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Introduction

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Research Program

THE IMPACTS OF UNGULATES ON VEGETATION ASSOCIATED WITH WATER CATCHMENTS

Basic Information

Title:	THE IMPACTS OF UNGULATES ON VEGETATION ASSOCIATED WITH WATER CATCHMENTS
Project Number:	2002AZ1B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	14
Research Category:	Water Quality
Focus Category:	Water Supply, Management and Planning, Surface Water
Descriptors:	WS, M&P
Principal Investigators:	Paul Krausman, Jason Marshal

Publication

A. Problem and research objectives:

Land and wildlife managers in Arizona and California spend >$800,000/year designing, developing, and maintaining water catchments for wildlife. However, there has been very little research that has addressed how the catchments influence wildlife and their habitat. Recently, some individuals and organizations have challenged the value of water catchments and claimed that adding water into an area may have a negative influence on biotic and abiotic elements of the habitat for some species (Broyles 1995). Because water catchments are an important part of management and mitigation of wildlife throughout the Southwest (Rosenstock et al. 1999), state game agencies, federal agencies (i.e., U. S. Fish and Wildlife Service, U. S. Bureau of Land Management, Department of Defense), and nonprofit organizations (i.e., Defenders of Wildlife) want more information on the influences of water developments on wildlife and their habitats. Our objective was to determine how desert ungulates, primarily desert mule deer (*Odocoileus hemionus eremicus*), influenced vegetation in proximity to water catchments.

B. Methodology:

The study was conducted in the bajadas and flats around the eastern Chocolate Mountains, southeast California (33E N, 115E W). The climate was arid with summer temperatures > 45E C and low annual rainfall (70mm). Vegetation in the area was typical of the Lower Colorado River Valley Desert subdivision of the Sonoran Desert. Paloverde (*Cerciduim floridum*), ironwood *(Olneya tesota*), catclaw (*Acacia greggii*), mesquite (*Prosopis glandulosa*), and cheese bush (*Hymenoclea salsola*) were common in washes.

Seasons were spring (April, May, June), summer (July, August, September), autumn (October, November, December), and winter (January, February, March).

Other ungulates in the area were bighorn sheep (*Ovis canadensis*) and burros (*Equus asinus*). There were $29 water sources in the entire area, in addition to the Colorado River. The area is described in detail by Andrew et al. (1999).

To determine if desert ungulates were influencing the vegetation in proximity to water catchments, we compared forage abundance in washes immediately adjacent to 8 catchments and forage abundance in 8 washes $3 km to the nearest catchment (i.e., 16 wash sites in total). We selected washes so that each water catchment in a wash could be paired with a wash of similar size and in similar topography that did not contain a catchment. Catchments were from 1 to >40 years old. We selected catchment washes to reflect this range.

We established 1 transect at each of the 16 wash sites. Each transect was 3 km long and followed the edge vegetation of the wash leading down-wash. For the washes with catchments, the transects originated at the point on the wash nearest the catchment. At 500-m intervals, we established 20 plots (1 m x 1 m x 2 m). We placed 10 on each side of the wash, the first after a random starting point, and the rest every 20 m thereafter. For each transect there were 2 plots: 20 plots at 500 m, 20 at 1,000 m, 20 at 1,500 m, 20 at

2,000 m, 20 at 2,500 m, and 20 at 3,000 m. Each cluster of 20 plots allowed us to determine estimates of vegetation characteristics and variation in those characteristics at each 500-m interval from a catchment or its paired noncatchment wash interval.

For each plot, we determined percent plant species composition by the dry-weight-rank method (Mannetje and Haydock 1963), and plant biomass (green leaves and twigs) by a modification of the comparative yield method (Haydock and Shaw 1975). The amount of forage in each plot was visually assessed and assigned a rank from zero to 4. Zero represented a plot with no forage (either completely empty or with only inedible larger stems), 1 a plot 25% full of forage, 2 a plot 50% full of forage, 3 a plot 75% full of forage, and 4 a plot 100% full of forage. To determine biomass, we clipped several plots representing each rank. We used regression to determine a relationship between rank of the plot and biomass of forage it contains. We clipped 1 plot for every 20 plots we sampled (Haydock and Shaw 1975). Mazaika and Krausman (1991) determined that the dry-weight-rank technique was valid for desert systems. We conducted the biomass estimates every 3 months to determine seasonal changes in forage availability. We measured use along transects by deer and sheep by counting pellet groups in 2 x 20-m plots between each vegetation plot, along the edges of the sampled washes.

C. Principal Findings and Significance:

In general there were no consistent patterns in the amount of dry plant biomass in washes with or without catchments or with catchments built before or after 2000 (Figure 1). We could not determine that desert ungulates influenced the vegetation abundance. However, the catchments built before 2000 received more use by deer and sheep than all other classes in all years. These ungulates likely were familiar with catchments built before 2000 and either were not aware of recent developments (2001) or did not need to use them (Figure 2). There were more pellets found in washes with catchments that had established waters in all seasons at all intervals. Because biomass of vegetation was not significantly different along transects, it is likely desert ungulates used washes with water primarily for water, and any foraging was not influential enough to alter biomass (Figures 1, 2).

These data suggest at least 3 important findings. First, vegetation was not altered significantly from 500 to 3,000 m from water sources (Figure 1) by deer and sheep in our study area. Second, desert ungulates used washes with water more than washes without water. Third, established waters were used more than newly created water sources.

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Microbial Mediated Mobilization of Arsenic from Drinking Water Treatment Residuals in Landfills

Basic Information

Title:	Microbial Mediated Mobilization of Arsenic from Drinking Water Treatment Residuals in Landfills
Project Number:	2002AZ3B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	5
Research Category:	Biological Sciences
Focus Category:	Solute Transport, Hydrogeochemistry,
Descriptors:	arsenic, treatment residuals, landfills
Principal Investigators:	James Field, A. Jay Gandolfi, Reyes Sierra

Publication

1. Sierra, R., J. Field, W. Ela, I. Cortinas, C. de las Casas, G. Feijoo, and M. Moreira. Mobilization of arsenate from activated alumina under anaerobic landfill conditions?, 17th Annual Rocky Mountain Regional Meeting, American Chemical Society, October, 2002, Albuquerque, NM
2. Sierra, R., W. P. Ela, C. de las Casas, I. Cortinas, and J. Field. Microbially-mediated mobilization of arsenic from drinking water treatment residuals in landfills? 75th Annual Conference of Arizona Water & Pollution Control Association, May 1-3, 2002, Mesa, Arizona
3. Sierra-Alvarez, R,. J. A. Field, I. Cortinas, C. de las Casas, G. Feijoo, M. T. Moreira and W. Ela. Microbial reduction and mobilization of arsenate under anaerobic conditions. VII Latin America Workshop and Symposium on Anaerobic Digestion, Oct 22-25, 2002, Merida, Mexico
4. Sierra-Alvarez, R., I. Cortinas, J. A. Field. Microbial reduction and mobilization of arsenate under anaerobic conditions. Transition of Basic Science into Practical Applications to Meet Environmental and Public Health Challenges (National Institute of Environmental Health Sciences and Environmental Protection Agency Superfund Basic Research Program) November 3-6, 2002, Tucson, Arizona
5. Ela, WP, R Sierra-Alvarez, JA. Field, A. Ghosh, I. Cortinas, & C. de las Casas. 2003. Laboratory Tests on the Fate of Arsenic in Landfills. Presented at the Proceedings of the 2003 Residuals and Biosolids Symposium, Baltimore, MD, February, 2003.

A. Problem and Research Objectives

Problem. The Environmental Protection Agency (EPA) has enacted a new drinking water legislation which will lower the standard for arsenic (As) in drinking water to 10 parts per billion (ppb). The new legislation will have the highest impact on small drinking water suppliers in the US Southwest (including Arizona), where the background levels of arsenate are often higher than 10 ppb. Arsenic in water exists as arsenate (As(V)) or arsenite (As(III)). The EPA recommended treatment alternative for small-scale drinking water suppliers is the oxidation of As(III) to As(V), followed by adsorption of arsenate onto activated alumina (AA, Al_2O_3) or ferrihydrite (Fhy, $Fe(OH)_3 \cdot nH_2O$). The EPA suggests these solid residuals may be disposed of in non-hazardous waste landfills . As a result of the newly enacted standard, approximately, 6 million pounds of As-laden drinking water residues, containing 40,000 pounds of As will be landfilled annually. This represents an unprecedented quantity of a known carcinogen to be deposited into non-hazardous landfills, justifying a closer look at the potential hazard of As mobilization.

The residuals will pass the current EPA protocol, *Toxicity Characteristic Leaching Procedure* (TCLP), regulating toxic waste disposal. However, the TCLP was designed for leaching cationic metals and thus is not very challenging for arsenate (an anion) and as such the protocol is very inadequate for regulating arsenate bearing wastes. The inadequacy is emphasized further by the fact that the TCLP does not take into account microbial mediated reduction processes expected in landfills, facilitating the mobilization of As from the disposed residuals.

Research Objectives. The primary objectives of the research are two-fold:

i) Test the hypothesis that microbial reduction processes will significantly contribute to the mobilization and thus the hazard of arsenate adsorbed onto landfilled drinking water treatment residuals.

ii) Evaluate whether combined microbial, physicochemical, and hydraulic conditions representative of landfills leads to significant leaching of arsenic from treatment residuals.

B. Methodology

Initially, batch bioassays were conducted to monitor the bioconversion of arsenate to arsenite in serum bottles inoculated with a mixed anaerobic microbial consortium. The batch assys were conducted in 135 ml flasks with 50 ml of medium. Granular methanogenic sludge from a full-scale up-flow anaerobic sludge bed (UASB) reactor was selected a stable methanogenic consortium for the use in these tests and the sludge was supplied at aproximately 1.5 g volatile suspended solids (VSS) per liter. The electron-donating substrate was typically a mixture of volatile fatty acids (acetate, propionate and butyrate) supplied at 2 g chemical oxygen demand per liter or otherwise 10 mM lactate unless alternative electron donors were studied as specified. Arsenate was typically supplied at 500 μM. The medium also contained basal mineral nutrients (macro- and micronutrients) and sodium bicarbonate (5 g/l) as a buffer. The medium was prepared with minimal sulfur content to avoid precipitation of arsenite. The headspace was filled with a flush gas composed of N_2:CO_2 80:20% (unless hydrogen was used as electron donor in which case H_2:CO_2 80:20% was used). In each experiment control were carried out in which arsenate was incubated with sterile medium or with the medium and autoclaved sludge in order to confirm minimal abiotic removal of arsenate.

In a second set of experiments, three continuous columns of 0.25 L each were operated and continuously fed with synthetic landfill leachate (Figure 1). All the reactors were loaded with 100 g dry weight of activated alumina containing 0.657 mg adsorbed arsenate (expressed as arsenic) per g dry weight activated alumina. The adsorbed concentration corresponds to an isotherm equilibrated with 20 ppb arsenic. Columns 1 and 2 were inoculated with 27 g VSS/L of granular anaerobic sludge to imitate the methanogenic conditions in a landfill; column 3 received no inoculum. All three columns received synthetic inorganic landfill leachate, with pH, bicarbonate and ammonia levels adjusted to average leachate values from mature landfills and additional nutrients of basal medium as indicated in Table 1. Only column 1 received an organic electron donating substrate representative of landfill leachate, which was a mixture of five volatile fatty acids (acetate, propionate, butyrate, valerate and caproate). Columns 1 and 2 represent the disposal conditions in a mature mixed landfill (receiving both organic and inorganic wastes). Column 1 represents the situation with continued release of leachates containing volatile fatty acid. Column 2 represents a landfill with stabilized organic matter (in the form of stable microbial biomass). Column 3 represents the situation in separated landfill cells (receiving only inorganic wastes) in which only physiochemical processes predominate.

