and Research Objectives**

PROJECT STILL IN PROGRESS The goals of this project are to identify statistically important relationships in the studies areas between climatic information and streamflow measurements, incorporating these relationships in a streamflow forecast model, using those forecasts to improve reservoir operations and quantifying the value of the improved forecasts. The resulting methodologies will be applied to the Salt River system, which is the most critical system in the study. Also being examined are the Lewis River in Idaho and the Santa Ynez in California.

## **Methodology**

PROJECT STILL IN PROGRESS Management of large water resources projects is strongly influenced by long term weather conditions and hydroclimatic variation. More accurate streamflow forecasts will result in better operational planning. Reservoir operation decisions, in particular, can take advantage of improved forecasts, by allocating storage and releases in anticipation of likely events. For example, in the fall of 1997 the Salt River Project, recognizing the strongly developing ENSO, began supplying users from their surface water reservoirs rather than from groundwater sources. The decision was based on the likelihood of high flows but was not based on quantitative forecasts. The risk involved potentially not re-filling the reservoir this spring. Their decision was successful with higher than average snowfall that brought reservoirs to acceptable levels. The result is a long-term gain in overall aquifer storage and on the order of a million dollars in reduced pumping costs. Additional lead time and more accurate forecasts of the influence of ENSO could further improve their operation policies on an annual basis. This project, in part, focuses on methodologies for improving hydrologic forecasts. However, it is critically important that beneficial products of advanced research are passed to the practicing community. Therefore, this proposal is centered about the development of a decision support system (DSS) to assist system managers in situations, like the one noted above, and improving their operational planning. Three primary objectives will be pursued in the development and application of the DSS. They are to: 1) Develop an improved methodology for making streamflow forecasts for the western US considering ENSO influences; 2) Examine the influence of forecasts on reservoir system management; and 3) Provide an operator friendly interface for comparing operational plans and determining optimal policies, based on the improved forecasts. As noted, forecasts of likely future events can be invaluable in planning under uncertainty. The work in this aspect of the project will be to develop a data fusion system that will incorporate 1) forecasted ENSO; 2) other variables including snow water equivalents; 3) persistence-based forecasts; and 4) up-to-date observations. The resulting operational model will be based upon the Kalman filter method and produce streamflow forecasts and error bounds on the forecasts. The influence of forecasts and their uncertainty on river system management will be studied on three systems. The first is the Salt River Project on the Salt and Verde rivers in Arizona. This system is operated primarily for water supply for the Phoenix metropolitan area. The Sacramento/American River system in northern California supplies

water to the Central Valley and South Coast regions of California and is the second system in our proposed study. The reservoirs in this system are operated for multiple purposes. The third system is the Lewis River in the Pacific Northwest. These systems are in different climate regions and are operated for different purposes; as such the utility of forecasts and the uncertainty of the forecasts may vary. Data has been collected on each including reservoir capacities, historical streamflow, and operation policies. Using these systems as a basis, a series of questions will be considered through simulations. The questions include: 1) How should management decisions be changed during ENSO influenced years versus non-ENSO years? 2) How are management decisions affected by differing system characteristics, climatic conditions and objectives under ENSO influenced years? 3) How will the time increment of forecasts (e.g. months or seasons) affect uncertainty and management decisions? 4) How will the initiating period of forecasts affect management decisions? To address these questions, the tradeoff between forecast error in future streamflows as measured by the root mean square error and the increase in return from the system as compared to the present operation scheme. A comparison can also be made between the forecasting uncertainty and the variability in the objective function at the optimal solution.

### **Principal Findings and Significance**

**PROJECT STILL IN PROGRESS** From anecdotal evidence, a direct relationship between El Nino climatic conditions and high streamflows in the Salt River basin and generally in Arizona were expected. Similarly, low flows were expected during La Nina conditions. However, upon detailed data analysis, this relationship was not as strong as expected. A significant effort was spent in examining alternative gages, sub-periods during the year, and other potential indicators. None proved very successful.

### **Descriptors**

Reservoir Management, Hydroclimatology, Stochastic Hydrology, Mathematical Models, Optimization, Arid Climates

### **Articles in Refereed Scientific Journals**

Loaiciga, H.A., Climate-change impacts in regional-scale aquifers: principles and field applications, in Ground Water Updates, Sato, K. and Iwasa, Y., eds., Springer Verlag, Tokyo, 247-252, 2000.  
Loaiciga, H.A., Floods in changing streams: part 1, flood factors, Proceedings of the International Symposium on Integrated Water Resources, Intl. Assoc. Hydrol. Sciences, Davis, California, April 10-12. (Article in Review)  
Loaiciga, H.A., Floods in changing streams: part 2, hydraulic analysis, Proceedings of the International Symposium on Integrated Water Resources, Intl. Assoc. Hydrol. Sciences, Davis, California, April 10-12. (Article in Review).

### **Book Chapters**

Loaiciga, H.A., Climate Change and Ground Water, Encyclopedia of Life Support Systems, UNESCO, Paris. 2000. (Book Chapter)  
Loaiciga, H.A., Global Variations in the Chemistry of Ground Water, Encyclopedia of Life Support, UNESCO, Paris. 2000. (Book Chapter).

### **Dissertations**

### **Water Resources Research Institute Reports**

## Conference Proceedings

Koch, R.W. and A.R. Fisher. 2000, Effects of Inter-annual and Decadal-scale Climate Variability on Winter and Spring Streamflow in Western Oregon and Washington , to Appear in the Proceeding of the Western Snow Conference , Port Angeles, WA. Valdes, J.B. and D. Entekhabi, Invited, "Hydrologic Forecasting Using Climatic Precursors," Sixth International Conference on Southern Hemisphere Meteorology and Oceanography (6ISCHMO), American Meteorological Society and University of Chile, April 3-7, 2000, Santiago Chile Valdes, J.B., and D. Entekhabi, H-M Shin and H-H Hsieh, "An Evaluation of the Impact of ENSO on the Discharges of the Salt River, Arizona. "Proceedings of the 26th Annual Conference of the ASCE Water Resources Planning and Management Division, Tempe AZ. June 1999. Entekhabi, D., J.B. Valdes and S.E. Nicholson, "Evaluation of the prediction of Seasonal Rainfall," Proceedings of the 23rd Hurricanes and Tropical Meteorology Symposium, American Meteorological Society Annual Meeting , Dallas TX, January 1999, 905-908. Valdes, J.B., L. Bastidas, D. Entekhabi, and N. Garcia. "Climate-based Hydrologic Forecasting with Uncertainty Propagation," 24th Climate Diagnostic Workshop, November 1-5, 1999, Tucson, AZ. Valdes, J.B., D. Entekhabi and H-H Hsieh, "Analysis of the Impact of the 1997-98 ENSO Episode on the Southwest Hydrometeorology," Invited, American Geophysical Union 1998 Fall Annual Meeting, San Francisco CA, December 1998. Loaiciga, H.A., Effect of well interference on long-term ground water management: cooperative and non-cooperative strategies, Proceedings of the 2nd Inter-Regional Conference on Environment Water, Presses Polytechniques et Universitaires Romandes, Ecole Polytechnique Federal, Lausanne, Switzerland, Paper 9.2 in CD-ROM, September 1-3, 1999.

## Other Publications

Loaiciga, H.A., and Marino, M.A. Optimization of Reservoir Operation with Applications to the Northern California Central Valley Project, Water Science and Engineering Papers 3013, Department of Land, Air, and Water Resources, University of California, Davis, California, 444p., September 1999. (Grant Report).

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## Basic Project Information

<b>Basic Project Information</b>	
<b>Category</b>	<b>Data</b>
<b>Title</b>	Approaches To Reduce Taste and Odor Problems in Drinking Water
<b>Project Number</b>	B-99-02
<b>Start Date</b>	03/01/1999
<b>End Date</b>	02/28/2000
<b>Research Category</b>	Water Quality
<b>Focus Category #1</b>	Water Quality
<b>Focus Category #2</b>	None
<b>Focus Category #3</b>	None
<b>Lead Institution</b>	Arizona State University

## Principal Investigators

<b>Principal Investigators</b>			
<b>Name</b>	<b>Title During Project Period</b>	<b>Affiliated Organization</b>	<b>Order</b>
Milton R. Sommerfeld	Professor	Arizona State University	01
Thomas A. Dempster	Research Associate	Arizona State University	02

## **Problem and Research Objectives**

Taste and odor problems associated with drinking water are a pervasive problem for many municipalities. Suffet et al.<sup>1</sup> reported that 22% of the water providers surveyed in a national study reported taste and odor problems in their source waters. Taste and odor problems have been traced to both planktonic and benthic algae in surface impoundments and in water supply and distribution networks, including canals (Izaguirre et al.<sup>2</sup>; Means and McGuire<sup>3</sup>; Izaguirre and Taylor<sup>4</sup>). Municipalities in the Phoenix Metropolitan area have experienced taste and odor problems for many years, but the problems seem to be increasing, especially beginning during the late summer and extending well into the late winter. Water treatment costs for taste and odor problems alone have become exorbitant and consumers are more outspoken about expectations of receiving water that tastes and smells good, as well as is safe to drink. Two compounds, 2-methylisoborneol (MIB) and geosmin, are most commonly cited as imparting unpleasant earthy/musty tastes and odors to water. The source of these and other compounds associated with taste and odor is primarily blue-green algae (cyanobacteria) and certain fungi (actinomycetes). Research objectives were achieved through collaboration between operators of the City of Chandler Treatment Plant and researchers at Arizona State University, in cooperation with the Salt River Project. The on-going and focused effort was instrumental in an attempt to (1) identify the organisms causing the taste and odor problems, and (2) to explore the use of citral to mitigate taste and odor problems.

