Water Resources Research Center
Annual Technical Report
FY 2009

Introduction

Since its founding, the University of Arizona's Water Resources Research Center (WRRC) has become a hub for water resources research and information transfer in Arizona. Its mission is to promote understanding of critical state and regional water management and policy issues through research, community outreach and public education. A Research and Extension unit of the College of Agriculture and Life Sciences, the WRRC is the designated state water resources research institute established under the 1964 Federal Water Resources Research Act. As such, the WRRC administers research grant programs, conducts water management and policy research, and runs a strong information transfer program that includes publications, presentations, conferences and other public events. In addition to its activities pursuant to the Act, the WRRC accomplishes its mission through multiple collaborations and cooperative arrangements. It is one of five University of Arizona centers responsible for implementing the Water Sustainability Program funded from the UA's Technology and Research Initiative Fund (TRIF) and houses the WSP coordination office. As a Research and Extension unit, the WRRC maintains a mutually beneficial relationship with the Cooperative Extension system. Two associated programs at the WRRC, Arizona Project WET and Arizona NEMO, which operate under the Cooperative Extension umbrella, expand the breadth and reach of WRRC programs and initiatives.

Research Program Introduction

The University of Arizona's WRRC manages a research grant program under the WRRA, Section 104(b). Funds provide grant support to researchers at each of the three state universities in Arizona. The WRRC typically funds three or four small projects each year to examine water issues of statewide importance. A wide range of projects have been funded over the past 45 years. In recent years, projects have emphasized improvements in water supply reliability and quality, and explored new ideas to address water problems or expand understanding of water and water-related phenomena. During the project year (March 2009 through February 2010), funded projects developed a publically accessible database for research on two Arizona-Sonora transboundary aquifers; investigated the relationship of forest management actions with water supply and forest health; refined and tested techniques for identifying the sources of mercury (Hg) in the environment; and studied patterns of Hg occurrence in an urban watershed.

The WRRC manages a research program for Arizona under the United States-Mexico Transboundary Aquifer Assessment Act of 2006. Since 2007, the WRRC along with its partner institutions in New Mexico and Texas, the United States Geological Survey (USGS), and the International Boundary and Water Commission (IBWC) have begun implementing the program to assess priority aquifers along the U.S.-Mexico border with research activities including hydrogeologic characterization, mapping, modeling and institutional assessment. The two priority aquifers in Arizona are the Santa Cruz aquifer and the San Pedro Valley aquifer.

The WRRC also administers for Arizona the competitive grant program funded by the USGS under WRRA Section 104(g).

Database Creation: Transboundary San Pedro Valley Aquifer

Basic Information

Title:	Database Creation: Transboundary San Pedro Valley Aquifer
Project Number:	2008AZ346B
Start Date:	2/27/2009
End Date:	11/1/2009
Funding Source:	104B
Congressional District:	Arizona 7
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Management and Planning, Water Supply
Descriptors:	transboundary groundwater, aquifer assessment,
Principal Investigators:	Christopher A Scott

Publication

1. Vandervoet, Prescott and Christopher A. Scott, continuously updated, Transboundary San Pedro Valley Aquifer Database, at http://ag.arizona.edu/AZWATER/taap/.

Database Creation: Transboundary San Pedro Valley Aquifer

Problem and Research Objectives

The upper San Pedro River aquifer was designated as a priority aquifer for assessment activities under the Transboundary Aquifer Assessment Act, U.S. Public Law 109-448. "Evaluating all available data and publications as part of the development of study plans for each priority transboundary aquifer" is a principal objective of the legislation.

The upper San Pedro River basin in the United States has been referred to as one of the most comprehensively-studied rivers in the entire nation. A wide variety of work related to basin hydrology has been carried out, particularly in areas such as Walnut Gulch, where the USDA Agricultural Research Service has extensively monitored a confined tributary of the upper basin. The USGS monitors surface flow at Palominas, Lewis Springs, Charleston, Tombstone, and Benson, all located on the upper San Pedro. Many ecologically-focused studies have used the San Pedro River National Conservation Area as a study site, as if occupies a corridor of the river between the international border with Mexico to approximately 40 miles north, downstream.