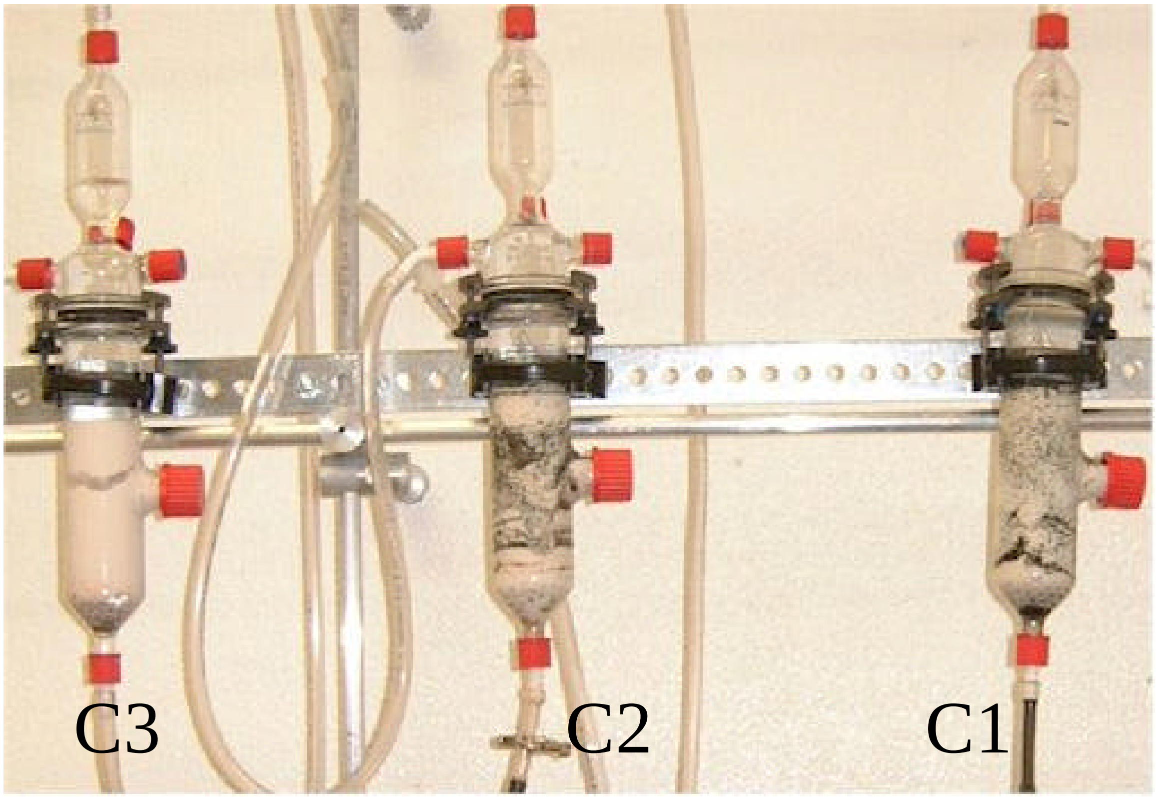

Figure 1. 0.5-L laboratory-scale anaerobic columns used to investigate the microbial mobilization and biotransformation of arsenate sorbed onto activated alumina under simulated landfill conditions. (**C1**) Biological column fed a synthetic landfill leachate containing both inorganic and organic components. (**C2**) Control column fed with an inorganic leachate (lacking organic substrates). (**C3**) Abiotic column fed with an inorganic leachate

The columns were operated initially 10 h empty bed hydraulic retention time for the first 24 days and later with a 20 h empty bed hydraulic retention time for the remainder of the experiment (lasting 6 months).

Arsenic speciation in liquid samples was analyzed by ion chromatography/inductively coupled plasma/ mass spectrometry (IC/ICP/MS) (LC Agilent 1100 series, ICP-MS Agilent 7500, Agilent Technologies), courtesy of the NIEHS Superfund Program based in the College of Pharmacy, using a Dionex IonPac AS7 analytical column. Aqueous As species determined included: arsenate; arsenite; as well as mono- and dimethylated trivalent and pentavalent arsenic derivatives (methylarsonic acid (MMA(V)), dimethylarsinic acid (DMA(V)), methylarsonous acid (MMA(III)), and dimethylarsinous acid (DMA(III)).

Table 1. Composition of Synthetic Landfill Leachate Utilized in the Continuous Study

Compounds	**Inorganic Leachate Components**	**Organic Leachate Components**
:	columns 1, 2 & 3	column 1 only
	(mg/L)	mg/L
KH_2PO_4	37	
$CaCl_2 \cdot 2H_2O$	10	
$MgSO_4 \cdot 7H_2O$	10	
$MgCl_2 \cdot 6H_2O$	78	
NH_4Cl	668	
$NaHCO_3$	2000	
Trace Element Solution†	1 (mL/L)	
Acetate		115
Propionate		47
Butyrate		115
Valerate		48
Caproate		72

†Trace Element Solution (ingredients in mg/L): $FeC1_3$.4 H_20, 2000; $CoCl_2$. 6 H_20, 2000; $MnCl_2$ 4 H_20, 50; $AlCl_3$ 6 H_20, 90; $CuCl_2$.2H_20, 30; $ZnCl_2$, 50; H_3BO_3, 50; $(NH_4)_6Mo_7O_2$.4 H_2O, 90; Na_2SeO_3.5 H_2O, 100; $NiCl_2$.6 H_20, 50; EDTA, 1000; HCl 36% (1 ml).

C. Principal Findings and Significance

Principal Findings. The research was divided into two tasks. The first task concerned batch assays evaluating the reductive biotransformation of arsenate to arsenite under various physiological conditions. The second tasks evaluated the mobilization of arsenate adsorbed onto activated alumina in simulated landfill columns.

Batch Assays. In the first set of experiments, the reductive biotransformation of arsenate to arsenite was evaluated in methanogenic sludge utilizing different electron donating substrates. These experiments were considered reloevant since the microbial ecology in a mature landfill is principally a methanogenic consortium. Figure 2 illustrates the relative ease by which 500 μM arsenate is transformed to arsenite under anaerobic conditions. In just a matter of several days the arsenate is stoichiometrically converted to arsenite in methanogenic sludge with no previous experience with arsenicals, suggesting that the biotransformation is a fortuitous capacity of methanogenic consortia. No conversion of arsenate occurred in control experiments with media containing autoclaved sludge, suggesting that transformation of arsenate is biologically catalyzed by microorganisms in the "living" sludge. Secondly, exogenous electron donating substrates, stimulated the transformation compared to assays with only slowly hydrolyzing endogenous substrates in the sludge. The stimulation was greatest with hydrogen, followed by glucose and lactate (not shown). The stimulation was least with acetate. A volatile fatty acid mixture representing the substrates available in landfill leachate was intermediate between H2 and acetate in stimulating arsenate reduction. The pattern follows that anticipated with respect to substrates providing the most interspecies H_2.

A second set of batch experiments evaluated the effect of arsenate concentration on arsenate biotransformation rates with lactate as the electron donating substrate. The results shown in Figure 3 indicate that the arsenate removal rates, which were similar to the arsenite formation rates, have a clear optimum at 2 mM arsenate. The lower rates at lower arsenate concentrations are most likely due to Monod kinetics. The decline in rates at concentrations in excess of 2 mM may reflect toxicity of arsenate or formed arsenite on arsenate reduction. Inhibition studies evaluating the toxicity of arsenate and arsenite to methanogenic activity revealed that arsenate was non-toxic; whereas, arsenite was highly toxic causing a 50% inhibition of methanogenesis as low as 20 μM.

Continuous Columns. Microbial reduction of As(V) sorbed onto activated alumina (AA) was also observed in the continuous-flow experiments operated under anaerobic conditions (Figure 4). The mobilization of arsenic from the AA was greatly stimulated in columns inoculated with anaerobic sludge. The mobilization was also the greatest in column 1, which received the electron donating volatile fatty acid substrate. However significant mobilization of arsenate was also observed in column 2, which did not receive any exogenous electron donor in the leachate. Reduction of arsenate was probably still feasible due to the slow decomposition of sludge. Initially the supply of electron donating substrate was limiting, accounting for a more rapid initial release of arsenic from column 1. During the initial period, effluent concentrations of arsenic reached 600 μg/l or greater. Approximately 80% of the leached arsenic was recovered as arsenite, clearly demonstrating that microbial reduction was the main mechanism of arsenic mobilization (Figure 5). Low amounts of the pentavalent organoarsenic metabolites, methylarsonic acid (MMA^V) and dimethylarsinic acid (DMA^V) were also detected.

After 40 days of operation, the rate of arsenic release from columns 1 and 2 were similar indicating that supply of electron donating substrate was no longer rate limiting. Instead limited bioavailability of sorbed arsenate probably became the rate-determining step. After 190 days, 16% of sorbed arsenate was leached from AA.

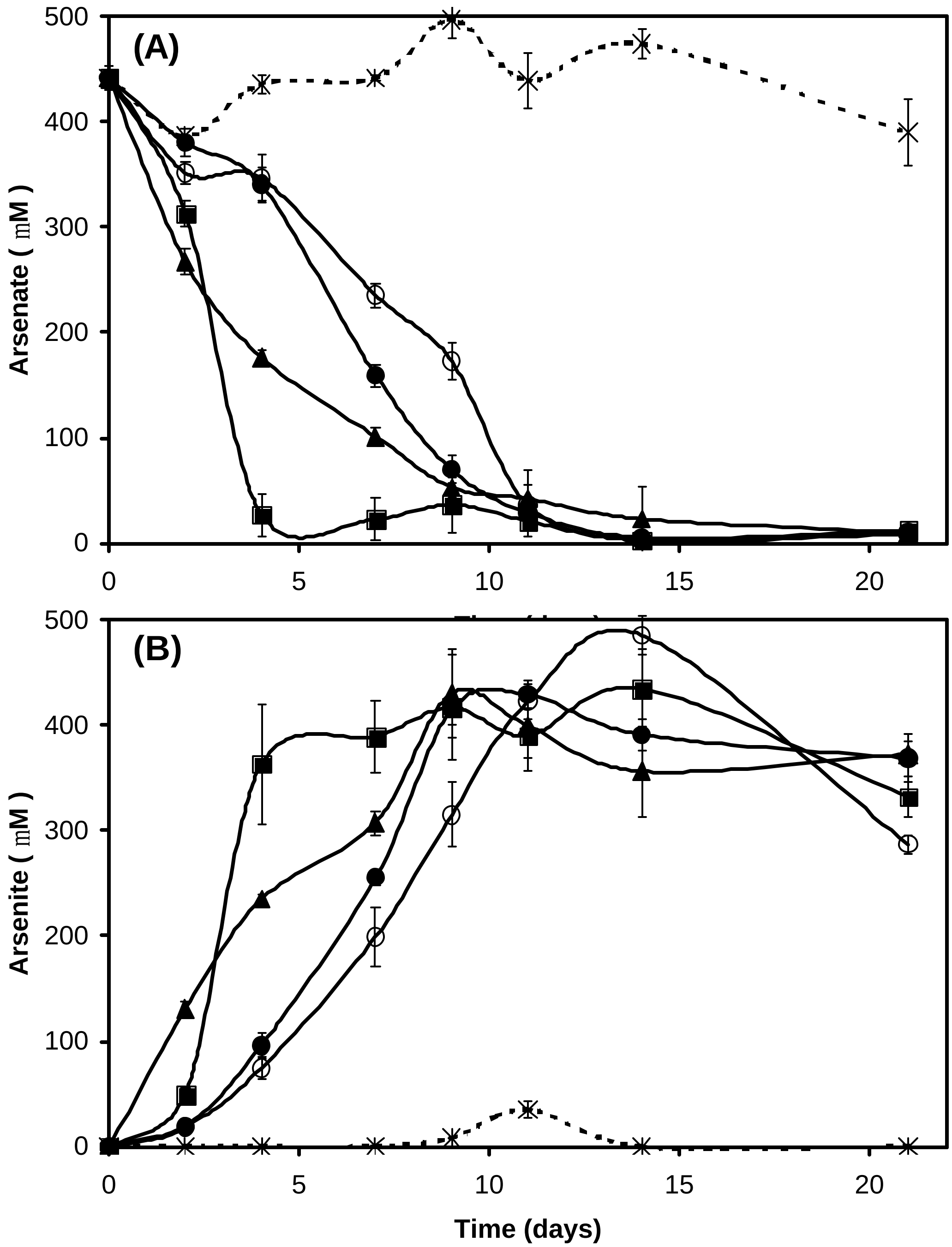

Figure 2. Effect of different electron donating substrates on the time course of arsenate reduction to arsenite in anaerobic granular sludge. **Panel A**. arsenate concentrations. **Panel B**. arsenite concentrations. Legend: ■, hydrogen 0.8 atm; ? , glucose 10 mM; ●, acetate 10 mM; ?, no added substrate, *, killed sludge (autoclaved).