## **Methodology**

Water samples were collected from two sites along the South Canal and five sites along the Consolidated Canal, including the intake into the Chandler Water Treatment Plant. Each sample was collected and stored on ice in 16-ounce plastic Whirl-Pak storage bags in the field and transferred to 125-ml plastic screw top bottles in the laboratory. Bottles were subsequently kept on storage racks at room temperature under light conditions similar to those in the natural environment. Aliquots of each sample were streaked on agar plates (1.5%) of Bold's Basic Medium (BBM; Carolina Biological Supply Co.) with an inoculating loop. After approximately two weeks, isolated colonies were transferred to culture tubes with 10-ml of liquid BBM. Additional streaks were performed when multiple organisms appeared in the same colony. This procedure was performed repeatedly in an attempt to isolate the maximum number of organisms from each sample. Cultures grown on BBM agar plates and in liquid medium were repeatedly checked in an attempt to detect earthy/musty odors. Solid phase microextraction (SPME) and Gas Chromatography/Mass Spectroscopy (GC/MS) were employed to determine the effect of citral on the compounds MIB and geosmin, as well as the determination of optimum PAC concentrations to mitigate tastes and odors from MIB and geosmin. During SPME, 25-ml of sample was added to a 40-ml septum-capped vial containing 9 grams of desiccated sodium chloride and a magnetic stir bar. An internal standard, 2,4,6-trichloroanisole (TCA), was then added to the sample at a concentration of 10 ng/l. The sample was heated to 50 +/- 1.5 °C in a water bath. An SPME fiber (Supelco # 57348 U) was injected through the septum into the gas-phase headspace (approx. 11.0 cm<sup>3</sup>) above the sample. The sample was maintained at the elevated

temperature and stirred for 30 minutes. The SPME fiber was removed from the vial and inserted into the gas chromatograph injector at 250 °C for 5 min. to desorb compounds from the fiber. Compounds were eluted from the column and analyzed using selective ion storage (m/z values: 95 for MIB; 112 for geosmin; 152 for citral; 165 for TCA). Spectrum peaks identified as citral, MIB, geosmin, and TCA were analyzed for area under the peak (a measure of total ion count). Compound concentrations were calculated from predetermined calibration curves generated from commercially available products (citral, Aldrich #C8300-7; MIB/geosmin mixture, Supelco #47525-U; TCA, Aldrich #23539-3). Odor profile analysis (OPA) panels were assembled on two occasions at Arizona State University to determine odor threshold concentrations for MIB, geosmin and citral using the human sense of smell. The panel was also used to elucidate the citral and PAC concentrations necessary to mitigate or remove the odors associated with different concentrations of MIB and geosmin from the water. The OPA panel was subjected to a matrix of samples which contain either 0 or 50 ng/L of both MIB and geosmin, a concentration range of citral from 0-100 nl/L, and PAC concentrations from 0-600 mg/L. The City of Chandler flavor profile analysis (FPA) panel was also used to test for the presence of taste and odor compounds using the human senses of taste and smell. The panel rated each sample on a scale of 0 to 1 based on the intensity (0=undetectable to 1=most intense) of a variety of tastes and odors, e.g., earthy, musty, chlorine, septic, etc. The panel was conducted weekly from July to November 1999 and tested water samples from the canal intake, sedimentation basins, filtered water storage and finished water. The weekly results were used in a 15-week study that compared the efficiency of Chandler's FPA panel to the GC/MS results generated at Arizona State University on parallel water samples. Chandler operators conducted weekly tannin/lignin tests (Method 5550-B; Standard Methods for the Examination of Water and Wastewater (18th Edition/1992) on water samples from the canal intake, sedimentation basins, filtered water storage and finished water. The potential for using tannin/lignin concentrations to predict future taste and odor episodes was investigated by comparing the weekly tannin/lignin results to the GC/MS results generated at Arizona State University on parallel water samples during the 15-week comparative study.

## **Principal Findings and Significance**

Sampling and subsequent isolations indicate that taste and odor compounds most likely originate in "hotspots" along the canals rather than being distributed uniformly throughout the supply system. Detectable earthy/musty odors occurred intermittently along the supply system, as opposed to similar intensities at each site. Approximately 40 organisms (algae) have been isolated. Three of these isolates, two *Oscillatoria* spp. and *Pseudanabaena* sp. appear to be MIB and/or geosmin producers. These results must be verified using GC/MS after individual organisms have been cultured in larger quantities. These results are significant because the cost of the current approach of applying chemical treatments to the entire system to eliminate taste and odor problems may be reduced substantially if treatment efforts can be concentrated at supply system "hotspots". OPA panel results suggest that a citral concentration of 100 nl/L renders 50 ng/L of each MIB and geosmin undetectable and concentrations as low as 10 nl/L make 50 ng/L of each MIB and geosmin barely detectable to the human sense of smell. GC/MS results revealed that citral masks the tastes and odors associated with MIB and geosmin. At the concentration used, citral also imparted a "citrus" aroma to the water. MIB, geosmin and citral were all detected at their original concentrations (100 ng/L) when water was spiked with all three compounds. There was neither an indication that citral initiated a chemical change in MIB or geosmin, nor that citral increased the binding efficiency of PAC. Despite the initial promise of using citral as a cost efficient alternative or supplement to PAC, citral was found to be an oily compound that was not readily miscible in water. At the present time, additional research is required to determine whether citral may be mixed thoroughly enough with supply water during water treatment to make its use feasible and cost effective. The propensity for citral to float on the water surface

currently renders its use a non-viable solution for treating taste and odor problems. Due to the oily characteristic of citral, we were unable to determine the optimum citral:PAC ratio for maximum reduction of taste and odor compounds. Therefore, pilot-scale studies were not conducted. As a result of the difficulty associated with using citral for water treatment, we examined an additional question with a direct impact on water treatment efficiency and cost for the City of Chandler. A collaborative study examined weekly water samples for 15 weeks from Chandler's canal intake, sedimentation, filtered water storage and finished water. The study was designed to 1) correlate the effectiveness of the City of Chandler's FPA panel measurements for monitoring taste and odor compounds with GC/MS results at Arizona State University, and 2) determine whether the tannin/lignin concentration in the supply system is a reliable predictive indicator of future taste and odor episodes. Taste and odor results from Chandler's FPA panel were compared to actual MIB and geosmin concentrations determined by GC/MS analyses at Arizona State University. Chandler operators performed tannin/lignin tests on the same samples. Although results were variable, comparison of the Arizona State University GC/MS results with City of Chandler's FPA panel odor and taste results revealed that the FPA panel results were much more reliable at detecting the presence of taste and odor compounds (MIB and geosmin) in water samples than could be predicted by tannin/lignin concentrations. The results support the use of the City of Chandler's FPA panel as a fairly accurate and cost efficient way to quickly assess water quality before it reaches consumers. No relationship appeared to exist between the MIB and geosmin results from GC/MS and weekly tannin/lignin concentrations.

### **Descriptors**

2-methylisoborneol (MIB), geosmin, taste and odor problems, earthy/musty odor, water treatment, blue-green algae, cyanobacteria, citral, powder activated carbon (PAC)

### **Articles in Refereed Scientific Journals**

None

### **Book Chapters**

None

### **Dissertations**

None completed, but one in progress as follows: Dempster, Thomas A. "Taste and Odor Problems in Water Supplies in Phoenix Metropolitan Area" Ph.D. Dissertation Department of Plant Biology, Arizona State University, Tempe, AZ 85287-1601

### **Water Resources Research Institute Reports**

None

### **Conference Proceedings**

In Preparation

### **Other Publications**

None

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## Basic Project Information

Basic Project Information	
Category	Data
Title	Isotope Biogeochemistry of an Ephemeral Drainage
Project Number	B-99-03
Start Date	03/01/1999
End Date	02/28/2000
Research Category	Ground-water Flow and Transport
Focus Category #1	Geomorphological and Geochemical Processes
Focus Category #2	Hydrology
Focus Category #3	Surface Water
Lead Institution	The University of Arizona

## Principal Investigators

Principal Investigators			
Name	Title During Project Period	Affiliated Organization	Order
David Greg Williams	Assistant Professor	The University of Arizona	01

## Problem and Research Objectives

Ephemeral channels are integral components of groundwater/surface water systems in arid basins of the Southwest, yet we have inadequate knowledge of pattern and process relating to water movement through these systems. Specifically, knowledge on transpiration losses from groundwater and soil by dominant woody riparian species and details of recharge in specific ephemeral drainages are lacking. Surface/groundwater models, for example, do not take into account the potential for plant roots to passively redistribute water from groundwater to dry surface soil layers. Passive redistribution of water by plant roots in these riparian systems may have consequences for total evapotranspiration and affect hydrological fluxes at the basin scale. We propose a suite of hydrological and ecophysiological isotope studies at Walnut Gulch in southeastern Arizona to characterize the fate of water moving through a representative ephemeral drainage in a semi-arid region. We had four objectives for the study: 1) assess the magnitude and seasonality of ephemeral channel recharge, 2) monitor the dynamics of transpiration and water movement through a flumed reach along an ephemeral channel at the event time scale, 3) assess the magnitude, seasonality, and species specificity of soil water redistribution by plant roots in phreatophytic vegetation, and 4) compare isotope, sap flow, and psychrometric methods for estimating plant hydraulic redistribution of soil water.