The Upper San Pedro Partnership (USPP), a consortium of stakeholders representing various governmental and non-governmental interests in the upper basin in Arizona, has actively sought out options for sustainable use of groundwater in the region. The USPP has engaged a variety of researchers and organizations to analyze groundwater-related issues, thus significantly adding to the data related to regional hydrology. Much of this information is presented in the form of annual reports to Congress, commonly known as 321 Reports, due to Section 321 of the Defense Authorization Ace of 2004, Public Law 108-136, directing the Secretary of the Interior "to prepare reports to Congress on steps to be taken to reduce the overdraft and restore the sustainable yield of ground water in the Sierra Vista Subwatershed."

In Mexico, the northwestern office of the federal water authority (the National Water Commission- CNA by its Spanish abbreviation) created a basin commission for the San Pedro River- the Basin Commission for the Upper San Pedro River (CCARP by its Spanish abbreviation). This commission, headed by a representative of the State Water Commission presently charged with operating the municipal potable water provision system, convened and participated in meetings in Cananea, Sonora and Sierra Vista, Arizona. They actively sought to encourage engagement with US stakeholders. Although the CCARP has recently been semi-inactive, it remains an important entity related to management issues of the binational upper basin.

Despite a large amount of research having been conducted on the upper San Pedro River basin and the formation of stakeholder-lead organizations (The USPP in Arizona and the CCARSP in Mexico), few published scientific and management materials are readily accessible to an audience unfamiliar to the particular issues and organizations which address the specific topics. There exists no "clearinghouse" for materials that cross organizational or thematic

divides, even within the same geographical area. Groundwater as a fundamental resource for development is an important unifying theme among management and scientific organizations and the study of such should be link across disciplines for more robust understanding.

The objective of this research was to evaluate and compile report materials from a broad range of sources that were related to groundwater hydrology of the transboundary upper San Pedro River aquifer. The region of focus was more specifically defined as the upper basin within Mexico and the area referred to as the Sierra Vista subwatershed in the US. Published materials under a variety of themes were reviewed for inclusion in the database, as long as they were directly related to groundwater within the study area.

By reviewing source materials and compiling information on the status and location of such, the TAAP-A/S San Pedro Database provides an important service to stakeholders who may not have the resources or capacity to search and appraise reports and documents related to groundwater issues. While this is a "living document" that undergoes continual updates, the TAAP-A/S San Pedro database will be an online resource, available for download by users. The database is currently hosted on the webpage maintained by the Water Resources Research Center at the University of Arizona. The database is being provided in both MS Access and MS Excel formats, as MS Excel tends to be more common among users of the MS Office suite, though data fields may be limited in Excel.

Methodology

This project followed similar protocol as the previously created database for references related to the transboundary Santa Cruz River aquifer, an activity developed as part of the US-Mexico Transboundary Aquifer Assessment Program. Using Microsoft Access, metadata were entered for hydrological and related studies of the transboundary upper San Pedro River aquifer (encompassing the Mexican section of the river basin and the Sierra Vista sub-basin on the U.S. side of the river system). The database was created with the fields shown in Table 1, as well as specific content from source materials- such as author-provided summaries or abstracts.

The criteria for database inclusion were focused on a single particular theme- groundwater hydrology in the transboundary area of focus. Yet, this particular theme is wide reaching, which is a function of the regional importance of groundwater. Documents related to geohydrological studies, ecosystem status, management and development, and other themes made up an important component of the database compilation.

Table 1. Database Fields

Principal Author- Last Name	Principal Author- First Name	Other Authors	Year Published	Title	Type of Material	Thesis/ Dissertation
Degree/Title Obtained	Academic Institution	U of A Department	Journal Article	Journal Title	Issue	Volume
Edition/Number	Pages	Book Title	Editors	ADWR Report	Modeling Report #	Map
Number of Pages	Summary	Author Provided Abstract	Other Publishing Info	URL Link	Keyword 1- Place	Keyword 2
Keyword 3	Keyword 4	Language	Location	Location Details		

Electronic resources were searched via University of Arizona library online databases, as well as state and federal government web pages and other online resources. Federal and State-level Mexican governmental offices were visited in Hermosillo and Cananea, Sonora. The municipal water provider in Cananea, Sonora is managed by the state-level water commission (CEA-Sonora by its Spanish abbreviation), and thus no municipal-level authority was contacted. In Sierra Vista, Arizona the archival materials of the Upper San Pedro Partnership, a consortium of governmental and non-governmental agencies and entities was reviewed. Documents from the offices of the Public Works Department of the City of Sierra Vista were requested. Also, higher education facilities in Hermosillo, Sonora were visited, with the goal of acquiring print resources or access to electronic resources, as long as they were for public dissemination.