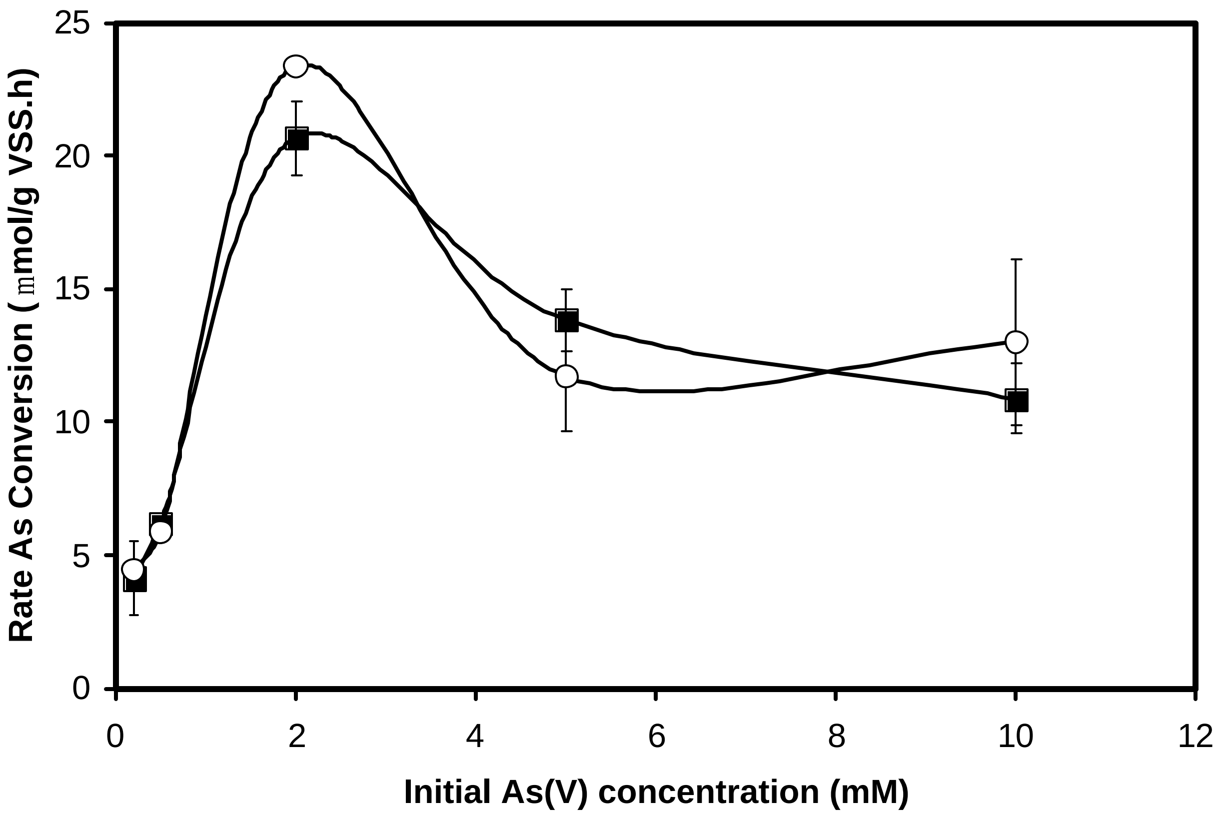

Figure 3. The rate of arsenate reduction to arsenite in anaerobic granular sludge incubated with at variable initial concentrations of arsenate (As(V)) with 10 mM of lactate as electron donor. Legend: ■, arsenate removal rate; O, arsenite formation rate.

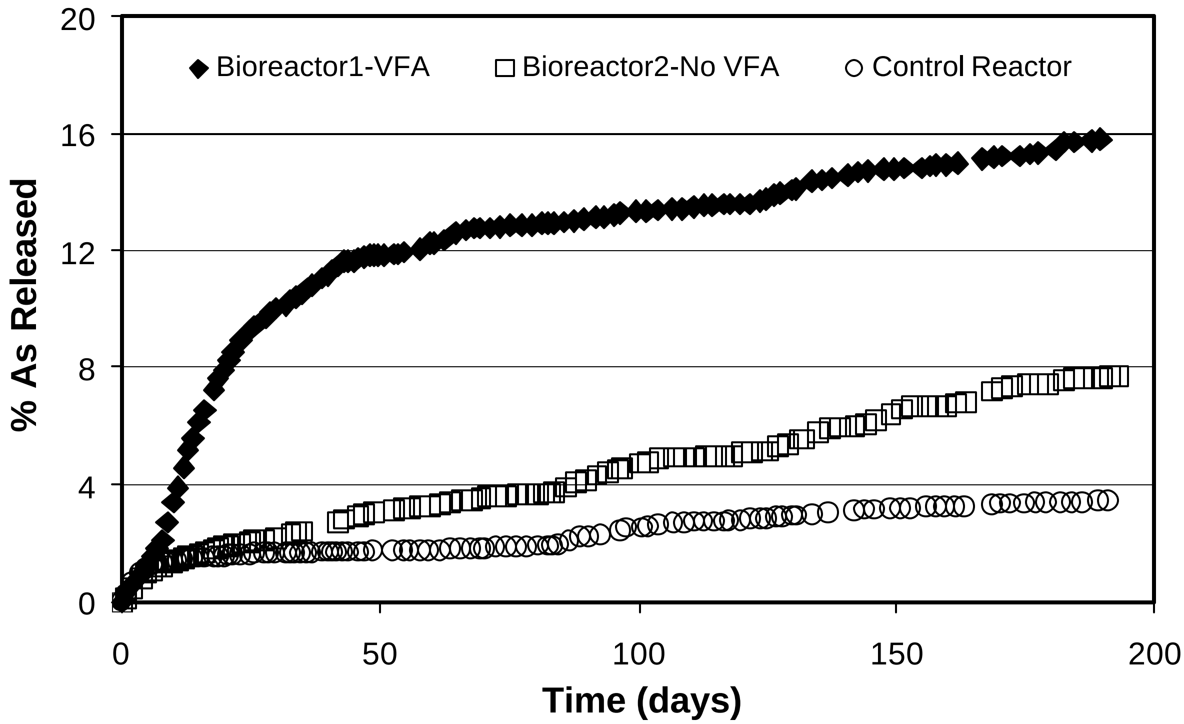

Figure 4. Release of arsenic (As) from activated alumina with sorbed arsenate in anaerobic columns percolated with model landfill leachate. Bioreactor 1 and 2 were inoculated with anaerobic sludge, but only bioreactor 1 was supplied with organic substrate, volatile fatty acid mixture (VFA). The control reactor was not inoculated.

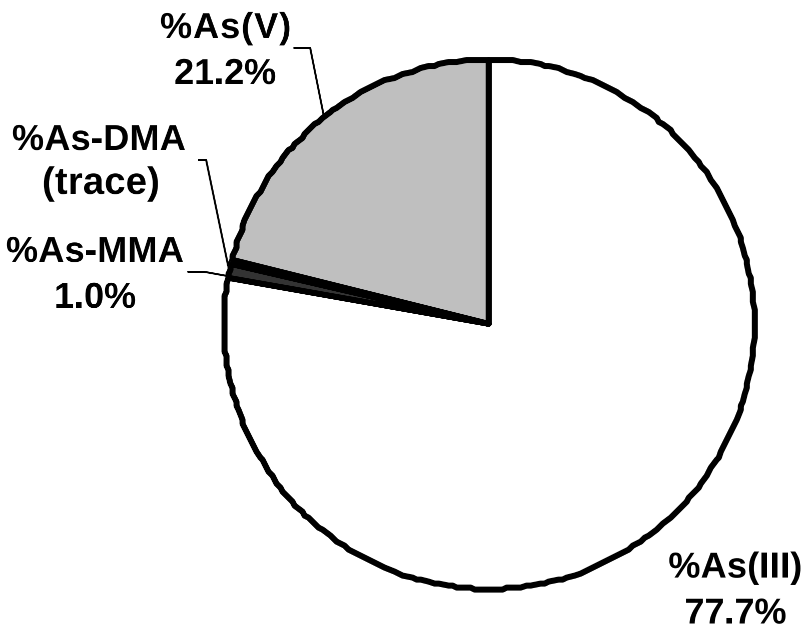

Figure 5. Arsenic speciation determined in the effluent of the anaerobic reactor (column 1) fed with a simulated landfill leachate containing organic substrates. Results shown are the average of the second month of reactor operation.

D. Conclusions

The results obtained indicate that extensive reduction and mobilization of As(V) sorbed onto AA should be expected if this spent sorbent is disposed of in municipal landfills. This finding provides strong evidence to support the importance of revising the current rule of the US-EPA that classifies As-bearing AA as a non-hazardous waste. Implied in this statement is a call to improve the protocol currently applied to determine the toxic characteristics of As-bearing waste materials such as spent AA, which neglects the impact of microbial processes.

The results also demonstrate that the mobilization of arsenate from spent sorbents can be minimized by preventing contact with microbial substrates. A practical outcome could be separate disposal of As-laden drinking water residuals in landfill cells lacking organic wastes.

Acknowledgements

Analyses of MMA and DMA were performed by the Hazard Identification Core from NIEHS-supported Superfund Basic Research Program Grant (NIH ES-04940). We are grateful to Michael Kopplin for performing the analyses.

The effect of mycorrhizae on competitive ability and drought tolerance of cottonwood (Populus fremontii) and saltcedar (Tamarix ramosissima)

Basic Information

Title:	The effect of mycorrhizae on competitive ability and drought tolerance of cottonwood (Populus fremontii) and saltcedar (Tamarix ramosissima)
Project Number:	2002AZ4B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	1
Research Category:	Biological Sciences
Focus Category:	Drought, Wetlands, Ecology
Descriptors:	DROU, ECL, WL
Principal Investigators:	Julie Stromberg, Vanessa Beauchamp, Jean Stutz

Publication

A. Research objectives

The objective of this project is to investigate the effects of mycorrhizal fungi on growth and competitive ability of Fremont cottonwood and saltcedar, under drought and non-drought conditions. By monitoring growth, productivity, and survivorship of seedlings grown with and without fungi, we will (1) determine whether mycorrhizal fungi influence growth and competitive ability of Fremont cottonwood and saltcedar, and (2) determine whether the fungal symbionts increase drought tolerance of either woody species.

B. Methodology

Saltcedar seeds were sown in 20, 8-gallon tree pots on August 2, 2002. All soil was sterilized prior to planting. Half of these pots were inoculated with a mixture of endo- and ectomycorrhizae obtained from Fremont cottonwood root zones, and the remainder served as uninoculated controls. All pots were placed in 5 gallon buckets and bottom-watered to simulate a water-table. On September 1, the seedlings were thinned to 15 per pot and the water level in the buckets was dropped to 15 cm to reduce algal growth. Three to five sudan grass (*Sorghum vulgare var. sudanens*) seeds were planted in each pot to serve as colonization indicators. Sudan grass is colonized by most endomycorrhizae and measurement of root colonization levels will allow us to determine if the inoculation in each experimental pot was successful and to ensure that no control pots were contaminated with mycorrhizae during the experiment.

After thinning, the standing height of the seven tallest seedlings per pot was measured weekly. Beginning on October 11, the length of the longest stem was also measured weekly and beginning on October 29, the length of all stems on all 15 seedlings per pot was measured monthly. Water was turned off to all pots on November 25 and the pots were allowed to dry down. Due to cold temperatures and cloudy days, the pots dried very slowly. On December 2, all excess water was siphoned from the pots, and on January 13, 2003, the pots were removed from the buckets to facilitate draining. Many of the pots were still saturated in the lower levels.

All saltcedar and grass seedlings were harvested on January 18-22. Above-ground saltcedar biomass was stored in a drying oven at 60^{o}C for one week. Extensive intermingling of saltcedar and grass root systems prevented collection of saltcedar belowground biomass. Roots found physically attached to grass or saltcedar plants were collected and stored for assessment of mycorrhizal colonization.

Very few saltcedar seedlings reached the size necessary to perform accurate measurements of photosynthesis and water potential. These measurements were not taken during this experiment, but will be performed on cottonwood in the next experiment.

C. Preliminary results

Repeated measures ANOVA showed no significant differences in standing height, height of longest stem, average total plant length (sum of all stems), and average stem length per pot between inoculated and uninoculated seedlings. Seedlings in uninoculated pots had a marginally higher number of stems per pot (p=0.06). There was no difference in above-ground biomass between inoculated and uninoculated seedlings. Mycorrhizal colonization was very low in the inoculated seedlings (7.8%) but higher than the sterile controls (0.02%; Mann-Whitney U p=0.001) Only hyphae and vacuoles were encountered in saltcedar roots.