## Methodology

Our study area was along a flumed reach of the USDA-ARS Walnut Gulch Experimental Watershed in Cochise County, Arizona. We quantified plant transpiration (one component of transmission loss)

within this using sapflow measurements. We measured stable isotopes of  $H_2O$  to investigate the timing and quantity of runoff from ephemeral channels that recharges the shallow and regional aquifer by sampling shallow and deep wells within and adjacent to the channel. Along with isotopes, intensity of runoff and recharge during flow events was measured between the flumed reach. Inflow/outflow between the reach was assessed with gauged flumes. Recharge intensity will be estimated from these data using well head pressure from piezometers. Combining these methods has allowed us to begin evaluation of the magnitude and seasonality of recharge and to monitor the fate of individual runoff events within the flumed reach. We are currently assessing and quantifying patterns of hydraulic redistribution by plant roots of woody plants occurring in the channel. This plant-mediated process potentially adds a measurable component to channel evapotranspiration. After intense rain events, the direction of hydraulic redistribution by roots may be reversed; plants may transfer water from the moist upper layer of soil to deeper soil layers facilitating taproot growth and deep percolation. We are now comparing three techniques to assess hydraulic redistribution by woody-plant root systems including isotope analysis, soil psychrometry, and root sap flow. We are examining the magnitude and pattern of woody plant hydraulic redistribution this season (2000) in the ephemeral channel.

### **Principal Findings and Significance**

Eight shallow wells within the perched aquifer system and four deep wells throughout the regional aquifer were instrumented with water level recorders in June, 1999 to gauge changes in depth before and after runoff events. Prior to the initiation of this monsoon season the perched aquifer system was nearly dry, the first time in almost 30 years of observation. In terms of both number and size of runoff events the 1999 monsoon season was the best observed in a number of years. Significant groundwater level response was observed in both the shallow wells monitored above flume 2 and in the deep wells above flume 1. The recorded well levels for three of the shallow wells above flume 2 responded rapidly after runoff events. The shallow well closest to the channel responded most rapidly after a runoff event. The time to water level response increased with increasing distance from the channel, as expected. The deep wells near flume 1 did not respond until nearly a month after the onset of monsoon runoff events. Water levels continued to increase in the deep wells for roughly 6 months. The maximum increase in water levels in the three deep wells ranged from 4 to approximately 5.2 feet. Our approach also uses stable isotopes ( $^2H$ ,  $^{18}O$ ) to estimate the timing and quantity of surface water runoff from ephemeral channels recharging into the regional aquifer. To collect runoff water, pump samplers were placed at flume 6 and flume 2 to collect water incrementally during runoff events. These units were installed in June, 1999 and successfully sampled all runoff events during the 1999 monsoon. Wells extending to the regional aquifer were sampled before the monsoon to obtain a base line isotope value. These wells, along with the shallow wells within the perched aquifer were sampled extensively during and after the monsoon. Likewise rainwater was collected throughout the rainy season adjacent to both flumes and at the USDA-ARS Tombstone location after individual rain events. A significant number of runoff and groundwater samples from wells were collected prior to and after the monsoon of 1999. We were concerned that the stable isotope composition of water withdrawn from deep wells would be poorly mixed with the surrounding aquifer and that the isotope signature might be altered in the well casing. However, water taken before and after pumping from well casings showed no change in deuterium or  $^{18}O$  values. We are still in the process of analyzing rain, runoff, and well samples for stable isotope composition from the 1999 monsoon. However, initial results look very promising; runoff water was evidently transmitted to deep wells. The stable isotope composition of monsoon rain and runoff water was unexpectedly depleted in the heavy isotopes (highly negative D and  $^{18}O$  values) compared to typical values for the summer period. This did not hinder our ability to use isotopes of hydrogen and oxygen to trace the movement of runoff water to the deep aquifer since the isotope

composition of the runoff water deviated significantly from that of the deep aquifer. Isotope values measured from deep wells were typical of those for the regional aquifer on the east side of the basin. Deuterium ratios (D) ranged from -55 to -45 per mil (‰) prior to the 1999 monsoon runoff events. The two most positive values observed prior to the monsoon were from the Scheffli Monument (D = -44 ‰), a relatively shallow well located between Flume 1 and 2, and Montillo Flat (D = -45 ‰), a deep well below Flume 1. Isotope values for these two wells shifted toward runoff values after the runoff events (they became more negative in D and  $^{18}\text{O}$ ). Evidently, direct recharge from runoff to these deep aquifer locations occurred. We do not yet have enough of the samples analyzed to resolve the spatial and temporal pattern of recharge to the deep aquifer, but it appears that recharge is taking place mostly in the lower sections of Walnut Gulch. Isotope values from wells above Flume 2 (e.g., near the shooting range) did not show any isotopic evidence of recharge. To address objective 2, we are directly assessing ephemeral channel vegetation ET by measuring stem sap flow using the heat pulse velocity approach. Heat pulse systems were in place at two locations near flume 2 during the growing season (June-October) in 1999. Sap flow data will be scaled by measuring stem sap wood area and leaf area throughout this stream reach. These data will be used to constrain Penman-Monteith model estimates of ET. Also, plant stems were collected throughout the growing season of 1999 to determine the isotopic value of stem water, and hence, estimate the source of transpired water (i.e. groundwater versus surface soil water). Our efforts to this point have been to analyze the water samples for stable isotope composition. We are not yet prepared to show tree transpiration data (sap flow) from the flumed channel.

## **Descriptors**

Arid climates, Groundwater Hydrology, Hydrogeology, Isotopes, Riparian Vegetation

## **Articles in Refereed Scientific Journals**

None

## **Book Chapters**

None

## **Dissertations**

None

## **Water Resources Research Institute Reports**

None

## **Conference Proceedings**

None

## **Other Publications**

None

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## Basic Project Information

Basic Project Information	
Category	Data
<b>Title</b>	Physical Effects of Flood Flows on Seedling Growth and Survivorship: Comparative Responses of Native Riparian Trees and Shrubs to Saltcedar
<b>Project Number</b>	B-99-05
<b>Start Date</b>	03/01/1999
<b>End Date</b>	02/28/2000
<b>Research Category</b>	Biological Sciences
<b>Focus Category #1</b>	Ecology
<b>Focus Category #2</b>	Floods
<b>Focus Category #3</b>	Wetlands
<b>Lead Institution</b>	Arizona State University

## Principal Investigators

Principal Investigators			
Name	Title During Project Period	Affiliated Organization	Order
Juliet Clare Stromberg	Assistant Professor	Arizona State University	01

## Problem and Research Objectives

Native riparian forests, vegetated by Fremont cottonwood (*Populus fremontii*) and Goodding willow (*Salix gooddingii*), have declined in Arizona. Altered water regimes have caused much of the degradation of cottonwood-willow forests, regionally and nationwide (Fenner et al. 1985, Rood and Heinze-Milne 1989, Rood and Mahoney 1990, Howe and Knopf 1991, Busch and Smith 1995, Stromberg et al. 1996, Scott et al. 1999, Shafroth et al. 2000). Dams and diversions modify surface flow rates, flood periodicity, and sediment and nutrient transport, often to the detriment of riparian plants. Many of the water regime changes inhibit recruitment and/or establishment of native plants, and, thus, create "functional gaps" in riparian communities. These un-occupied niches become prime colonization sites for more opportunistic, stress-tolerant, or xerophytic plants, and can trigger large-scale replacement of biodiverse riparian forests by homogeneous stands of "weedy" native plants or exotic species. Probably the most widely noted exotic invader of southwestern riparian areas is saltcedar or Eurasian tamarisk (in our region, *Tamarix ramosissima*). *Tamarix ramosissima* and the closely-related shrub species, *T. chinensis*, and *T. pentandra* have become the dominant woody species in many riparian areas. *Tamarix* appears to proliferate at higher rates and densities on dammed, flow-managed, heavily-utilized, and salty rivers; however, broad geographic studies are needed to quantify