Operations occurred at the University of Arizona, in Tucson, Arizona, but site visits were made to the appropriate entities that held relevant materials for database inclusion. The project team sought input from an (informal) steering committee comprised of staff of the Water Resources Research Center (University of Arizona), USGS Tucson Science Center, Upper San Pedro Partnership, Comisión Nacional del Agua and Comisión Estatal del Agua de Sonora.

Principal Findings and Significance

Currently the database contains 131 referenced materials. Metadata as defined above has been collected and inputted for each material, though in some cases fields have been left blank due to lack of accessibility or missing information. The database continues to be updated as new materials are located or published. The database is available for download in either in either MS

Access or MS Excel file format. Fields have been translated into Spanish, though metadata remains in English, unless the original source material is in Spanish.

The TAAP-A/S San Pedro database identified the need for improved data sharing among stakeholders within the binational upper San Pedro basin. Although still in draft format, the database can fill a unique niche within this group of actors. Additional tasks include complete translation of all metadata and increased efforts for dissemination, especially within agencies and/or organizations that contributed materials for inclusion.

Copies of the database file in both MS Access and MS Excel are attached as Table 1, which only lists key database fields, to avoid a lengthy report. They can also be downloaded at: http://ag.arizona.edu/AZWATER/taap/.

The database has proven very useful in the development of work plans for binational assessment of the San Pedro aquifer, as discussed in draft format during the November 3-4, 2009 workshop titled, "Developing a Work Plan for the Assessment of the Santa Cruz and San Pedro Aquifers" <http://www.cals.arizona.edu/azwater/taap/>, which was an important planning activity under the TAAP project.

The database will continue to be developed and, we expect, accessed by researchers and other stakeholders as part of the ongoing TAAP project.

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Cooperative Agreement No. 08HQAG0058 Transboundary Aquifer Assessment Program

Basic Information

Title:	Cooperative Agreement No. 08HQAG0058 Transboundary Aquifer Assessment Program
Project Number:	2008AZ366S
Start Date:	3/17/2008
End Date:	3/16/2010
Funding Source:	Supplemental
Congressional District:	7
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Management and Planning, None
Descriptors:	
Principal Investigators:	Sharon Megdal, Christopher A Scott

Publications

1. Megdal, Sharon B., 2007. “Front-Row View of Federal Water Lawmaking Shows Process Works – U.S. Mexico Transboundary Aquifer Assessment Act Pondered, Passed and Signed,” Arizona Water Resource, January-February 2007.
2. Megdal, Sharon B., 2008. “Front-Row View of Federal Water Lawmaking Shows Process Works – U.S. Mexico Transboundary Aquifer Assessment Act Pondered, Passed and Signed” (updated/revised version of 2007 column), in Norman, Laura M., Hirsch, Derrick D., and Ward, A. Wesley, eds., 2008, Proceedings of a USGS Workshop on Facing Tomorrow's Challenges Along the U.S.-Mexico Border; monitoring, modeling, and forecasting change within the Arizona-Sonora transboundary watersheds, U.S Geological Survey Circular 1322, http://pubs.usgs.gov/circ/1322/.
3. Scott, Christopher A., Sharon Megdal, Lucas Antonio Oroz, James Callegary, Prescott Vandervoet 2009. “Assessment of United States – Mexico Transboundary Aquifers Facing Climate Change and Growth in Urban Water Demand” Climate Change (in review).
4. Scott, Christopher A., Sharon Megdal,Lucas Antonio Oroz, Martin Mexía, Hildebrando Ramos, 2008. "Building Shared Vision: assessment of transboundary aquifers along the United States – Mexico border." In Proceedings of International Conference on Water Scarcity, Global Changes, and Groundwater Management Responses, University of California – Irvine, UNESCO, USGS, Irvine, CA, December 1st to 5th, 2008.
5. Vandervoet, Prescott L., 2009. "Transboundary Aquifer Assessment Program Arizona," Annual Meeting for the Association for Borderlands Studies. Albuquerque, New Mexico, April 16, 2009.
6. Milman, Anita, Christopher A. Scott, 2010. "Beneath the Surface: Intra-National Institutions and Management of the United States – Mexico Transboundary Santa Cruz Aquifer," Environment and Planning C: Government and Policy. In press.