These results indicate that saltcedar can be colonized my mycorrhizae, but the low levels of colonization, lack of arbuscules, and similarity in growth between the two treatments suggest that saltcedar does not benefit from mycorrhizal colonization in the wet conditions used in this experiment.

Competition between saltcedar and cottonwood could not be evaluated because facilities problems at ASU delayed the start of this experiment until August, and the cottonwood seeds we collected would no longer germinate. Thus, we decided to re-focus the experiment on the effects of mycorrhizae on the survival and growth of saltcedar. Drawing on knowledge gained in this experiment, a second experiment will be initiated in early summer of 2003 to study effects of mycorrihzae on competition between cottonwood and saltcedar, under drought and non-drought condition.

Regional Aquifers Characterization Through Spring Discharge Analysis

Basic Information

Title:	Regional Aquifers Characterization Through Spring Discharge Analysis
Project Number:	2002AZ5B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	6
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Surface Water, Water Supply
Descriptors:	GW, SW, WS
Principal Investigators:	Abe Springer, Stephen Flora

Publication

1. Springer, A.E., L.E. Stevens, D.E. Anderson, S.P. Flora, D.K. Kreamer, in press, Springs Classification, Hydrology, Geomorphology, Geochemistry, and Distribution, in Spring Ecosystems of the North American Deserts: Ecology, Hydrology, and Conservation, U. Arizona Press, Tucson, AZ.
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4. Springer, A.E., L.E. Stevens, D.E. Anderson, R.A. Parnell, D.K. Kreamer, and S.P. Flora, 2002. Springs classification, hydrology, geomorphology, geochemistry, and distribution. Joint annual meetings of the Ecological Society of America and Society for Ecological Restoration, August 4-9, Tucson, AZ. p. 49.

A. Problem and Research Objectives

The Problem

The problem we addressed is the lack of understanding of spring discharge fluctuations and the relationship between the hydrogeologic unit in which the spring discharges to determine the unit characteristics. There are not many studies that provide a detailed understanding of the springs in the Lower and Middle Verde Valley Region and those that have been done are outdated or only consider discharge measurements at a single time. Water planning for the future will be highly inaccurate based on these out-of-date, historical measurements of these dynamic springs.

Objectives

The purpose of the proposed project is to describe and where possible quantify changes in spring hydrogeology of the Middle Verde River Area. The study area is defined as the Verde River watershed from Horseshoe Dam at the Yavapai/Maricopa County Line, upstream to the confluence with Sycamore Creek above Clarkdale.

Specific objectives of this study included

1. Developing routine monitoring program for springs characteristic of each hydrogeologic unit,

2. Comparing recent monitoring to any available historic monitoring and characterize any change, and

3. Determining aquifer properties from spring discharge monitoring.

B. Methodology

Background Database

Existing information on springs in the Verde River Watershed was collected from the existing USGS database of springs and USFS database. The USGS database includes information on roughly 300 springs located within the study area with single or various measurements. It includes location and discharge measurements (gpm) that were taken between 1950 and 2000 with most measurements before 1990. The USFS database includes information on roughly 160 springs located in the eastern portion of the Verde River watershed from Sycamore Creek to the East Verde River. This database includes information on UTM locations, elevation, geologic unit, discharge (gpm), USGS quadrangle, date of visit, and comments. Most of these springs are taken from existing information collected from 1950 –1990, but 44 springs include information from visits in 1999 and 2000. The information from these two databases was combined with the information from springs visited in Phase I of this project in an Access database to compared historical discharge measurements with recent measurements taken in the summer of 2002.

Phase I

Phase I of this project was done throughout the summer of 2002 and over 150 springs were visited and characterized to build an inventory of springs in the watershed. Springs were located by using USGS topographic maps, USFS maps, and from information in existing USGS and USFS databases. There were a small number of springs (5 to 10) that were not present on the topographic maps or in existing databases that were located in searching for other springs. There were also a small number of springs (5 to 10) that were present on topographic maps, but were not found because they were dry and there was no evidence of the spring. Fieldwork was conducted with the help of NAU student field assistants Lanya Ross and Rebecca Lara and consisted of day trips and several camping trips throughout the summer and early fall to visit as many springs in the watershed as possible. The accessibility of springs varied from parking at or near the spring to 1 to 5 mile hikes to get to the springs.

At each spring several measurements and descriptions were taken to characterize and inventory each spring (Table 3). For Phase I, each spring was characterized, photographed, and located with an accurate survey grade GPS unit (Table 1). Spring Discharge and water chemistry were measured at each spring using the instruments described in Table 1. At each spring descriptions of the geomorphology, vegetation/biology, and development of the springs were described. Also the geologic unit from which the spring discharges was identified. The description of geomorphology includes measuring the length of flow in the channel using a measured pace, describing the bed material, channel, and source of the spring. The sources of the springs were classified as Rheocrene (flowing spring), Helocrene (marshy spring), or Limnocrene (pooling spring). The vegetation was described using a field guide to the plants of Arizona. The terrestrial, riparian, and aquatic vegetation was dependent on the elevation (climate) and amount of water at or near the surface. Also any fauna or evidence of fauna at the spring was described as well as any development of the spring. Summarize amounts of discharge per individual geologic units.

Table 1. Summary of instruments used to take measurements at springs during Phase I of Verde springs monitoring study.

Measurement	Instruments	Accuracy/measurement
GPS Location UTM NAD 83 UTM NAD 27 Lat/Long Elevation (meters) Elevation (feet)	Survey Grade GPS (TDS Ranger Solo) from Tonto National Forest (first choice) 90% of springs	0.1 – 1.0 meter
	Handheld GPS (second choice) 8% of springs	10 – 40 feet
	Topographic map (third choice) 2% of springs	10 – 100 feet
Discharge Gallons per minute	Baski portable Box Flume (1 inch and 8 inch necks) 0 – 1000 gpm	Variable (75-99% of flow) typically accounts for greater than 95% of flow
	V-notch weir (0 –10 gpm)	> 95% of flow +/- 0.25 gpm
	Flow meter (100 – 10000 gpm)	Variable (75-99% of flow) +/- 5.0 - 100 gpm
Basic Water Quality	YSI water quality instrument	temperature, pH, and specific conductance

Phase II

Phase II involved monthly monitoring of discharge at a select number of springs in different geologic units throughout the Verde River watershed based on the reconnaissance of Phase I. Phase II began mid-way through this project and will continue for 6 months past the end of this funded 104b project. Discharge was measured at each spring monthly by regular site visits with hand measurements of discharge using the instruments described in Table 1. Stable isotopes analysis samples have been collected once in December and will be collected again in May (pending availability of funding). Also changes in basic water chemistry, geomorphology, and vegetation at the spring were noted if there were significant changes. Sites corresponded with each major stratigraphic unit (alluvium, volcanic rocks, Verde Formation, Kaibab Formation,, Coconino Sandstone, Supai Formation, Naco Formation, Redwall Limestone, Martin Formation, Basement rocks). The monitoring was designed to use appropriate techniques to characterize appropriate diurnal, seasonal, and climatic variations in spring discharge. Monitoring was designed to characterize variability in flow which would affect estimates of total annual discharge or characterize trends in baseflow. Information was used to describe hydrogeologic properties of individual units.

C. Principal Findings and Significance

We were able to complete Phase I of the study in 2002 largely with funds from sources other than the 104b funds reported here. This phase included the synoptic survey of as many springs as we could visit and completion of a database and GIS map of the springs. We did not receive any continuing funds to finish Phase II of the study. We have begun Phase II by using some unexpended resources saved from Phase I and the USGS Section 104b funds, which expired February 28, 2003.

Database

The spring database has been built. The database includes detailed information on springs visited in Phase I of this project and limited information on springs located in existing USGS and USFS databases. The database was built in Microsoft Access and consists of five tables that include information on springs visited and one table on existing information on springs. The six tables are separated into background information, GPS location, water quality and discharge data, physical properties, vegetation information, and existing information and data on springs (Table 2).

Table 2: Organization of database for Verde Springs monitoring study.

Table	**Fields**
Background information	Name of spring, investigators, national forest, date and time of visit, weather, location, drainage system, and USGS quadrangle
GPS location data	Name of Spring, Latitude, Longitude, NAD83 UTM north, NAD83 UTM east, NAD27 UTM north, NAD27 UTM east, Elevation (meters), Elevation (feet), Accuracy
Water Quality and Discharge data	Name of Spring, discharge instrument used, discharge (gpm), Discharge accuracy, discharge variability, air temperature (°C), water temperature (°C), pH, specific conductance
Physical Properties	Name of Spring, geologic unit, bed material, source classification, emergence description, channel description, length of flow (meters), length of channel (meters), human development
Vegetation/Biology	Name of Spring, area of spring related vegetation, terrestrial vegetation, riparian vegetation, aquatic vegetation, fauna present, evidence of fauna
Existing information	Name of Spring, source of data, UTM north, UTM east, elevation, discharge (gpm), geologic unit, USGS quadrangle, dates visited, and other comments

All of the six tables were related by the name of the spring. The database is searchable by several fields and displayed in Reports. The database is available as a searchable database on the NAU Verde Watershed Research and Education Program website at http://verde.nau.edu.

Phase I

Discharge from springs in the Verde River watershed is important to the baseflow of the Verde River. By far, the two highest discharging springs in the watershed are Fossil Springs (~20,000 gpm) and Page Springs (~13,000 gpm). These two springs as well as several other major springs were not characterized in Phase I of this project since there are recent studies on these springs. A total of 160 springs were visited during the summer of 2002 and each spring was characterized as described in the methodology section. Figure 1 is a GIS map of all of the springs visited in Phase I of this project and major springs not visited.

The focus of phase I was on lower discharging springs, typically below 100 gpm with the exception of 5 springs (Summer ~3,600 gpm, Sterling ~310 gpm, Pieper Hatchery ~185 gpm, Spring Creek ~171 gpm, and Tonto Natural Bridge ~108 gpm). The average discharge of the springs below 100 gpm is 2.77 gpm or 5.77 gpm, counting only springs with surface discharge. Figure 2 shows the distribution of springs based on their discharge using the Meinzer (1923) discharge classes. The total amount of discharge for the springs visited and characterized in Phase I was 4691.36 gpm. The 5 highest discharging springs in the third and fourth classes account for only 3.3% of the springs characterized but account for 93.0% of the total discharge for all of the springs. Table 3 shows the number of springs characterized in Phase I that discharge from the different geologic units in the watershed. The total discharge for each geologic unit is also shown in this table.

Temperature, pH, and specific conductance of the water discharging from each spring were also measured during Phase I. The temperature of water for all the springs averaged 19.2°C and ranged from 7.8°C to 38.2°C and included two hot springs. The pH ranged from 6.30 to 9.18 and was an average of 7.48. The specific conductance ranged from 0.05 to 5.63ms/cm, but the average value was only 0.700ms/cm. As for geomorphology classifications for the springs, roughly 62% of the springs were classified as Rheocrenes (flowing springs), 28% Helocrenes (marshy springs), and 10% Limnocrenes (pooling springs). The length of flow for the springs ranged from 0 meters to several thousand meters of flow that eventually reached the Verde River or other major tributary. The average length of flow for the springs with surface discharge was 106.9 meters. Also roughly half (50%) of the springs characterized in Phase I had some form of anthropogenic modification at the spring. These include cement spring boxes, pipes diverting flow, water storage tanks, stock tanks, cement or earthen dams, and fences.

Figure 1 – GIS Map of springs from Phase I of Middle Verde River Watershed springs monitoring study.