and document the site factors associated with greatest *Tamarix* abundance. Among the autecological factors that may contribute to the success of *Tamarix* species along southwestern rivers include a high degree of stress tolerance and a high degree of reproductive plasticity. *Tamarix* has been reported to be more drought tolerant than many native riparian pioneer trees (Horton et al. 1960, Horton 1972, Busch and Smith 1995, Cleverly et al. 1997, Smith et al. 1998, Shafroth et al. 2000). It has a greater ability to utilize deeper groundwater than some, more shallow-rooted, riparian species (Gary 1963, Brotherson and Winkel 1986), but also has high ability to draw upon surface water sources, such as precipitation and floodwater, to supplement inadequate available groundwater (Gary 1963, Horton 1972, Busch and Smith 1995, Smith et al. 1998). Some studies (Busch and Smith 1995, Cleverly et al. 1997, Smith et al. 1998) report that *Tamarix* has a higher water use efficiency than native *Populus* and *Salix* species, though Glenn et al. (1998) indicates that it does not. Additional research is needed to gain a full understanding of the water-relations of *Tamarix*, however, it appears to be generally well-equipped to survive along waterways which are experiencing either continued lowering of the water tables or highly variable water levels. *Tamarix* is more salt tolerant than many native *Populus* and *Salix* species, and as a halophyte, is capable of great osmotic adjustment in saline soils (Decker 1961, Brotherson and Winkel 1986, Busch and Smith 1995, Shafroth et al. 1995, Glenn et al. 1998, Smith et al. 1998). *Tamarix ramosissima* can successfully germinate at salinity levels much greater than *P. fremontii* and *S. gooddingii* can tolerate (Shafroth et al. 1995). Under saline conditions, mature *Tamarix* absorb dissolved solids with water and exude the excess through glands in the leaves (Decker 1961), possibly exhibiting a form of allelopathy to surrounding vegetation. This may be an important factor contributing to its spread, since the accumulation of leachates from agricultural run-off and salinization of evaporating reservoir waters has increased the salinity level in many rivers (Everitt 1980). Floodplain soils along below-dam reaches without cleansing floods and in *Tamarix*-dominated areas where secreted salts accumulate have probably also become more saline (Anderson 1995, Shafroth et al. 1995, Smith et al. 1998). The timing of flood flows is critical to native species, which have evolved to produce seed concurrent with spring flood high waters; even small differences in the timing of spring floods can influence relative recruitment success between species due to phenology (Stromberg et al. 1991). *Tamarix* may be less dependant on specific fluvial processes, allowing it to establish more readily on flow-regulated rivers where natives have declined. It is known to produce large quantities of seed throughout most of the growing season in contrast to many native *Populus* and *Salix* species which disperse seed only in the spring (Horton 1957, Warren and Turner 1975, Stromberg 1997, Shafroth et al. 1998, Cooper et al. 1999). *Tamarix*'s longer dispersal period may augment its establishment potential since viable seed would be present to exploit favorable germination conditions created by floods of various timing. Changes in flood regimes also may influence the relative abundance of *Tamarix*, *Populus*, and *Salix* by modifying flood mortality processes. Everitt (1980) suggests that *Tamarix* competes better with native vegetation on regulated rivers because it does not do well under conditions of frequent or severe flooding. *Tamarix* seedlings are thought to be less tolerant of physical fluvial processes, such as sediment burial or scouring, than native *Salices* (Warren and Turner 1975, Stromberg 1997), but more tolerant of prolonged inundation (Horton et al. 1960, Warren and Turner 1975). However, there is some evidence that first year *T. ramosissima* seedlings are less able to survive prolonged inundation than natives (Gladwin and Roelle 1998). *Tamarix* may have higher mortality to flooding because it often establishes late in the growing season during low flow where damage from additional summer flooding is probable (Stromberg 1997). Also, there may be physiological differences between species in tolerance for flood scour or sediment burial that should be experimentally tested (Stromberg 1997). Much research has focused on controlling the spread of *Tamarix* by chemical and/or mechanical methods (Barrows 1993, Sudbrock 1993, Brock 1994, Stevens and Walker 1998, Taylor and McDaniel 1998). Some chemical/ mechanical methods have met with success in specific, isolated locations (Barrows 1993), but on a large scale, chemical and mechanical methods of removal are often expensive, time and work intensive, and usually have to be repeated annually (Brock 1994, Anderson 1995). In addition, both can be damaging to the

environment. Recently, biocontrol has gained some support as a more ecologically-friendly means of control (Watts et al. 1977, De Loach 1997, Thomas and Willis 1998). However, since scientists can't really control biology, adding yet another foreign agent to an ecosystem may result in unforeseen consequences. It may be time to stop focusing on how to remove the invader itself, and to start investigating how to remove the ecological stressors that are the underlying cause of the invasion. Ecological control is an alternative method to curb the spread of exotic species and restore native species abundance. Ecological control involves manipulating environmental factors such as fire and water flow in a way that provides a competitive edge to target native species against the invasive species (ESA Fact Sheet on Invasive Species, <http://esa.sdsc.edu/invas3.htm>). There is some evidence that self-repair is possible in some damaged riparian ecosystems, if we can reinstate the key environmental factors that have been altered or eliminated: *Tamarix ramosissima* has been declining unaided along some perennial reaches of the San Pedro River where hydrologic and livestock grazing conditions have recently shifted to favor establishment of native cottonwood and willow species (Stromberg 1998). Additionally, populations of *Populus* have been restored to some below-dam reaches in response to controlled flood releases with appropriate timing and rate of change (Rood and Mahoney 1990, Gourley 1997, Shafroth 1998). *Tamarix*'s steady advance into areas that formerly supported native plants has generated much research into its assumed competitive abilities. However, further research is necessary to more fully understand, and to ultimately restore to altered rivers, the ecological conditions and processes under which the native species are more competitive (Anderson 1995, Stromberg 1997, 1998, Briggs and Cornelius 1998, Lovich and De Gouvenain 1998, Cooper et al. 1999). Our objectives were 1) to determine relative seedling growth success and survival thresholds of four dominant woody riparian species (*Populus fremontii*, *Salix gooddingii*, *Baccharis salicifolia*, *Tamarix ramosissima*) in response to the physical fluvial processes of (a) sediment burial and (b) simulated scour and; 2) to prescribe ecological methods for curtailing the spread of *Tamarix* and restoring native trees to dominance.

## Methodology

Seedlings of 2 riparian tree species (*P. fremontii* and *S. gooddingii*) and 2 riparian shrub species (*B. salicifolia* and *T. ramosissima*) were experimentally buried with sediment at progressive time intervals up to 90 days. Treatments varied in terms of depth deposited (1 & 2 cm) and method of application (undisturbed sifting or forceful burial). In sifting treatments, the sediment was applied through a 2 mm standard sieve over the top of and around the seedlings. In most cases, smaller seedlings were bent over by the weight of the sediment and were either completely or partially buried, but were not physically disturbed prior to deposition. As sift-treated seedlings grew larger, sediment would cover only the lower stem leaving the foliage generally unaffected above the soil surface. In burial treatments, seedlings were forcibly prostrated prior to deposition and the full treatment depth was deposited over the seedling, completely covering the plant. Sediment was sifted through a 2 mm standard sieve prior to burial. The burial method became progressively more difficult to perform as seedlings grew taller. Tall seedlings had to be twined around the pot multiple times in order to flatten them and some stems may have broken. We conducted three sets of similar sediment burial experiments in an attempt to determine the best methodology. All experiments were conducted in greenhouses at Arizona State University with evaporative coolers to maintain humidity and lessen extreme high temperatures. All seed was collected at local rivers. Seeds were sown in plastic pots on sandy loam (approximately 77% sand, 7% clay, 16% silt) soil collected from the dry riverbed of the Salt River. Soil was kept moist by bottom watering. All pots were over-seeded and thinned to the experimental target number (10 or 3 per pot) prior to the first treatment. Some pots had less than the target number. Pots were randomly assigned to treatment groups by age, sediment depth, and method of sediment application. Growth measurements were recorded immediately prior to treatment.

Measurements taken per pot were maximum standing height, maximum shoot length (non-vertical *T. ramosissima* stems were measured along their entire stem axis), maximum shoot number, maximum branch number, maximum leaf number, and maximum leaf length. Measurements were taken on all seedlings but only the maximum values per pot were recorded. Survivorship was recorded 7 to 11 days after treatment, depending on experiment. Percent survival was calculated per pot.

## Principal Findings and Significance

Sediment sifting experiments Our studies indicated that at an early age, *P. fremontii* had significantly greater ability than *T. ramosissima*, *S. gooddingii* and *B. salicifolia* to survive 1 cm sifted sediment deposition (Experiment 4). However, as the seedlings aged and became taller (by day 36), survivorship of *S. gooddingii* and *T. ramosissima* approached or equaled that of *P. fremontii*. Conversely, *B. salicifolia* seedlings grew poorly and had low survivorship throughout experiment 4. *Populus fremontii* was the tallest at the first treatment date (2.2 cm at seedling age 14 days;) and had the highest survivorship of all four species ( $93 \pm 13\%$ ). *Populus fremontii* maintained highest survivorship at the second treatment date ( $80 \pm 16\%$  at 25 days), even though *T. ramosissima* was slightly taller (3.8 cm vs 2.9 cm for *P. fremontii* at seedling age 25 days). Compared to both *P. fremontii* and *T. ramosissima*, seedlings of *S. gooddingii* grew very slowly at first and had low survivorship at the early treatment dates ( $< 7\%$  through day 25). Size and survivorship of *S. gooddingii* and *T. ramosissima* sharply increased by treatment day 36. By 36 days, *P. fremontii*, *S. gooddingii* and *T. ramosissima* all had high survivorship. Two cm of sifted sediment deposition caused high mortality of *B. salicifolia* and *T. ramosissima* seedlings up to 56 days old ( $< 50\%$  survivorship through day 56; Experiment 1). Pair-wise comparisons at specific treatment dates showed no significant differences in survival between the two species. However, there was a significant difference between experimental treatment groups overall when *T. ramosissima*-edge seedlings were eliminated from the analysis (Edge seedlings were those that survived because they fell against the pot edge and were physically held above the soil surface during treatment). Seedling height was similar between *B. salicifolia* and *T. ramosissima* throughout experiment 1; *B. salicifolia* was statistically taller overall ( $p < 0.01$ ), most noticeably during the first 36 days of the experiment. Survivorship overall was greater in the sifting treatments than the burial treatments. Few seedlings of any species survived complete burial treatments ( $< 50\%$  for all species and all burial experiments through 68 days of age). Although scattered seedlings of *B. salicifolia*, *P. fremontii* and *S. gooddingii* showed initial recovery after 1 cm burial, none survived to the conclusion of the glasshouse experiments (Experiments 5, 6). Only *T. ramosissima* exhibited any ultimate survival to either 1 cm or 2 cm complete burial (Experiments 5, 6). *Tamarix ramosissima*'s increased survivorship was significant when all seedlings were included in the analysis. However, when the edge-affected seedlings were eliminated from the analysis, *T. ramosissima* survivorship was not significant (edge seedlings were those that survived because they fell against the pot edge and were physically held above the soil surface during treatment). Some *B. salicifolia* seedlings did survive 1 cm complete burial to the conclusion of the second greenhouse experiment along with *T. ramosissima* (Experiment 2), however, none survived 2 cm burial (Experiment 3). There were no *T. ramosissima* survivors after the edge-affected plants had been eliminated from the analysis (Experiments 2, 3), which was significant in experiment 2. It was not significant in experiment 3 because neither *B. salicifolia* nor *T. ramosissima* had any long term survivors. *Tamarix ramosissima* was generally taller than *B. salicifolia* throughout experiments 2 and 3 (height data not shown). Seedling size and growth patterns Survivorship increased in all four species as seedlings aged and grew taller. *Populus fremontii* was significantly taller than all three other species on day 14 ( $p < 0.01$ ; height data not shown). Mean *T. ramosissima* seedling height was slightly greater than mean *P. fremontii* height by day 25, but was not found to be statistically significant. On day 36, *T. ramosissima* was significantly taller than *P. fremontii* ( $p < 0.01$ ). *Tamarix ramosissima* was significantly taller than *B. salicifolia* and *S. gooddingii*