Cooperative Agreement No. 08HQAG0058
Transboundary Aquifer Assessment Program

Introduction

Following protocol outlined by the Transboundary Aquifer Assessment Act (Public Law 109-448), a binational group of stakeholders led by the University of Arizona's Water Resources Research Center and the USGS-Tucson has worked to identify and prioritize assessment activities for the transboundary Santa Cruz River aquifer, with preliminary prioritization for the Santa Cruz River aquifer. A central goal of priority-setting meetings and field activities has been the continued engagement of this integrated cross border stakeholder group. Participants represent municipal, state, federal, and binational agencies, as well as citizen groups and university researchers. In an effort to disseminate information on the Transboundary Aquifer Assessment Program- Arizona/Sonora (TAAP-A/S) and specifically the Arizona component's activities, the project has developed a public face by making presentations at public forums and conferences as outlined below.

Progress

Databases

TAAP-A/S has created two databases which aim to compile published and publicly available data related to the transboundary Santa Cruz River and San Pedro River aquifers. These databases, created in Microsoft Access format, catalogue over 130 reference materials each from various sources. The creation of such databases, in addition to providing a valuable source of information in respect to research on the Santa Cruz and San Pedro Rivers, has also allowed TAAP-A/S to create strong networks among agencies and individuals that have contributed source material for database inclusion. The Santa Cruz Database was created exclusively using TAAP-A/S support while work on the San Pedro database received additional support from a WRRC 104B grant program. Materials dealing with hydrological groundwater modeling were priorities for database inclusion, yet any project/report related to the state of groundwater in the priority aquifers have been identified. Compilation of source material has occurred both electronically, as well as in person at the following locations:

- Arizona Department of Water Resources; Nogales, Arizona
- Organismo Operador Municipal de Agua Potable, Alcantarillado y Saneamiento; Nogales, Sonora
- Comisión Estatal del Agua; Hermosillo and Cananea, Sonora
- City of Nogales; Nogales, Arizona
- Bureau of Reclamation; Tucson, Arizona
- Comisión Nacional del Agua; Hermosillo, Sonora
-Upper San Pedro Partnership; Sierra Vista, Arizona
-University of Sonora; Hermosillo, Sonora
-College of Sonora; Hermosillo, Sonora
-University of Arizona; Tucson, Arizona

Workshop

The University of Arizona's Water Resources Research Center and the United States Geological Survey's Arizona Water Science Center hosted a workshop on November 3-4, 2009 in Tucson, Arizona as part of the U.S. – Mexico Transboundary Aquifer Assessment Program. The primary objective was to review progress of the Arizona-Sonora component of the U.S.-Mexico Transboundary Aquifer Assessment Program (TAAP- A/S) and confirm or modify priorities in the draft work plan that will guide assessment of the Santa Cruz and San Pedro aquifers. This workshop brought together stakeholders from both sides of the border, including federal, state, and local agencies, non-governmental organizations, and university researchers. Following an initial afternoon of presentations, breakout groups formed to discuss in detail assessment activities for the Santa Cruz and San Pedro aquifers, based on a draft plan prepared and presented by the workshop organizers. This report synthesizes observations made that have led to a modified work plan and can be viewed here <http://www.cals.arizona.edu/azwater/taap/>

The workshop resulted in the following recommendations for continued assessment of the Santa Cruz and San Pedro aquifers:

- Numerous studies, models, and reports exist for physical characteristics of the aquifers on each side of the border; however, relatively little combined work exists that encompasses both U.S. and Mexican sides of the aquifers.
- There is a need for additional social and institutional assessment of the aquifers, including decision-making and regulation.
- Cross-border coordination is crucial to successful assessment of shared aquifer resources; the preparatory phase of TAAP-A/S has set the stage for such coordination.
- Additional funding support is necessary to implement activities identified in the work plan.