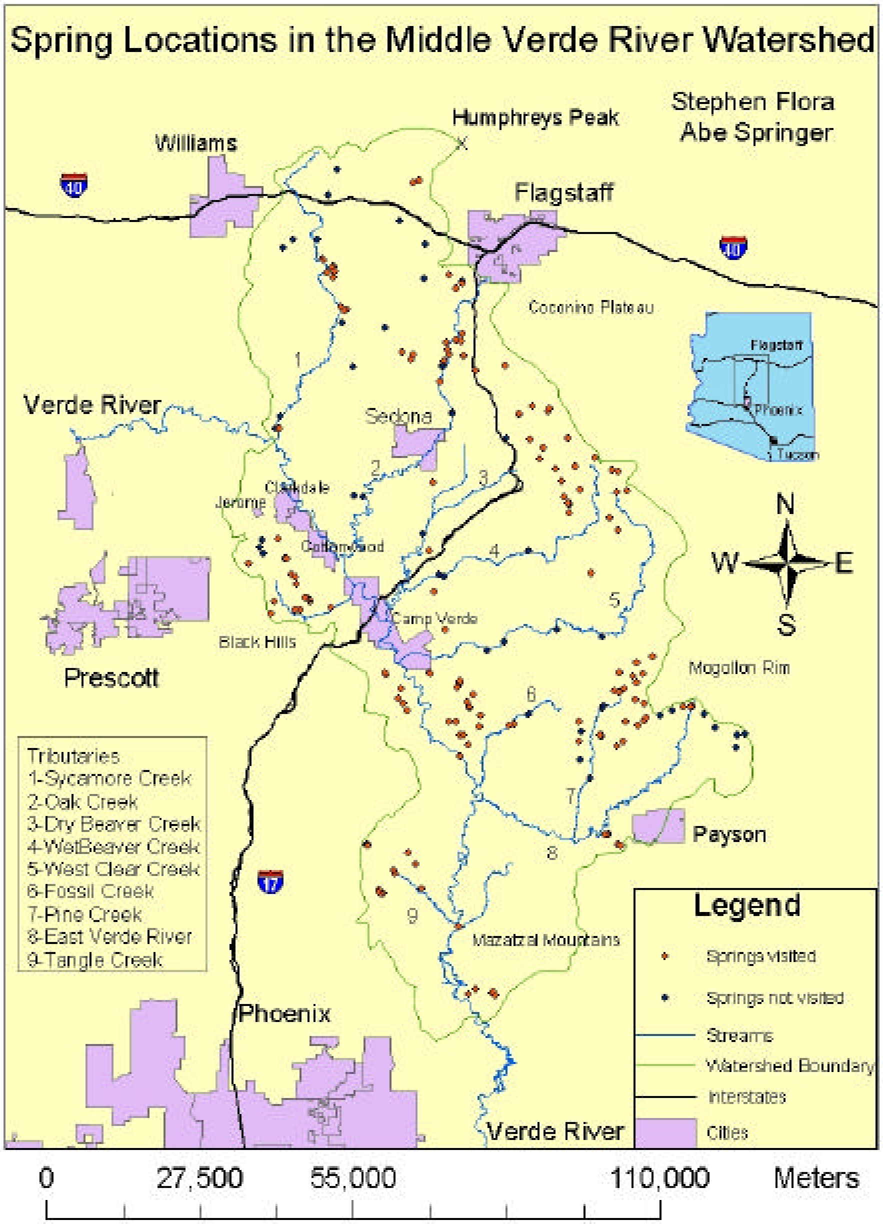


Figure 2 – Distribution of spring discharges measured in Phase I of the Verde Springs monitoring study.

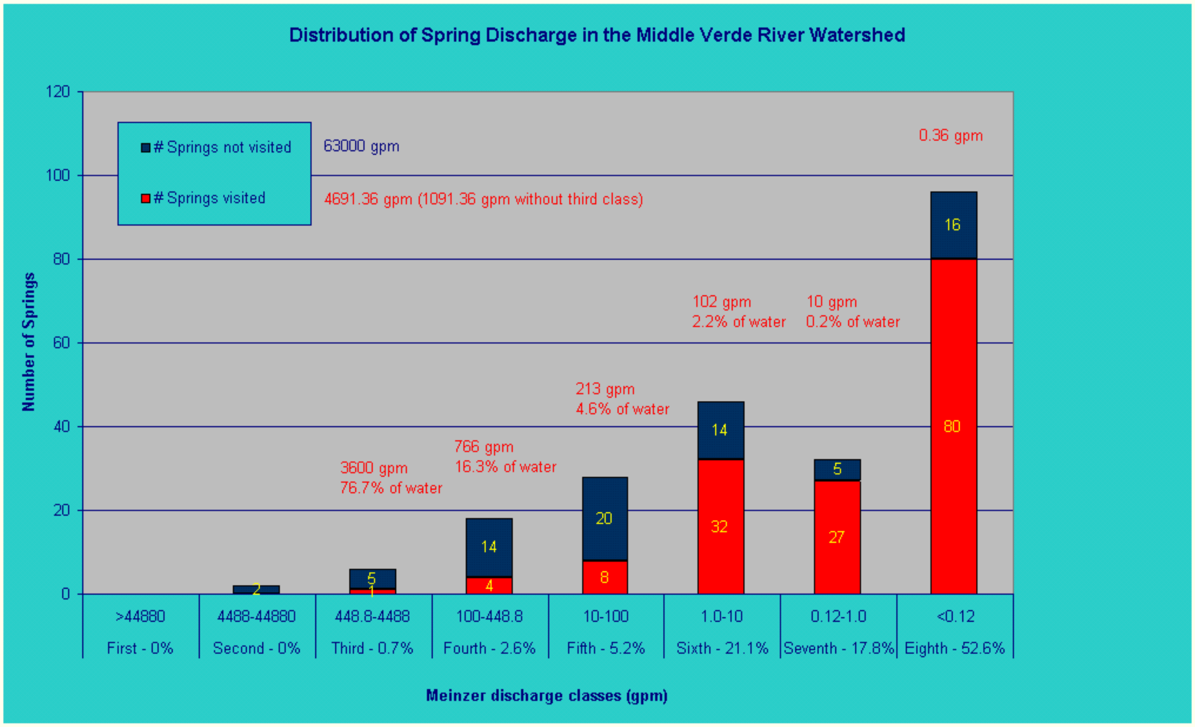


Table 4. Summary of number of springs and total spring discharge for each geologic unit from Phase I of Verde springs monitoring study.

Geologic Unit	Description	# of Springs	% springs	Total Discharge (gpm)	% Discharge
Alluvium	Holocene sand and gravels in channels	8	5.3	2.75	0.06
Verde Formation / Quaternary deposits	Lake Sediments, Conglomerates, tan sandstones, gray mudstones limestone	6	3.9	180.46	3.85
Tertiary Rim Basalts	Pliocene to Miocene Basaltic lava flows	45	29.6	42.07	0.9
Tertiary Volcanic Rocks	Pliocene to Miocene Rhyolitic to Andesitic lava flows	34	22.4	122.94	2.62
Kaibab Formation	Gray fractured and cavernous limestone	11	7.2	8.31	0.18
Coconino Formation	Permian, fine grained massive sandstone cross bedding	4	2.6	369.31	7.88
Schnebly Hill Formation	Red sandstone and shale	1	0.7	0.00	0.00
Supai Group	Formations of thick red sandstone, siltstone and limestone	13	8.5	214.38	4.58
Redwall Formation	Reddish Gray fractured and cavernous limestone	7	4.6	3701.50	79.01
Martin/Naco Formation	Gray dolomitic limestone with shaly mudstone				
Tapeats Formation	Medium grained sandstone grading upward to siltstone and limy mudstone	1	0.7	0.00	0.00
Precambrian Basement Rocks	Proterozoic granite and metamorphic rocks	22	14.5	43.10	0.92
Totals		152	100	4684.82	100

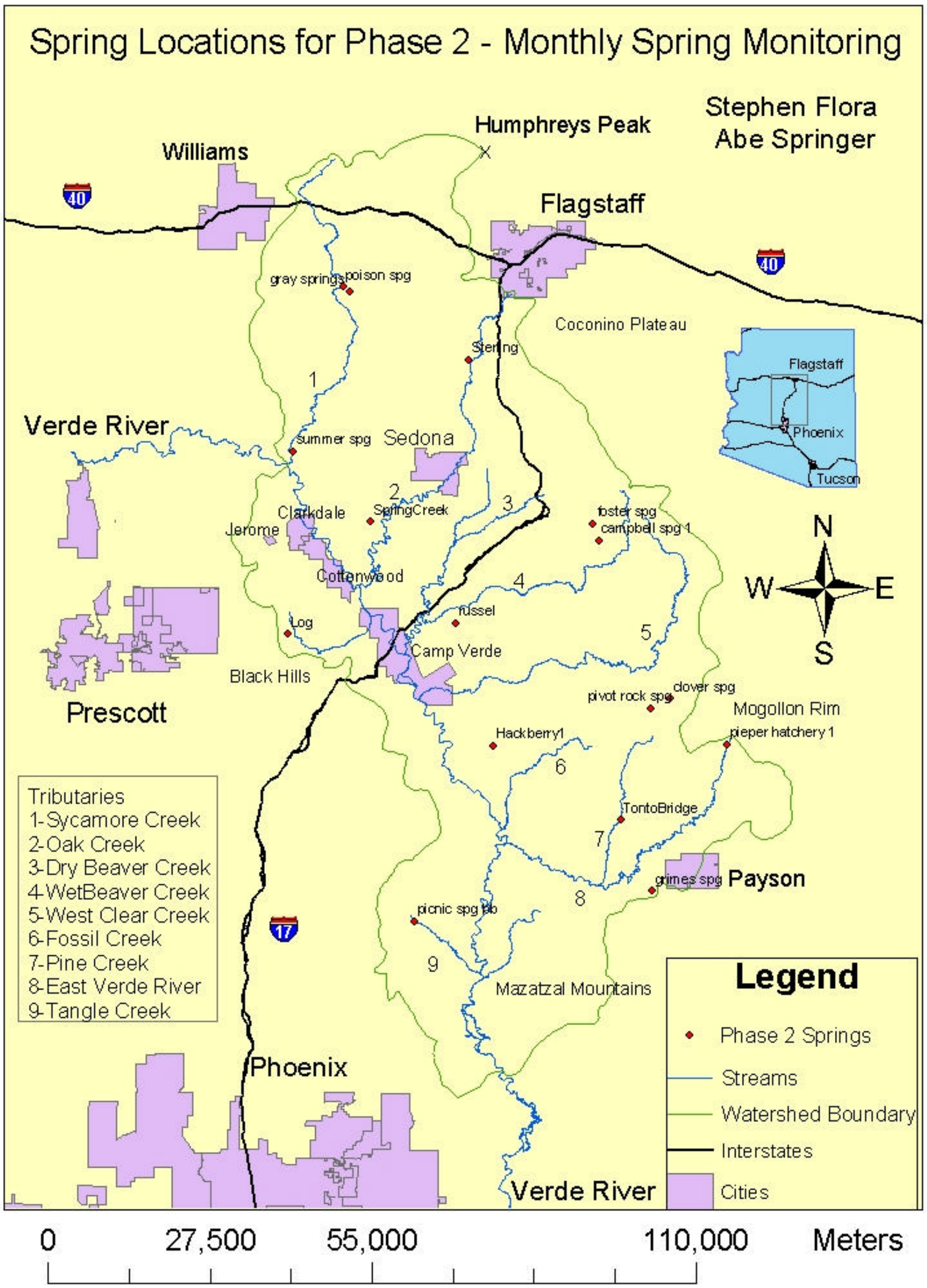
Phase II

In fall of 2002, we developed a list of potential springs to visit in Phase II of the study. We circulated this list to all stakeholders involved in the project. We incorporated their comments into our final list of sites to use for Phase II. We will only report on the partial results of Phase II (in progress) here, but following (Table 4) is a list of springs being visited monthly from November 2002 to October 2003 (pending availability of funding) and a GIS map (Figure 3) of these springs in the watershed. Discharge is measured at each spring monthly. So far results have shown no significant change in spring discharge from November 2002 through February 2003. Significant fluctuations in spring discharge are not expected until after March when snowmelt occurs and recharges the aquifers that provide water for these springs. Stable isotopes analysis samples have been collected once in December and will be collected again in May (pending availability of funding). Results from the Stable Isotope analysis in December have not yet been completed. Table 4 also includes the geologic unit, location, national forest, and December 2002 measured discharge for the springs for Phase II.

Table 4. List of springs in Phase II of the Verde springs monitoring study by geologic formation.