at each treatment date throughout the experiment ( $p < 0.01$ ). *Tamarix ramosissima* was consistently taller over the course of the experiment, determined by the Wilcoxon signed rank test on height averages across treatment dates ( $p < 0.05$ ). Further analysis on seedling height and its effects on plant survivorship to sediment deposition is in progress and will be detailed in a later publication. Descriptive growth measurements such as seedling leaf number, stem length, stem number and branch number all showed increasing trends with age, similar to plant height (data not shown). Stem number and length in *T. ramosissima* proved to be of some additional interest. *Tamarix ramosissima* stem number increased steadily until about 40 days of age, then leveled off, and began to decrease around day 60. When *T. ramosissima* is young, it often grows multiple horizontal stems in addition to a few main vertical stems. We found that the horizontal stems tend to be longer than the vertical ones until about day 45, at which time they begin to die off and are overtaken by the vertical stems. Additional analysis relating descriptive growth measurements to seedling survival of sediment burial will be conducted and detailed in a later publication. We know that many managed rivers have lost substantial portions of native riparian woodland. The regenerative role of natural flood cycles on seedling recruitment has been a major focus in restoration work, however, few studies have looked at how plant recruitment is affected by physical flood components like sedimentation and scour. Sedimentation is especially interesting because it holds a dual role. Sediment deposited by spring floods creates initial seed beds for germination. Later in the growing season sediment deposited on new seedlings can kill them, but also can create fresh seedbeds for seeds yet to be dispersed. Variations in the amount (and probably texture) of the sediment deposited, and the timing relative to seed dispersal phenology, will exert positive or negative effects, depending on the species. Unregulated rivers of the arid southwestern United States typically carry high sediment loads, and many have an unusual, bi-modal flood pattern (i.e., winter and summer floods). Spring-germinating seedlings of native riparian tree species may be well-adapted to withstand mid-summer floods and sedimentation. However, exotics, like *T. ramosissima*, may be less well adapted, one possible factor restricting their abundance establishment on free-flowing, frequently flooding rivers. A high stem growth rate is one factor that may reduce the likelihood of complete burial by summer flood-deposited sediment. Our experiments show that at an early age *P. fremontii* is taller and has greater ability than *T. ramosissima* to survive sediment deposition. *Tamarix ramosissima* had higher survivorship than the native species only when it was taller than they. However, seedling heights between our experiments differed greatly both between and among-species (e.g., *B. salicifolia* mean height = 3.5 cm at 42 days of age in Experiment 1, but only 0.7 cm at 45 days of age in Experiment 4; ), indicating that plant growth and resulting seedling tolerance to sedimentation are strongly context dependent. We don't fully understand how interactions of abiotic factors, such as soil moisture, temperature, and salinity, influence relative growth rates of the native and exotic riparian species. Previous work has shown that salinity causes more reduction in growth rate of natives than of *T. ramosissima* (Glenn et al. 1998); and there is evidence that *T. ramosissima* is more drought tolerant than many natives (Shafroth et al. 1995, Glenn et al. 1998, Smith et al. 1998). Thus, relative differences in seedling growth rates and survivorship of floods and sediment deposition will vary depending on how the river is managed in terms of base flows, water tables, and salinity levels. There are other factors in addition to height growth that affect a seedling's ability to survive flood sedimentation and scour. Seedlings of *P. fremontii* had shorter stems than *T. ramosissima* at day 25, but *P. fremontii* had the significantly higher survivorship. Seedlings of both species were taller than the 1 cm of sediment sifted over them. This pattern may be a function of plant growth form. The native seedlings we studied had more sturdy, erect stems than *T. ramosissima* (personal observation), which might enable them to remain upright under the weight of deposited sediment. Young *T. ramosissima* stems tend to be flaccid, and may be more easily prostrated and buried by sediment than the stems of the natives. In our experiments, we found that a *T. ramosissima* seedling tended to have higher survival when its frail stems were supported by pot edges. Many of *T. ramosissima*'s early shoots are fully horizontal, and can extend along the ground some distance. Although this trailing growth form may allow for easy sediment burial, the

presence of multiple-stems may give *T. ramosissima* an alternate competitive advantage. If, by chance, any one stem happens to emerge through the layer of deposited sediment the plant has a high chance of surviving. Not all flood-induced seedling mortality is caused by sediment deposition; sometimes seedlings are uprooted and washed downstream by scouring flows. Rapid root elongation may provide some insurance against being dislodged by scouring flows, however, our study did not address this aspect of riparian plant ecology. A seedling's leaf morphology may also affect its ability to either repel or collect sediment or other flood-borne debris.

**Descriptors**

Aquatic Plants, Channels, Evapotranspiration, Instream Flow, Plant Growth, Riparian Vegetation, Rivers

**Articles in Refereed Scientific Journals**

None

**Book Chapters**

None

**Dissertations**

None

**Water Resources Research Institute Reports**

None

**Conference Proceedings**

None

**Other Publications**

None

**Basic Project Information**

<b>Basic Project Information</b>	
<b>Category</b>	<b>Data</b>
<b>Title</b>	Partitioning the Causative Factors of Evapo-sublimation
<b>Project Number</b>	B-99-04
<b>Start Date</b>	03/01/1999
<b>End Date</b>	02/28/2000
<b>Research Category</b>	Not Applicable
<b>Focus Category #1</b>	Climatological Processes

<b>Focus Category #2</b>	Geomorphological and Geochemical Processes
<b>Focus Category #3</b>	Surface Water
<b>Lead Institution</b>	Northern Arizona University

### Principal Investigators

<b>Principal Investigators</b>			
<b>Name</b>	<b>Title During Project Period</b>	<b>Affiliated Organization</b>	<b>Order</b>
Charles C. Avery	Professor	Northern Arizona University	01
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### Problem and Research Objectives

Evapo-sublimation is the pathway(s) by which snow vaporizes: snow that doesn't melt can still "disappear" or evaporate. Under certain conditions, this pathway can account for snow ablation at a rate that—extrapolated over an average season—amounts to the total of all snowfall received during this average winter! For this and other reasons, a former Soil Conservation Service Snow Survey supervisor in Wyoming called evapo-sublimation "a thief that steals our water." To date, however, it is unclear exactly what factors influence this process and to what degree. Control and estimation of future losses due to evapo-sublimation depend on knowing its cause. Correlations can only point to intriguing questions. This research project was envisioned and funded to unravel some of those correlations. It began on 1 March 1999. Its primary objective was the enhancement of a mechanical device designed to determine evapo-sublimation rates. The device has the electronic capability for "real-time" recording of this dependent variable so that, after altering one or several independent variables, changes in evapo-sublimation rates could be noted. The secondary objective was statistical interpretation of the data derived from this device. The data recorded would then be subjected to stepwise multiple-regression analysis as well as simple regression analysis and the results would show how these factors interact. The monitored independent factors were temperature, wind speed, relative humidity, and solar radiation. These factors may influence evapo-sublimation rates, since they provide physical control over the rate of vaporization, and they may be relatively easily to simulate in environmental chambers. Other factors, such as ambient air pressure, were not selected as their control was considered too complex. Previous work by the principal investigators had produced a measurement tool that was based on the conservation of mass. It and its improvements are described later in this report. Early efforts by other investigators used this mass balance approach because of its elegance (or simplicity). It seemed appropriate to our situation. The purpose of this report is to document what was accomplished during the period that project funding was available from the Arizona Water Resources Institute. Data were collected during the period 1 March 1999 to 15 April 2000. Because of vagaries in the snowfall pattern throughout this period of time, not all aspects of the intended study were accomplished. Information derived from snowfalls of "Late Winter 1999," "Early Winter 1999-2000," and "Late Winter 2000" were used. This undertaking depended greatly on the local weather for the availability of natural snow. No one is quite sure of the details of snow evapo-sublimation. Does all of the ice first turn to water, or make use of a quasi-liquid "skin", which then evaporates? Does ice somehow "jump" across the triple point—a combination of temperature and pressure at which water can exist in all three phases simultaneously—and vaporize without melting? Snow has certain physical, as well as chemical, characteristics and physical laws govern any change-of-phase of this substance. When ice melts it absorbs its latent heat of fusion at the rate of 80 calories per gram from its surroundings; when water evaporates it incorporates 586 calories per gram into its

vapor state. Since some water, in a liquid state, is held in the pores of the snowpack, the amount of energy needed to release one gram of water from the snowpack is  $80 \times$  (1-fractional water content by weight) calories. The ratio of the weight of ice to the total weight of a unit volume of snow is often called the "snow quality index" and it usually varies from 0.9 to 1. The value can be determined calorimetrically. It seems reasonable to assume that at very low pressures both water vapor and liquid water would be present in the snowpack. The saturation vapor pressure of water at  $0^{\circ}\text{C}$  is equal to 6.13 mb, but to detect water vapor in snow would require advanced methodology. Perhaps "snow quality" should also include water vapor presence. "Snow quality" can also refer to other physical factors such as density, vapor pressure over the surface, and metamorphic state. This study did not include any index related to snow quality.

## Methodology

Fully instrumented field studies of snow evapo-sublimation carried out in winter-weather conditions are difficult to execute. In addition, it is difficult to control the numerous variables so that the effect of just a single variable can be measured. The objectives of this study dictated the use of a more controlled environment where a scaled mass balance approach could be used to separate melt from evapo-sublimation. The various contributing environmental factors could be changed one at a time and a stepwise regression model could be developed. We designed and built a relatively well-sealed evapo-sublimation tunnel that could be used inside the controlled temperature environment of a walk-in cold room. The principal function of the evapo-sublimation tunnel is to provide a closed system for conditioned air and energy flow over a lysimeter containing a small sample of natural snow. Space is provided within the system, both fore and aft of the lysimeter, to house various sensors for radiation, humidity, wind speed and temperature. Fans, heaters and drying chambers can be inserted into the system for environmental control. The tunnel is constructed around an angle-aluminum frame covered with Plexiglas sheet. The dimensions of the active area of the tunnel are approximately 0.5 m wide, 0.5 m tall and 2.0 m long. Both ends of the tunnel are fitted with a honeycomb arrangement of 10-cm long PVC pipe segments contained within a frame. The honeycomb is used to improve laminar characteristics of the airflow. Beyond the honeycomb, mounts allowed affixing a variety of inlet and outlet manifold configurations. The tunnel is fitted with a horizontal floor positioned 20 cm above the tunnel base. The floor approximates the surrounding snow surface and contains a square hole to accept a snow lysimeter with the lip of the lysimeter positioned even with the floor. The bulk of the lysimeter, its attendant Ohaus CT6000 digital balance, sensor mounts and accessories are positioned beneath the floor. The lysimeter itself is a 0.3-m x 0.3-m x 0.06-m open top box constructed of Thermax rigid closed cell foam insulation. Joints in the box are waterproofed and a drain tube is led from the bottom of the foam box to a melt carboy located outside the tunnel. Both the lysimeter and the melt carboy sit directly on the pan of an Ohaus CT6000 digital balance. The lysimeter is of similar design to that we have used in previous field experiments. Environmental variables are simulated by using sun lamps for solar radiation, desiccant salts for humidity control and a blower for wind speed variation. While the limits of each environmental variable are more or less continuous over the device output range, three fixed settings for each variable (i.e. high, medium and low) are used to produce an easily repeatable experimental design matrix. We mark the three desired settings directly on various device controllers and then use environmental sensors (described below) to determine the actual engineering units of output for each level. The solar radiation level was varied by using a rheostat, the humidity level is varied by inserting different quantities of the desiccant salts spread on screen trays and wind speed is changed by a Vari-AC controller on the fan motor. Environmental conditions are monitored by standard environmental sensing techniques. Tunnel air temperature is monitored by two Campbell Scientific 107 thermistors, one positioned in the air stream forward of the lysimeter and one aft. Humidity is sensed by two Visala (Omnidata #ES-120) relative humidity sensors, one positioned in

the air stream forward of the lysimeter and one aft. Wind is monitored with two RM Young 3-cup anemometers, one positioned in the air stream forward of the lysimeter and one aft. Solar radiation is sensed with a LiCor pyranometer placed slightly above the center of the lysimeter. All electronic sensors are wired to a Campbell Scientific CR10X datalogger. The datalogger is programmed to read the sensor array output every 15 seconds and store a 5-minute average to memory. An experimental matrix is designed around various combinations of high-medium-low environmental condition settings. Each node of the matrix comprises an "experimental run." To begin the run, the operator loads the lysimeter with about 5 kg of natural snow, sets the environmental levels and monitors the progress of the experiment via computer monitor outside the cold chamber. Occasionally the operator checks the chamber and descriptively notes conditions during the run that may have an impact on the output data. Each run lasts at least one hour or until snow ablation is complete. During the course of a run, the snow ripens and any generated meltwater travels via the drainage tube from the lysimeter to the melt carboy. As the datalogger stores the 5-min readings, two mass values are recorded for each digital balance. The first value is the mean 15 sec value over the 5 min period and the second value is a "grab sample" taken instantaneously at the close of the 5 min interval. A comparison of the two values is used as an indicator of mass stability. The difference between any change in snow mass and meltwater mass should be a measure of evapo-sublimation taking place in the chamber. Assume, for example, that the snow lysimeter balance records an initial mass of 3000 g. After 15 min, snow mass is recorded at 2980 g, indicating a loss in mass of 20 g. Meltwater mass during the same period increases from 0 g to 15 g, leaving a difference of 5g of mass that should be is "lost" to evapo-sublimation. In actuality, the technique produces unstable results when meltwater is traveling through the tube. We are forced to use evapo-sublimation data that is generated prior to the delivery of melt water to the tube when the data appear stable. We will need to correct this problem for future experiments. In addition to recording the digital balances, the datalogger captures wind speed, radiation, relative humidity, and temperature values for each 5-min interval. All data are retrieved in comma delimited ASCII format for transfer into spreadsheet and statistical software for detailed analysis.

## **Principal Findings and Significance**

To generate data for the analyses, local snowfall was collected and stored inside coolers that were in turn stored inside a walk-in cold chamber. (Average temperature within the cold chamber ranges from 2°C to 5°C.) Stored snow was replaced by "fresh" snow whenever possible. Six combinations of laboratory-controlled environmental conditions were established and three sets of data were collected under each condition during April and May ("Late Winter") 1999. Twenty-four combinations of controlled environmental conditions were established for the 2000 runs, conducted between February and April this year. One set of 24 runs was completed, but area snowfall ended when only 20 of the 24 runs in the second set had been finished. Therefore only 44 runs of data, rather than 48, were collected between February and April 2000. 1999 data collection. For the 1999 runs only two environmental conditions—relative humidity and wind speed—were varied. Eighteen sets of evapo-sublimation data were collected. (Solar radiation effects were not simulated and any radiant energy measured was incidental, created when overhead lights inside the cold chamber were briefly switched on.) Environmental conditions for these runs therefore included: Humidity control on Humidity control off no wind medium wind high wind no wind medium wind high wind 2000 data collection. For the 2000 runs, three environmental variables—relative humidity, wind speed, and radiant energy—were simulated. Temperature was always recorded but it was not intentionally varied. The 24 sets of possible environmental conditions within the 2000 runs therefore included: Humidity control on LIGHT OFF wind off wind low wind med wind high LIGHT MED wind off wind low wind med wind high LIGHT HIGH wind off wind low wind med wind high Humidity control off LIGHT OFF wind off wind low wind med wind high LIGHT MED wind off wind low wind med wind high LIGHT

HIGH wind off wind low wind med wind high Preliminary analysis of data indicated a sharp break in evapo-sublimation values during most runs between those accumulated before melt began (i.e., while melt water weight < 1g), and those accumulated after melt began. To more closely identify the relationship between evapo-sublimation and the environmental variables, we therefore confined regression analysis to data collected during the period before melt began. Data analyzed were those collected at each 5-min data point after scale stabilization until melt water weight reached a value = 1 g. Runs during which melt began within 15 min were therefore dropped from analysis. Six runs from those conducted in 1999 were dropped, leaving 12 for analysis. Nine were dropped from the total set for 2000, leaving 35 for analysis, or a total of 47 data sets from both years' runs. The datalogger collected average weights, temperature, wind speed, relative humidity, and radiant energy values at each 5-min interval. Typically, scale weight values were stabilizing during the first 5 to 10 min of a run, and these fluctuating values were dropped from analysis. The length of time from scale stabilization to beginning of melt ranged from 25 to 110 min. Within each set, all data collected during this time were used to calculate an average value for each environmental variable. Total evapo-sublimation was calculated as g per hour. Data are summarized in the table below; average values are from the "fore" sensor of the two sensors installed to monitor each environmental variable. All data included in the analysis are listed in Appendix A.