Name of Springs	Geologic Formation	Location	National Forest	Discharge 12/2002
Foster and Campbell Springs	Basalt	Stoneman Lake Upper Wet Beaver Creek	Coconino	0.5 gpm / 1.5 gpm
Poison and Gray Springs	Basalt	Upper Sycamore Creek	Coconino	1.10 gpm / 0.563 gpm
Clover and Pivot Rock Springs	Kaibab Limestone	Clints Well / Upper West Clear Creek	Coconino	0 gpm / 1.2 gpm
Sterling Spring	Coconino Sandstone	Upper Oak Creek	Coconino	310 gpm
Summer Spring	Redwall/Martin Limestone	Lower Sycamore Creek	Coconino	3600 gpm
Spring Creek Spring	Verde Formation	Lower Oak Creek	Coconino	228 gpm
Russell Spring	Verde Formation / alluvium	Lower Wet Beaver Creek / Montezuma Well region	Coconino	3.80 gpm
Hackberry Spring	Tertiary Volcanics / Alluvium	Fossil Creek, Hackberry Mtn	Coconino	4.0 gpm
Log Spring	Precambrian Granite	Cherry Creek	Prescott	2.25 gpm
Pieper Hatchery Spring	Supai Group	Upper East Verde River	Tonto	242 gpm
Tonto Natural Bridge Spring	Redwall / Naco limestone	South of Pine Pine Creek	Tonto	108 gpm
Grimes Spring	Precambrian Metamorphic / Igneous Rocks	West of Payson East Verde River	Tonto	0.25 gpm

Figure 3 – Map showing locations of springs (in Phase II) of Verde springs monitoring study.



Evaluating the Irrigation Efficiencies and Turf/Landscape Maintenance Practices on the Campus of Northern Arizona University

Basic Information

Title:	Evaluating the Irrigation Efficiencies and Turf/Landscape Maintenance Practices on the Campus of Northern Arizona University
Project Number:	2002AZ6B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	5
Research Category:	Climate and Hydrologic Processes
Focus Category:	Irrigation, Water Use, Conservation
Descriptors:	IG, WU,COV
Principal Investigators:	Donald Slack, Richard Bowen, Abigail Stella Roanhorse, Peter Waller

Publication

1. Roanhorse, Abigail S. July 2002, NAU Reclaimed Water Feasibility Study Final Report, Master of Engineering Project, Department of Agricultural and Biosystems Engineering, University of Arizona, Tucson, AZ, 83 pages.
2. Roanhorse, Abigail S.; Slack, Donald; and Waller, Peter. September 2002, Summary of Northern Arizona Universitys Reclaimed Water Feasibility Study in Arizona Hydrological Societys Annual Symposium, Flagstaff, Arizona
3. Roanhorse, Abigail S.; Slack, Donald; and Waller, Peter September 2001, Northern Arizona Universitys Reclaimed Water Feasibility Study in Arizona Hydrological Societys Annual Symposium, Tucson, Arizona

A. Problem and Research Objectives:

Water shortages are developing in many northern Arizona cities and towns as water demand resulting from population growth and expanded tourism approaches and/or exceeds the area's finite supplies of water. An issue of critical concern in the region is the growing volume of water consumed in turf and landscape irrigation as the number of residences, businesses, parks and golf resorts increase. Northern Arizona University (NAU) is Flagstaff's largest consumer of potable water. With the exception of one athletic field, the University is dependent on potable ground water for irrigation. The project completed an irrigation system efficiency evaluation of NAU's, identified system deficiencies (i.e., poor design vs. system management), and recommended possible solutions. The study concluded the optimization of NAU's existing irrigation system would conserve an estimated 35.4 million gallons of potable water per year or $93,102 per year.

There has been a growing demand for sound, science-based information on turf and landscape irrigation from county and city governments, water suppliers, landscape managers and concerned citizens. While there has been considerable emphasis placed on developing information pertaining to proper turf and landscape irrigation management in the desert areas of Arizona, considerably less attention has been paid to these same issues in northern Arizona. Much of the existing landscape irrigation information available for higher elevation arid and semiarid regions has not been summarized for use in Arizona. The project worked closely with the NAU grounds personnel to share information and increase awareness or more efficient water use practices. The project provided landscape maintenance/grounds personnel with environmental evaluations (i.e., soil and plant characteristics) and recommendations for optimizing irrigation maintenance practices and scheduling. Finally, this effort encouraged natural resource sustainability and water conservation from the City of Flagstaff's major water consumer, increasing water research opportunities in northern Arizona.

B. Methodology: The irrigation system evaluations included irrigation audits and double ring infiltrometer tests. Together these tests quantified the amount of water applied verses the amount of water infiltrated into the soil. The UA's Pima County Cooperative Extension Low 4 Program provided the project irrigation audit kits to evaluate the irrigation uniformity and efficiency of the existing system. Irrigation audits, also known as catch can tests, were performed to determine the irrigation or distribution uniformity, efficiency, irrigation depth, and system condition. The information recorded included:

- Number of sprinklers per station
- Irrigation times/duration
- Irrigation frequency (i.e., how many times per week)
- Sprinkler types
- Observed problems

The irrigation audits reported numerous design and system maintenance deficiencies (i.e., valve malfunctions, low pressure, high pressure, tilted sprinkler heads, spray deflections, sunken sprinklers, plugged equipment, arch misalignment, low sprinkler drainage, leaky seal or fittings, lateral or drip line leaks, missing or broken heads, slow drainage or ponding, soil compaction, thatch, runoff). A summary of the system deficiencies per field is provided below (Table 1). The irrigation audits reported clay and clay loam soils. These type of soils have an infiltration rate of 0.20 in/hour[1] with irrigation times rangeing from 10-21 minutes. The precipitation rates ranged from 0.57-0.82 in/hour, resulting in runoff and poor rooting depths (2”-3”). To reduce runoff the project recommends reducing runtimes and implementing “cycle and soak” irrigation practices. This will increase infiltration depths, rooting depths, and reduce runoff.

Table 1
Summary of NAU System Deficiencies

System Info/Problems	Hilltop	Lmbrjack	Quad	Gabaldon	Observ.	Nadat.	South
Rooting depth (in.)	3	3	3	3	3	3	3
Soil Type	clay	clay-loam	clay	clay-loam	clay-loam	clay-loam	clay-loam
No. of catch cans	45	56	56	56	45	91	76
Run times (minutes)	21[a]	Varied	17-18	10	10[a]	15	15
Pressure (psi)	45-60	45-50	20-40	40-55	35-60	45-70	35-55
Pressure Varies = 20%							
Times/week	6	6	6	6	6	6	6
DU	0.56	0.48	0.20	0.52	0.40	0.32	0.38
Precipitation rate (in/hr)	0.68	0.57	0.92	0.82	0.84	0.70	0.82
Infiltration rate (in/hr)[b]	0.22	0.80	0.20	0.53	0.41	0.34	0.25
Sprinkler type	I-40	I-40	Mixed	Mixed	Mixed	Mixed	Mixed
Valve malfunctions	-	-	-	-	-	Station 10	
Pressure (Lo/Hi)	Low	-	Both	Low	Low	Low	Low
Tilted sprinklers	4	1	3	1	1	3	2
Spray deflection	1	-	2	-	3	4	4
Sunken sprinklers	-	-	1	-	-	-	1
Plugged equip.	-	1	-	-	-	-	8
Arc misalignment	3	8	3	2	5	4	-
Low drainage	1	-	-	-	1	-	-
Leaking seals/fittings	-	-	2	1	1	-	-
Line leaks	-	-	-	-	-	Yes	-
Missing/broken heads	-	1	22	1	-	3	-
Ponding	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Compaction	Yes	-	Yes	-	-	-	-
Thatch	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Runoff	-	-	Yes	-	-	-	-
Sticking heads	-	1	Yes	-	-	4	5
Broken lines	-	-	Sta 11	-	-	-	-
A – Irrigation times and frequencies have been adjusted to 10 minutes, twice a week. B – Calculated from double ring infiltrometer tests.							

C. Principal Findings and Significance:

The summer of 2002 was the second-driest summer in 108 years. The City of Flagstaff is primarily dependent on groundwater to meet the water demands of its residents. NAU is

[1] Shepersky, Keith. *Landscape Irrigation Design Manual*, Rainbird Sprinkler Corporation, 1994

the City's largest consumer of potable water. The Study estimated the Mountain Campus consumes 154 million gallons of potable water per year for irrigation purposes. This demand corresponds to the City's increased water demand during the summer months (April – October). The Study estimated the amount of water wasted at NAU due to poor system performance was 35 million gallons per year.

The ultimate benefit of this Study was that it increased awareness of turf and landscape water consumption and sustainability. This will assist in water conservation efforts throughout the drought stricken regions of northern Arizona. The Study has received statewide recognition, with 8 articles published in *Arizona Water Resource Newsletter*, *The Arizona Daily Sun*, and *The Lumberjack*. The Study's legacy will continue through the recently state-funded "Improved Turf and Landscape Irrigation Management for Northern Arizona." This 3-year project (July 2003-June 2006) will continue to provide education and outreach in turf and landscape irrigation by establishing a landscape irrigation demonstration project on the NAU campus. In addition, the project will hold annual landscape irrigation workshops in Flagstaff, Prescott and Payson. These workshops will train attendees in the areas of irrigation design and management, irrigation scheduling, evapotranspiration, soil and plant water relationships, reclaimed/gray water use, pesticide use and water quality, and xeriscaping.

Agricultural Chemicals as a Major Non-Point Source of Arsenic: Microbial Transformation of Organic Arsenicals

Basic Information

Title:	Agricultural Chemicals as a Major Non-Point Source of Arsenic: Microbial Transformation of Organic Arsenicals
Project Number:	2002AZ9G
Start Date:	9/1/2001
End Date:	8/31/2003
Funding Source:	104G
Congressional District:	AZ05
Research Category:	Water Quality
Focus Category:	Water Quality, Agriculture, Non Point Pollution
Descriptors:	WQ, AG,NPP
Principal Investigators:	James Field, A. Jay Gandolfi, John R Garbarino, Reyes Sierra, Robert L Wershaw

Publication

First Year Progress Report

Agricultural Chemicals as a Major Non-Point Source of Arsenic: Microbial Transformation of Organic Arsenicals

James A. Field, A. Jay Gandolfi, Reyes Sierra
University of Arizona

John R Garbarino and Robert L Wershaw
USGS, Denver Federal Center

Large quantities of arsenic (As) can enter into the environment as organo-arsenic compounds through agricultural activity. Methylarsonic acid (MMA^V) and dimethylarsinic acid (DMA^V) are utilized as herbicides in cotton and roxarsone (3-nitro-4-hydroxyphenylarsonic acid) is used as a feed additive in poultry. The goal of this project is to evaluate the biodegradability and identify major metabolites accumulating from the bioconversion of organoarsenicals.

MMA^V (0.7 mM) and DMA^V (0.5 mM) were incubated in anaerobic microcosm established in serum bottles. Parent compounds and metabolites were monitored with ion chromatography/inductively coupled plasma/ mass spectrometry (IC/ICP/MS). Three redox conditions were tested, either denitrifying (with 32 mM NO_3^-), sulfate reducing (with 21 mM SO_4^{2-}) or methanogenic (no alternative electron acceptor added). Controls with sterile medium and autoclaved sludge were run in parallel to monitor abiotic losses. DMA^V was readily degraded under methanogenic and sulfate reducing conditions, the parent compounds were completely eliminated within 14 days. MMA^V was the only intermediate detected during DMA^V degradation, accounting for approximately 10% of the DMA^V added. MMA^V was also degraded under methanogenic and sulfate reducing conditions. 8 weeks were required to completely eliminate the parent compound with sulfate as electron acceptor; whereas in the same time period 60% of the parent compound was eliminated under methanogenic conditions. Methylarsonous acid (MMA^{III}) was detected as an intermediate, accounting for maximally 12 and 7% of added MMA^V under sulfate reducing and methanogenic conditions, respectively. Additionally traces of DMA^V and arsenate were observed. There was no significant removal of either DMA^V or MMA^V in controls nor under denitrifying conditions. Determination of total arsenicals in the gas and liquid phases demonstrate that the large hole in the arsenic balance was not due to volatile arsenicals nor due to unidentified metabolites in solution. Presently, efforts are underway to characterize arsenicals that are sorbed onto or precipitated in the sludge. Liquid samples from these experiments did not contain any toxicity according to the AMES test.

Recently experiments have been initiated to study the anaerobic bioconversion of roxarsone. Roxarsone concentrations are being monitored by an high performance liquid chromatography coupled to a diode array detector (HPLC-DAD). Roxarsone (500 µM) was incubated with anaerobic sludge under methanogenic, sulfate reducing and denitrifying conditions as a sole source of carbon and energy. Additionally in one treatment, lactate was added as an electron donor under methanogenic conditions to stimulate the reductive biotransformation of roxarsone. The parent compound was rapidly eliminated (100% in 8 days) unde the condition with lactate added and also under sulfate reducing conditions. Presently, possible metabolites from the biotransformation are being analyzed.