### **Descriptors**

Atmospheric Processes, Evaporation, Fluid Mechanics, Ice, Model Studies, Snow

### **Articles in Refereed Scientific Journals**

None

### **Book Chapters**

None

### **Dissertations**

None

### **Water Resources Research Institute Reports**

None

### **Conference Proceedings**

None

### **Other Publications**

None

WATER RESOURCES RESEARCH CENTER University of Arizona water research data base. A searchable data base was constructed on the WRRC web site to track water-related research at the University of Arizona. University researchers submit information on their current research projects, including topic, funding source, and expected completion dates. At the present time, 55 projects in 22 departments are represented with a total of \$37,288,612 in funding. The intent of the data base is to provide better and more extensive information about water research conducted at the UA. <http://ag.arizona.edu/AZWATER/uaresearch/> Gila River Basin Restoration Workshop. WRRC organized this workshop in Tucson in April 1999, with assistance and funding from the U.S. Bureau of Reclamation and the Midcontinent Ecological Services Division of the USGS. The purpose was to inform participants of the latest information on riparian restoration in the Gila River Basin, which includes most of Arizona. Participants came from agencies, consulting firms, non-profit groups, and universities. A proceedings was published and is available in downloadable form on the web. <http://ag.arizona.edu/AZWATER/> Patrick B. Shafroth, Barbara Tellman, and Mark Briggs. Riparian Ecosystem Restoration in the Gila River Basin: Opportunities and Constraints. Workshop Proceedings. April 8-9 1999. Water Resources Research Center. Issue Paper 21. October 1999. "Water in the Tucson Area: Seeking Sustainability." As a community service WRRC staff wrote and published this comprehensive report on Tucson water issues, addressing such topics as water quantity, water quality, treatment options, water uses and conservation, etc. The report was done at the request of University of Arizona President Peter Likins, to provide information to the public about critical Tucson water issues. The report contributed to the public debate that was at that time in progress, with citizens making up their minds about a proposition included in an upcoming election. The proposition pertained to Tucson's future water supplies and was a controversial community issue. The report objectively provided the scientific and public policy background to enable citizens to make an informed and appropriate decision regarding Proposition 200. The report is available on the WRRC web site and includes an interactive water budget exercise. <http://ag.arizona.edu/AZWATER/> Its availability on the web site ensures greater public access to the document and encourages its continued use as a community reference. Joe Gelt, Jim Henderson, Kenneth Seasholes, Barbara Tellman and Gary Woodard Community speakers. With the publication of the sustainability report, WRRC gained greater visibility as a community resource, with various organizations contacting the center to provide speakers and presentations on Tucson water issues. During the pre-election period, WRRC staff spoke to approximately 50 groups, discussing the important water issues confronting the community. WRRC staff continue to be available for public presentations. Water education class. WRRC also was involved in a UA sponsored course offered to the public. The course was free and was conducted on two consecutive Saturdays. WRRC staff helped organize the course and provided speakers to address water economics, Tucson water history and other topics. WRRC also set up displays. Newspaper supplement. The WRRC staff also wrote a newspaper supplement focusing on Tucson water issues. Written, designed, and formatted by WRRC staff members, the color supplement was included in the Sunday edition of the "The Arizona Daily Star," Tucson's major newspaper. Sunday was chosen for greatest public exposure. Boundary Study. During this period WRRC completed work on a Colorado River boundary study for the Arizona State Land Department. The purpose was to assemble historic material about changing boundaries and land uses along the Colorado River to assist the department in determining boundary disputes. WRRC produced a summary history of the lower Colorado River and assisted in developing a comprehensive bibliography of river history, technology, legal action and surveys. Stantec Consulting and 4 authors including Barbara Tellman, WRRC. Preliminary Draft. Colorado River Boundary Study. February 2000. Portable Exhibit of History of the Santa Cruz River. With a grant from the Tucson-Pima County Historical Commission, WRRC staff developed a traveling exhibit on the history of the Santa Cruz River. This exhibit was used in schools, public meetings, and was borrowed by two non-profit groups, The Arizona Hydrological Society and the Santa Cruz River Alliance, for public meetings. Invasive Exotic Species in the Sonoran Region. WRRC staff edited a book based on the symposium with the same name held at the Arizona Sonora Desert Museum in the spring of 1998. This comprehensive book is nearing final preparation for publication by the University of Arizona Press. The book covers methods of introduction, impacts on ecosystems (aquatic, grasslands, etc.), laws, and methods of control. Staff also assisted the Arizona Sonora Desert Museum

in publishing a short booklet on the same subject and contributed articles for that, as well as speaking to several groups. An Overview of Watersheds and Watercourses in Pima County. WRRC staff worked with two consulting firms to produce a comprehensive report on watersheds and watercourses as part of a series of reports within the Sonoran Desert Conservation Plan. This report is a general introduction to the physical features of watercourses, with a specific look at the flooding characteristics of the major watercourses in the county. Barbara Tellman, John Wallace and Clint Glass. An Overview of Watersheds and Watercourses in Pima County. Produced for Pima County. April 2000. WATER EDUCATION FOR TEACHERS: PROJECT WET WRRC has an ambitious and productive K-12 water education program, known as Arizona WET (Water Education for Teachers) for in-classroom teachers and other educators. The Arizona Project WET coordinator is the representative for this state and part of an international network from all 50 states, Mexico, Canada and Pacific Islands. The coordinator also trains and maintains a network of Arizona facilitators to conduct Project WET workshops. The program has one National curriculum and three Arizona specific curricula. Also WRRC staff create and provide state-specific, interdisciplinary, and supplementary water education materials and teaching tools. These materials are utilized by public and private schools, water companies, State Parks, youth groups, tribal governments, community colleges and state universities. Water education exhibits have been created for three Active Management Areas. • A 16 hour Project WET facilitator training was conducted on January 10, 11 and 12, 2000 in Phoenix. Twenty-two participants were from Natural Resource Conservation District Education Centers and Cooperative Extension Offices. • A groundwater flow model demonstration was presented on January 26, 2000 for hydrologists and scientists visiting from India at the WRRC. • A 6 hour Project WET teacher workshop was conducted in Sierra Vista on January 29, 2000. Twenty in- classroom teachers, educators and docents attended. • Groundwater flow model demo for three Native American educators at WRRC on February 29. • A 6 hour Project WET Facilitator workshop was conducted in Keams Canyon. Twelve teachers attended including four Native Americans. • A 6 hour Project WET Facilitator workshop was conducted in Holbrook. There was a total of eighteen participants, including four Native Americans. • A 6 hour Project WET Facilitator workshop was conducted in Show Low. Three teachers participated. • A 6 hour Project WET Facilitator workshop was conducted at Northland Pioneer College in Holbrook. A total of six teachers participated. • A 6 hour Project WET Facilitator workshop was conducted in Douglas. Eighteen teachers participated, including eleven Hispanics. • A 6 hour Project WET Facilitator workshop was held at the Water Resources Research Center in Tucson. Seventeen teachers attended, including two Hispanics. • A 6 hour Project WET Facilitator workshop was conducted in Coolidge. There was a total of nine participants, including four Hispanics. • A 6 hour Project WET Facilitator workshop was held in Yuma. The ten participants were teachers and city staff. • A 6 hour Project WET Facilitator workshop was conducted at Mormon Lake. There were twenty-two participants present. • One of the facilitators at the Water Resources Research Center worked with 41 Native American high school students and 2 Native American teachers at Northern Arizona University, as well as 346 elementary school students and 53 teachers at schools in Pima County. These sessions were hands-on work with the groundwater flow models. WATER CASA The Water Conservation Alliance of Southern Arizona (Water CASA) was formed three years ago to provide a means for member water providers to augment their individual conservation programs and to improve the region's overall water conservation efforts. To date, Water CASA's membership includes Metro Water District, Avra Water Co-op, Community Water Company of Green Valley, Flowing Wells Irrigation District, Pima County Wastewater Management and the U.S. Bureau of Reclamation. This alliance has rapidly become a productive organization effectively using economies of scale, and by providing a strong, unified voice on water conservation issues regionally. What follows is a summation of Water CASA's activities during the past year: Welcome Packets Water CASA continues to provide its members with a variety of brochures and information pieces that are distributed in Welcome Packets for new water customers. Water CASA developed and continues to update the literature in the packets. Members distribute more than 300 packets a month to their new customers and also to customers who request conservation information. We are now beginning to track water use patterns related to the packets and to thereby analyze the effectiveness of the Welcome Packet program. Conservation Devices Bulk orders of conservation devices continue to be made for, and divided among, the members of Water CASA. This is a good example of Water CASA's effectiveness in the use of economy of scale. We are able to purchase conservation devices at the lowest possible price with our bulk ordering. In addition, the US Bureau of