The results taken as a whole indicate that simple organoarsenicals are susceptible to anaerobic biotransformations.

The future research plans are to examine the aerobic and anaerrobic degradation of the simple methylarsenicals in impacted sediments collected from a cotton-growing region in Arkansas. Additionally, the toxicity of biotransformation products from roxarsone will be examined.

Develop Bioassay Capability for Modification of Water Quality Criteria & Effluent Testing Using Arid West Aquatic Species

Basic Information

Title:	Develop Bioassay Capability for Modification of Water Quality Criteria & Effluent Testing Using Arid West Aquatic Species
Project Number:	2002AZ21B
Start Date:	3/1/2001
End Date:	2/28/2004
Funding Source:	104B
Congressional District:	5
Research Category:	Water Quality
Focus Category:	Waste Water, Toxic Substances, Surface Water
Descriptors:	WW, TS, SW
Principal Investigators:	Donald Baumgartner, Kevin Fitzsimmons, Stephen G Nelson

Publication

Progress Report

Original Project Number: 2001 AZ961B

Having successfully maintained cultures of a native species of fish (longfin dace, *Agosia chrysogaster*) and the standard EPA test species (fathead minnow *Pimephales promelas*), as reported previously, we have added another candidate native bioassay fish species to our culture efforts. The major activity has been to produce offspring, which is important for two aspects of maintaining culture stock for bioassay trials. First, we need to have embryos, or in some cases, juveniles, to represent the most sensitive life forms to determine environmentally safe levels of aquatic concentrations of copper and other dissolved metals. Secondly, reproductive success is important to develop a continuing line of mature individuals capable of maintaining the genetic strain of bioassay specimens. We have been successful with rearing a first generation of one of the species, but the first trial with the other species was unsuccessful. We are attempting again to produce offspring in the second species. These early results, and the copper toxicity trials reported earlier, have been presented in a student paper at a regional meeting of the American Fisheries Society, with favorable acceptance.

Information Transfer Program

The Water Resources Research Center (WRRC) at the University of Arizona focuses on water resources research, education and outreach designed to foster a better understanding of critical Arizona water issues. WRRC activities involve interaction and collaboration with university water researchers and professionals throughout the state and with the broader water community, including individuals, public and private organizations with a professional interest in water, political leaders and policymakers, as well as citizens and other professionals interested in water affairs.

The WRRC carries out several public outreach and education activities. These include publication and free distribution of the bi-monthly WRRC newsletter, organizing conferences, informational briefings and seminars, writing reports, compiling directories, making community presentations, and designing exhibits. The WRRC has an ambitious and productive water education program for classroom teachers and educators. Project WET (Water Education for Teachers) reaches over 600 teachers annually and thousands of K-12 students.

WRRC Director, Peter Wierenga, and Associate Director, Sharon Megdal, have taken the leadership in coordinating the activities of the Water, Economic Development, and Sustainability Program, the water research, education and outreach program of the state-funded Technology & Research Initiative Fund (TRIF) at the University of Arizona.

The WRRC pursues regional water conservation efforts through the Water Conservation Alliance of Southern Arizona (Water CASA) which, since its inception in 1997, has been recognized as both a leader and innovator in the conservation field.

The WRRC collaborates extensively with other agencies in an effort to pool resources and magnify its efforts in the community. We have a close collaboration with the United States Geological Survey (USGS), which is housed on the University of Arizona campus. The USGS supports many graduate students from a number of departments, including the Hydrology and Water Resources Department, Geosciences and Geology. Nick Melcher, USGS District Chief, Tucson, Arizona serves on the WRRC External Advisory Board.

The WRRC also has close working relationships with the Arizona Department of Water Resources, the Central Arizona Project, the U.S. Bureau of Reclamation, the Arizona Department of Environmental Quality and the Salt River Project.

WRRC has an important and recognized role in the water affairs of the state, acting as a facilitator among various water interests, for the purpose of encouraging communication and cooperation among members of the Arizona water community and ensuring water education and information transfer opportunities.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2002AZ7B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	5
Research Category:	Not Applicable
Focus Category:	Water Use, Management and Planning, Water Supply
Descriptors:	WS, M&P, EDU
Principal Investigators:	Peter J. Wierenga, Joe Gelt, Val Little, Sharon Megdal, Kerry Schwartz, Terry Sprouse

Publication

1. Little, Val, 2002, Graywater Guidelines, The Water Conservation Alliance of Southern Arizona, Tucson, Arizona, 24 pgs.
2. Water Resources Research Center, 2002, Arizona Water Map, Water Resources Research Center, University of Arizona, Tucson, Arizona.

WATER RESOURCES RESEARCH CENTER

Public Outreach and Education

New WRRC Associate Director

In mid-February 2002, Sharon B. Megdal joined the WRRC as Associate Director. She also serves as Professor and Specialist, Department of Agricultural and Resource Economics. Dr. Megdal holds a Ph.D. in Economics from Princeton University. Dr. Megdal has years of experience working in water resources policy and management, including working on project development and implementation as a consultant, and has extensive experience working with water professionals and public sector, private sector and tribal officials. She served as a member of the Governor's Water Management Commission. At the WRRC, Dr. Megdal focuses on state and regional water policy and management matters. She writes a public policy column for the WRRC bi-monthly newsletter on Arizona water issues and is involved in several research projects, including a study of private versus public ownership of water systems in Arizona. Dr. Megdal regularly makes presentations on water issues. In January 2003, she was invited to provide a background briefing on Arizona water issues at the first regular session meeting of the Arizona State Senate Natural Resources and Transportation Committee. She has served on the Arizona Water Quality Appeals Board since March 2002. The Board is statutorily responsible for ruling on appeals of water quality permit decisions of the Director of the Department of Environmental Quality.

TRIF Water Program

An important development for the water community at the University of Arizona and for the WRRC in particular was new funding for water programs through the state-funded Technology & Research Initiative Fund (TRIF). The program began in the summer of 2001, with funds becoming available to the WRRC starting in December 2001. For the first two years of the program, approximately $500,000 in annual funding was distributed equally among the WRRC, three National Science Foundation-funded centers at the University of Arizona, and a joint water education and outreach program. During the reporting period, a business plan for the TRIF water program, known as the Water, Economic Development, and Sustainability Program, was developed and approved by the Arizona Board of Regents. Anticipating an increase in program funding to $2,000,000 for the fiscal year beginning July 1, 2003, a competitive grants program for water research, education and outreach was developed and implemented during the reporting period. In addition, a competitive student fellowship program was developed. Following a November 2002 request for proposals, a total of 66 proposals were received in the areas of water quality, water supply and economics, and water outreach and education. Three peer review panels ranked the proposals. Twenty-one proposals were recommended for funding. A competitive process was also used to award 5 undergraduate fellowships and 4 graduate assistantships in the water area. Going forward, a small portion of the TRIF funding was used to hire a TRIF program and fellowship coordinator (0.5 FTE), who will be housed at the WRRC, to assist with management of the grants program. An external advisory committee to the TRIF water program, consisting of representatives of water providers, industry and government, met for the first time in October 2002. WRRC Director, Peter Wierenga, has taken the leadership in coordinating the activities of TRIF in the water area at the University of Arizona.

WRRC Researcher Receives Fulbright Grant and is Appointed to IBWC Outreach Board

During the reporting period, WRRC senior research specialist Terry Sprouse successfully applied for a Fulbright Grant to study bi-national effluent management in Nogales, Sonora and Nogales, Arizona. Sprouse's study, to begin August 2003, is entitled "Developing options for equitable management of Mexican effluent in Ambos Nogales." Sprouse will work in collaboration with researchers at the University of Sonora. In addition, Dr. Sprouse was appointed to serve on the International Boundary and Water Commission (IBWC) Board of the Citizens' Forum for Southeast Arizona. Sprouse also serves as a representative center on the Pima Association of Governments, Environmental Planning Advisory Committee (EPAC) and Water Quality Subcommittee and participated in the development of the EPAC strategic plan. The plan provides guideline for protection of the environment and water resources in Pima County.

WRRC Future Work on U.S.-Mexico Border with USGS and other Centers

The Arizona WRRC will continue to work with the New Mexico and Texas Water Centers, the USGS and our respective Congressional delegations to obtain a special appropriation for Hydrology and Environmental investigations of trans-boundary rivers and aquifers along the U.S.-Mexico border.

USGS District Chief on WRRC Advisory Board

Nick Melcher, USGS District Chief, Tucson, Arizona serves as a member of the WRRC External Advisory Board. The Board, which meets at least once a year, is responsible for providing guidance to the WRRC for future projects and activities. The Board also evaluates grant proposals for the 104B grant program.

WRRC Web Site Upgraded

Notable improvements were made to the WRRC web site. They include the installation of a site search engine to search the entire web sits; improved printer friendly pages; a new navigation system to work with all browsers; and consistent text and page layouts throughout the site. Also, persons can now subscribe to the newsletter on-line. A total of 97 persons took advantage of this subscription feature in 2002. Also a low-band width version on the web site has been added for handicap access.

Community and Conference Speaking

WRRC faculty and staff continue to provide presentations on state, regional and local water issues to various organizations around the state. Faculty and staff also provide information to various media outlets around the state on water-related issues.

Brown Bag Seminars

The WRRC provides a forum for university and non-university personnel to share their water resources work through our Brown Bag Luncheon Seminar Series. Presentations include:

- Tom Carr of the Arizona Department of Water Resources, "History and Future Utilization of the Yuma Desalinization Plant";
- Dr. Katie Hirschboeck of the Laboratory of Tree-Ring Research, "Hydrologic History from Tree Rings: Droughts, Floods & Climatic Variability in the Southwest";
- Bruce Johnson and Mark Stratton of Metro Water Company, "Evaluation of Water Resources in Almaty, Kazakhstan";
- Kathy Jacobs of the Arizona Department of Water Resources, "Rural Water Issues"
- Dr. Ayman Mohammed Jarrar, Director of the Regulatory Directorate Palestine Water Authority, "Water Resources in Palestine";
- Professor Gao Chaoqun, Institute of Economics, Chinese Academy of Social Science, Beijing, "Water Management Issues in China"

Briefings for International Visitors

The WRRC has provided briefings for interdisciplinary groups of international visitors interested in natural resources and water. These visitors are sponsored by the United States Department of State. Presentations have been made to the group about Arizona water issues. These presentations, which are followed by questions and discussion, have been well received.

Meeting with Governor's Staff

During the reporting period, the WRRC worked on organizing an informational briefing, which was hosted at the WRRC in March 2003, on University of Arizona water resources research, education and outreach for Governor Napolitano's Chief Assistant for Policy, Noah Kroloff. Faculty and staff from many university departments and centers provided information on their water research, education and public information programs so that the Governor's Office would be aware of the resources available through the University of Arizona.

Water Map

The WRRC completed revisions of the state water map poster. The map revision was produced in collaboration with the U.S. Bureau of Reclamation, whose capabilities in GIS and graphics contributed substantially to the success of this project. A total of $20,000 was raised to revise the map. Additional agencies that contributed either monetary and/or technical support included the Arizona Department of Environmental Quality, the Arizona Department of Water Resources, the Central Arizona Project, the Salt River Project, and the University of Arizona Cooperative Extension. Since publication over 3,000 maps have been distributed.

Water Conference

Preparations were made during the reporting period for the 2003 annual water conference, entitled "Local Approaches to Resolving Water Resource Issues: What's Working, What Hasn't Worked and Building on Existing Efforts." The conference was held on May 1 and 2, 2003 in Prescott, Arizona and focused on local and regional approaches to water management, particularly for rural Arizona communities. Conference attendance included about 200 persons from more than 40 Arizona communities. Associate Director Sharon Megdal was largely responsible for developing the program for this very successful conference.

Revision of the WRRC's Desert Landscaping Compact Disk.

Work continued on the *Desert Landscaping: Plants for a Water-Scarce Environment* CD, which allows one to search for plants through a plant selector covering over 600 low water-use plants. Users can search by plant name, browse award-winning landscapes, compare groups of similar plants, or use the plant selector to precisely describe the plants one seeks. The rich multimedia database includes plant size and growth rate, soil and sun requirements, irrigation needs, place of origin, allergens, wildlife interactions, and dozens of other useful factors. Additional information is provided through links to landscaping tips and a bibliography. The original CD-ROM was produced in 1996 and was very popular throughout Arizona. The revised version will operate more quickly and efficiently, have more and newer photos, and provide vastly more information on desert landscaping plants.