Reclamation supports this program with \$7,500 toward the purchase of the showerheads and aerators. These conservation devices are included in Welcome Packets for new customers moving into older homes and are also available to water customers on request. Field staff who respond to customer questions or complaints also hand out devices, which has proved to be an effective customer service. Graywater Project Water CASA has identified residential graywater reuse as having huge conservation potential. The Alliance applied for and was awarded an ADWR conservation assistance grant in 1998 to look at actual "wildcat" graywater systems throughout Pima County. The just completed study has determined that approximately 13% of single family residences are making use of one or more sources of their graywater Health risk associated with actual graywater systems and have been found to be within acceptable limits. We are currently involved with support of the Arizona Department of Environmental Quality's efforts to simplify the rules for residential graywater reuse and to create rules based upon performance standards. Ordinances In 1998, at the request of Pima County, Water CASA drafted and submitted to the County ten potential water conservation ordinances. Those ordinances still await adoption. Pima County's adoption of our suggested water ordinances will strengthen conservation efforts not only in Water CASA members service areas but will benefit the entire County as well. Safe Yield Dialogue Water CASA has consistently promoted development of a dialogue within the region and throughout the State to look at overall effective water management. Partly from our efforts, ADWR has established task forces in each AMA to examine safe-yield and funnel recommendations to a Statewide Water Management Commission soon to be appointed. One of the four subcommittees within our Tucson AMA task force deals with conservation and Water CASA Manager, Val Little, continues to serve as co-chair of that subcommittee and is a member of the task force's steering committee. Water CASA Board Member, and Vice-Chair, Alan Forrest, has been selected to serve on the Statewide Technical Advisory Committee for the Water Management Commission. Conserve This! In early 1999 the Water CASA board determined that, to deal effectively with a number of policy issues that affect water conservation, a working conference should be organized. Our goal was to have a unique, interactive conference in which solutions, not just problems, are identified to improve water conservation effectiveness. Conserve This! held September 28, 1999, attracted more than 125 people from all facets of the water conservation community throughout the state. We view Conserve This! as an effective compliment to ADWR's safe yield task force and plan that solutions arrived at during the Conference will be recommended and implemented through this process. Groundwater Management Act Anniversary Conference Water CASA was a sponsor of this statewide meeting, held on the occasion of the 20th anniversary of the GMA. Water CASA Manager, Val Little represented the Tucson AMA in a presentation to the joint GUAC meeting held in conjunction with the Conference. Conservation Assistance Fund ADWR has funds available for conservation assistance grants, which in previous years have been spread among more than 20 projects. Water CASA has consistently advocated for not more than three to five conservation projects to be selected for their overall, quantifiable benefit to the region. Our goal is the most efficient use of the dwindling monies available. Water CASA has taken leadership in advocacy for the regional and statewide multimedia program 'There are Number of Ways to Save Water' as a primary target for funding. Water CASA withdrew both of its Conservation Assistance Fund proposals to be consistent with our advocacy. News Articles & Press Releases Press releases and news articles have been drafted and used by Water CASA members throughout this past year. These items have either been used as is by local newspapers, been adapted as features by the print media or have been used in Water CASA member newsletters to customers. Our goal for the coming year is to see an increase in news articles coming from Water CASA and to increase the visibility of the Alliance overall. Demonstration Gardens Water CASA has a goal to develop public, low-water-using demonstration gardens in the service area of each member. A public installation of the Metro Water Demonstration Garden was held in the fall for phase one and this spring for phase two. We were able to get Rainbird to fund the irrigation supplies necessary for the garden installation. The installation event provided an opportunity for Metro Water Customers to observe the installation of a drip irrigation system installation and the proper techniques for desert plantings and plant maintenance. A demonstration garden for Avra Water Co-op has been designed, an irrigation plan is being developed and is scheduled for installation this fall. Individual Member Services Water CASA continues to assist members with development of Reasonable Conservation Measures's negotiated with ADWR, to assist with negotiates of stipulation and consent decrees, and to provide auditing services through our partnership with the Low 4 Program. Dual (or Sub-) Metering Project WATER CASA

believes the greatest conservation potential exists with exterior water usage, but data is lacking to determine what portion of total residential water use occurs outdoors. As a way to obtain the needed data, WATER CASA has outlined a project in which a new subdivision would be designed with separate meters at each residence to track indoor and outdoor water use. A project like this is a difficult undertaking because the up-front costs are large and the responsibility to it is long-term. Despite efforts to move this project forward, Water CASA has been unable thus far to find a developer with a project in the design stage, willing and able to participate with this project. The project is, for now, on the back burner but it may well come to the fore through the above discussed ADWR Conservation Assistance Grants.

### Basic Project Information

Basic Project Information	
Category	Data
<b>Title</b>	Arizona Water Resource
<b>Description</b>	12 page newsletter presenting general news, events and issues analysis for Arizona water community. Focus on issue was Drought increasing CAP demand and Hydrology dept to lead water sustainability center
<b>Start Date</b>	07/01/1999
<b>End Date</b>	08/31/1999
<b>Type</b>	Newsletter
<b>Lead Institution</b>	The University of Arizona

### Principal Investigators

Principal Investigators			
Name	Title During Project Period	Affiliated Organization	Order
Joseph Gelt	Professional Staff	The University of Arizona	01

### Problem and Research Objectives

### Methodology

### Principal Findings and Significance

### Articles in Refereed Scientific Journals

### Book Chapters

### Dissertations

### Water Resources Research Institute Reports

### Conference Proceedings

### Other Publications

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## Basic Project Information

Basic Project Information	
Category	Data
<b>Title</b>	Arizona Water Resource
<b>Description</b>	12 page newsletter presenting general news, events and issues analysis for Arizona water community. Focus of issue is Aquatic Fern Threatens AZ Waterways
<b>Start Date</b>	09/01/1999
<b>End Date</b>	10/31/1999
<b>Type</b>	Newsletter
<b>Lead Institution</b>	The University of Arizona

## Principal Investigators

Principal Investigators			
Name	Title During Project Period	Affiliated Organization	Order
Joseph Gelt	Professional Staff	The University of Arizona	01

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## Basic Project Information

Basic Project Information	
Category	Data
<b>Title</b>	Arizona Water Resource
<b>Description</b>	12 page newsletter presenting general news, events and issues analysis for Arizona water community. Focus of issue was on Court Backing Indian Groundwater Claims and Global Water Shortage Looms In New Century
<b>Start Date</b>	11/01/1999
<b>End Date</b>	12/31/1999
<b>Type</b>	Newsletter
<b>Lead Institution</b>	The University of Arizona

## Principal Investigators

Principal Investigators			
Name	Title During Project Period	Affiliated Organization	Order
Joseph Gelt	Professional Staff	The University of Arizona	01

## Problem and Research Objectives

## Methodology

## Principal Findings and Significance

## Articles in Refereed Scientific Journals

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## Basic Project Information

Basic Project Information	
Category	Data
<b>Title</b>	Arroyo
<b>Description</b>	12 page newsletter focus on water conservation, including history and current information
<b>Start Date</b>	12/01/1999
<b>End Date</b>	12/31/1999
<b>Type</b>	Newsletter
<b>Lead Institution</b>	The University of Arizona

## Principal Investigators

Principal Investigators			
Name	Title During Project Period	Affiliated Organization	Order
Joseph Gelt	Professional Staff	The University of Arizona	01

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## Methodology

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## Book Chapters

## Dissertations

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## Other Publications

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## Basic Project Information

<b>Basic Project Information</b>	
<b>Category</b>	<b>Data</b>
<b>Title</b>	Arizona Water Resource
<b>Description</b>	12 page newsletter presenting general news, events and issues analysis for Arizona water community. Focus on this issue was Salty Irrigation Water Raising Groundwater Levels and Concerns
<b>Start Date</b>	01/01/2000
<b>End Date</b>	02/28/2000
<b>Type</b>	Newsletter
<b>Lead Institution</b>	The University of Arizona

### **Principal Investigators**

<b>Principal Investigators</b>			
<b>Name</b>	<b>Title During Project Period</b>	<b>Affiliated Organization</b>	<b>Order</b>
Joseph Gelt	Professional Staff	The University of Arizona	01

### **Problem and Research Objectives**

### **Methodology**

### **Principal Findings and Significance**

### **Articles in Refereed Scientific Journals**

### **Book Chapters**

### **Dissertations**

### **Water Resources Research Institute Reports**

### **Conference Proceedings**

### **Other Publications**

### **Basic Project Information**

<b>Basic Project Information</b>	
<b>Category</b>	<b>Data</b>
<b>Title</b>	Arizona Water Resource
<b>Description</b>	12 page newsletter presenting general news, events and issues analysis for Arizona water community. Focus on 20 years of GMA, and Feds, State Work out CAP Cost Settlement
<b>Start Date</b>	03/01/2000
<b>End Date</b>	04/30/2000
<b>Type</b>	Newsletter
<b>Lead Institution</b>	The University of Arizona

### Principal Investigators

<b>Principal Investigators</b>			
<b>Name</b>	<b>Title During Project Period</b>	<b>Affiliated Organization</b>	<b>Order</b>
Joseph Gelt	Professional Staff	The University of Arizona	01

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## USGS Internship Program

## Student Support

<b>Student Support</b>					
<b>Category</b>	<b>Section 104 Base Grant</b>	<b>Section 104 RCGP Award</b>	<b>NIWR-USGS Internship</b>	<b>Supplemental Awards</b>	<b>Total</b>
<b>Undergraduate</b>	6	N/A	N/A	N/A	6
<b>Masters</b>	2	2	N/A	N/A	4
<b>Ph.D.</b>	3	2	N/A	N/A	5
<b>Post-Doc.</b>	N/A	N/A	N/A	N/A	N/A
<b>Total</b>	11	4	N/A	N/A	15

## **Awards & Achievements**

Governor's Pride Award - Water CASA was nominated for and received the first ever Governor's Pride in Arizona Award for Water Conservation. We were lauded for our innovative approaches to water conservation, and impressive results in a rather brief period of time. "The program's goal of involving water companies with community members impressed the judges and earned the organization the award." The award committee also commended Water CASA for being instrumental in drafting water conservation ordinances for Pima County, studying graywater reuse in the Tucson area, and promoting low-water-using landscapes. A cooperative and collaborative effort between personnel from the City of Chandler, Arizona and researchers from Arizona State University demonstrated that the practical experience of plant operators and staff, and the scientific approach and technology available at the University can be successfully brought together to address water quality problems.

## **Publications from Prior Projects**

**Articles in Refereed Scientific Journals**

**Book Chapters**

**Dissertations**

**Water Resources Research Institute Reports**

**Conference Proceedings**

**Other Publications**