The Arizona Water Resource Newsletter

The WRRC publishes the Arizona Water Resource Newsletter six times a year. The newsletter is 12-pages and presents general news, events and issues analysis for the Arizona water community. The newsletter is distributed by mail free of charge to over 2,200 individuals and is available on-line. Sections include: Water Vapors, News Briefs. AZ Water Community News, Guest View, Legislation and Law, Publications, Special Projects, Announcements, Outside Readings and Public Policy Review by Sharon Megdal. Goals of the newsletter include: 1) to be a reliable source of varied water-related news and information; 2) to provide water related news and information not usually covered by the news media; 3) to broaden readers' awareness of critical water issues of importance to the state; and 4) to serve as an Arizona water "bulletin board", enabling water-related organizations and agencies to publicize news and information.

In 2002, the newsletter attracted over $6,000 from outside agencies and organizations, to help cover publication costs.

Articles and features from the newsletter have been reprinted in Capitol Times, U.S. Water News, local newspapers throughout the state and various state water newsletters throughout the county.

Arizona Water Resource Newsletter articles for this year included: "*Dry* Power Plants Produce Energy Using Less Water;" "Rural Northern AZ Plans Its Water Future;" "First Arizona Water Treatment Plant Using Ozone Now On-Line;" "System Provides Real Time Water Quality Information;" "Budget Cuts Take Toll on ADWR's Operations;" "Bill Would Settle Tribal Water Rights; "2002 Farm Bill Has Options for Arizona; and, Q & A With Herb Guenther, New ADWR Director."

The Arroyo Newsletter

The Arroyo newsletter is published less frequently and focuses the entire publication on one topic. Topics for Arroyo are usually issues that are presently being discussed by citizens and decision makers. The additional newsletter space allows for an in-depth analysis of the issues and perspectives surrounding the topic. The featured topic for this year's issue of the Arroyo Newsletter was "Arizona Rural Water Issues Attracting Attention."

K-12 Water Education Programs

The WRRC WET (Water Education for Teachers) Program Coordinator is the state representative for the National Project WET program. As such, the WET Program Coordinator is responsible for promoting an understanding of water and water-related issues statewide. Project WET activities provide an opportunity for people of all ages in all places to better understand the water resource issues facing their community and the world. The position of WET coordinator is funded by the state, through WRRC, but this year the coordinator received additional grants totaling around $319,000 from the Bureau of Reclamation, the Arizona Department of Water Resources (ADWR), the Central Arizona Project (CAP) , the City of Phoenix and National Project WET. Project WET also receives $15,000 annually and from the state-funded Technology & Research Initiative Fund (TRIF).

WRRC has an ambitious and productive water education program for classroom teachers and educators. WRRC coordinates a network of 60 trained facilitators statewide that lead teacher training workshops for over 450 teachers per year and reach thousands of K – 12 students. This program reaches classroom teachers in public and private schools, youth groups leaders, tribal governments, environmental education centers (including gardens), community colleges and state universities.

Considerable effort, this reporting period, has gone into creating a network of Phoenix metropolitan area facilitators trained in Phoenix-specific water resources and equipped with nationally recognized teaching activities and pedagogy. Funding was provided by TRIF. Through additional Arizona Department of Water Resources grant funding, a 6-day intensive Arizona water resources training was held in July 2002 and a two-day facilitator training was held February 21-22 bringing the Phoenix facilitator network up to forty facilitators. These facilitators are offered ongoing training opportunities and small stipends for 8-hour workshops delivered through the grant. During the next reporting period, the Bureau of Reclamation has committed to funding the development of additional facilitator networks in northern and southern Arizona.

Grant funding discussions continue with the ADWR Tucson Active Management Area (AMA) and the City of Tucson. In addition, workshops are conducted with cooperation from Cooperative Extension specialists, the Science Coordinators and/or the Staff Development Coordinators for school districts in Arizona, Arizona State Parks, and the Natural Resource Conservation District Education Centers.

National Water Education Day – Water Festival

The Project WET Coordinator, is responsible for planning, organizing and implementing an annual Water Festival for National Water Education Day. The Arizona water festival is one of the simultaneous water festivals being held in all 50 states. In this and other efforts, the coordinator has a responsibility to stay connected to the education community as well as the water community.

The Water Festival celebrating National Water Education Day, held in September 2002, benefited from the sponsorship of the U.S. Bureau of Reclamation, Arizona Department of Water Resources, Salt River Project, Central Arizona Project, Arizona Department of Environmental Quality and Scottsdale School District Elementary Schools. An extraordinary, interactive educational opportunity was offered to 1000 4th grade students and their teachers in Arizona. Planning for 2003 water festivals has begun in Safford and Surprise, Arizona.

Tucson Interactive Water Education Exhibit

The Tucson Interactive Water Education Exhibit was created to offer schools state of the art information on water in the Tucson AMA. The exhibit was set up at elementary schools so that librarians and teachers could lead students through the exhibit over the course of a week or two. The color-coded sections of the Tucson Interactive Water Education Exhibit included:

I. Water in the Desert
II. Water Cycle

III. Sources of Water
IV. Water Uses
V. Water for the Future
VI. Water History

In 2002, the Tucson Interactive Water Education Exhibit was hosted in four different school districts and been toured by more than 5,000 students. The response from teachers and librarians was so overwhelmingly positive that the Tucson AMA funded a new grant cycle for the 2002-03 school year. During the summer months, the Interactive Water Education Exhibit was set up at the Arizona Sonora Desert Museum.

Groundwater Flow Model Demonstrations

As a resource for teachers seeking water resources education information, the Project WET coordinators train teachers to use water oriented teaching tools. The groundwater flow models are an incredibly good tool for teaching about groundwater and aquifers. Groundwater flow model demonstrations are conducted with visiting scientists, government employees, and at all educator workshops. Groundwater presentations conducted with WRRC flow models reached over 2,000 students and 500 adults this year. Groundwater flow models are maintained by WRRC staff for use by teachers and for use at training workshops.

WATER CASA

Formed in 1997, the Water Conservation Alliance of Southern Arizona (Water CASA) provides a means for member water providers to augment their individual conservation programs and to improve the region's overall water conservation efforts. Water CASA's membership includes Avra Water Co-op, Community Water Company of Green Valley, Flowing Wells Irrigation District, Town of Marana Water Department, Metro Water District, Oro Valley Water Utility, Pima County Wastewater Management, and the U.S. Bureau of Reclamation. The annual budget for WATER CASA is approximately $235,000. This year it received grants totaling around $110,000 from the Bureau of Reclamation, Tucson Water Company, the Arizona Department of Water Resources and from the Technology & Research Initiative Fund.

This alliance has rapidly become an organization effectively using economies of scale and providing a strong, unified voice on water conservation issues regionally. Summaries of Water CASA:s services, activities, and accomplishments follow. More detailed information is available on the Water CASA website: www.watercasa.org .

In October of 2002, Water CASA celebrated its five-year anniversary with a conference attended by over 75 members of the Arizona water conservation community. Keynote speaker Amy Vickers, author of the “Handbook of Water Conservation,” addressed the audience with her talk “Water Conservation: a New Era and New Dimensions.”

Graywater Guidelines

In July of 2002, Water CASA published the booklet "Graywater Guidelines." This convenient reference publication clarifies graywater issues in a simple and straightforward manner. The text is targeted to the interested public enabling the reader to decide if graywater is appropriated for them, and provides guidelines on a variety of appropriate materials and methods of system installation. Copies of the booklet can be downloaded from www.watercasa.org.

Dual Metering Project

With support of the US Bureau of Reclamation, Water CASA has launched the first of three phases of a dual metering project to measure indoor and outdoor water use separately in single family residences. The project will provide, over the next 20 years, information about actual water use by season and through time as landscapes and families mature. The first year's water use records have been generated. These data show generally less out-door water use in this new development during the first year than was anticipated.

Water on the Web

Last year Water CASA successfully completed the Water on the Web pilot program, which enables members' customers to access individual water consumption and conservation information via the web. The goal of Water on the Web is to provide water customers a convenient way to review their monthly water consumption in a format that most importantly enables them to compare their usage with that of their neighbors and the community. Water CASA believes that this pilot program creatively and effectively promotes water conservation by allowing customers to easily compare their water usage through seasons, from year to year, and to similar households.

This analytical consumption comparison promotes customer water awareness resulting in additional, voluntary conservation. Customers also receive either water saving tips or a pat on the back, depending on their water usage. Water on the Web is a valuable service to Water CASA members that lack the ability to provide this information as part of their water bills. The pilot program, was funded by the U.S. Bureau of Reclamation.

Welcome Packets

Water CASA provides its members with a variety of brochures and information pieces that are distributed with a Welcome Packet 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. Water CASA is tracking the water use patterns related to the packets and analyzes the effectiveness of the Welcome Packet program.

Conservation Devices

Bulk orders of conservation devices are 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. Water CASA is able to purchase conservation devices at the lowest possible price by bulk ordering. In addition, the US Bureau of Reclamation supports this program with $10,000 toward the purchase of these devices such as showerheads and faucet aerators. 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 effective as a customer service.

Slow the Flow

This year Water CASA and Pima County Wastewater began collaborating on a pilot program to reduce sewer flows through intensive indoor water conservation efforts. In an effort to mitigate sewer flow in targeted neighborhoods which are at capacity, the County will be investing in cost-effective water conservation strategies which will help eliminate the need to replace and expand the capacity of existing sewer infrastructure, a costly and inconvenient strategy. Using a multi-prong approach to reduce sewer flow, save water, and save money, Water CASA has begun developing a pilot program to test the interest, cost-effectiveness, and water savings of various conservation measures.

Collaboration With Jordan

In May 2001 and again in January of 2002, the Center for the Study of the Built Environment (CSBE), in Amman, Jordan invited Water CASA to travel there to head a team of water conservation experts. The team provided water conservation and appropriate plant material information to their counterparts in Jordan. The Association for Educational Development, the U.S. Embassy, and the CSBE sponsored the trip. Water CASA shared the results of its Residential Graywater Reuse Study. A portion of the trip included an extensive tour of Jordan's centuries old water harvesting structures and techniques.

The establishment of a collaborative relationship with CSBE has resulted in an exchange of ideas and information beneficial to both groups. The exchange of ideas and information continued this year with a visit in June 2002, of a delegation from Jordan representing the Ministry of Water and Education, the Ministry of Public Works, and WEPIA. Water CASA organized a study tour where the 9 delegates enjoyed discussions with area experts on local water issues, tours of Pima County Waste Water Treatment Plant, Sweetwater water reclamation site, Metro Water facilities, residential water-harvesting sites, and the Arizona-Sonora Desert Museum's wetlands project.

USGS Summer Intern Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	6	0	0	0	6
Masters	6	0	0	0	6
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	13	0	0	0	13

Notable Awards and Achievements

Kerry Schwartz, Program Coordinator for Project WET, received grants totaling approximately $319,000 from the Bureau of Reclamation, the Arizona Department of Water Resources (ADWR), the Central Arizona Project (CAP), the City of Phoenix and National Project WET. Project WET also receives $15,000 annually and from the state-funded Technology & Research Initiative Fund (TRIF).

The Center for the Study of the Built Environment, in Amman, Jordan invited Val Little of Water CASA to travel there as head of a team of water conservation experts.

Water CASA received grants and awards totalling approximately $100,000 from organizations including: the Bureau of Reclamation, Tucson Water Company, the Arizona Department of Water Resources and the Technology & Research Initiative Fund (TRIF).

Terry Sprouse, Senior Researcher at the WRRC was appointed to serve on the Board of the Citizens Forum for Southeast Arizona. The Board, organized by the International and Boundary Commission (IBWC), meets four times a year at different border communities to solicit public input on upcoming, or ongoing, border water projects.

Terry Sprouse, Senior Research Specialist, received a grant of $68,000 from the National Park Service to establish water quality monitoring plans for selected surface water resources in Southern Arizona Parks.

WRRC Senior Research Specialist Terry Sprouse was awarded a Fulbright Grant to study bi-national effluent management in Nogales, Sonora and Nogales, Arizona.

Publications from Prior Projects

None