IBWC Agreements

On August 19, 2009, Commissioners of the International Boundary and Water Commission (IBWC) formally approved the Joint Report of the Principal Engineers regarding the Joint Cooperative Process United States-Mexico for the Transboundary Aquifer Assessment Program. Principal Engineers John Merino and Antonio Rascon of US and Mexican sections of the IBWC were both present at the November 2009 TAAP-A/S workshop. This agreement sets a framework for data sharing and alignment of priorities between US and Mexican portions of the priority aquifers.

Other activities in which TAAP-A/S is currently involved include:

- Analysis and delineation of institutional context of water management along and across the Arizona-Mexico border.
- Determination of bi-national modeling needs. This process is ongoing in conjunction with binational stakeholders.
- Participation in the ISARM2010 International Conference: "Transboundary Aquifers:

Challenges and new directions", Paris, 6-8 December, 2010.

- Participation in ISARM of the Americas workshop in Argentina- dates to be determined

Future Activities

As a result of preliminary priority-setting discussions, a variety of assessment activities have been outlined for inclusion in a draft work plan. A primary goal throughout potential activities (through FY13) is to work with partners on both sides of the border to create physically-based hydrologic models of Upper Santa Cruz and San Pedro River Basins that integrates surface-, ground-, and unsaturated-zone water. These hydrologic models will create and combine information to address a range of hydrologic questions and knowledge gaps, and decision-support for authorities in the U.S. and Mexico to plan for changes in population, climate, infrastructure, and water use (mining and agriculture). A work plan draft for potential FY 2010-2011 activities has been created and is being shared with Mexican counterparts. Using the FY 2009-10 work plan as a template, and following recommendations from the November 3-4, 2009 workshop, a new work plan has been created for FY 2010-11 and is being shared with Mexican counterparts. The Mexican work plan is similarly under development. It is expected that, per the TAAP legislation, US funds will support up to half of the costs of assessment activities in Mexico. The revised US plan includes a new focus area of vulnerability assessment, within the overarching theme of hydrological assessment.

<u>Vulnerability Assessment</u>

With a focus on urban areas, evolving vulnerability in Cananea, Sierra Vista, and Ambos Nogales is a significant issue for transboundary groundwater due to dependence on the resource. Detrimental effects of storm events have become increasingly important due to runoff and basin topography in Ambos Nogales. Access to potable water and sewerage is also an issue in Nogales, Sonora. Increased groundwater supply in the Santa Cruz Active Management Area has been studied due to limiting hydrogeologic factors such as microbasins.

- Data collection of land use, zoning, economic and population growth, infrastructure, etc.
  Develop profiles and corresponding pressures on groundwater resources originating from focal urban and rural areas using GIS and remote sensing tools, census data, and economic indicators. Current population figures are considered inadequate for groundwater use planning. Municipal potable water supply systems also need to be quantified. Figures for registered / metered users need to be compared to those of actual connections to the urban supply system.

- Urban growth characterization and effect on watershed land use and hydrology
  The effect of land use change, primarily due to urban growth affects basin hydrology. Increased runoff and sediment in surface flow and decreased infiltration are primary results of such. The way in which populations grow and urban areas expand, including evolving usage of groundwater resources, are important issues to be analyzed.

- Binational water balances and supply / demand analysis

  Urban and rural development rates and climate change have important effects on groundwater usage. Evolving usage between the agriculture, industrial, and residential sectors has a direct impact on groundwater pumping within each basin. Potential increased industrial and residential usage for both Cananea and Nogales, Sonora may affect downstream riparians.

- Groundwater Vulnerability Assessment

  Conduct a groundwater vulnerability assessment for the Santa Cruz and San Pedro aquifer systems. This entails integrating land use, climate, and hydrogeologic (soil type, depth to groundwater) data to evaluate the potential for groundwater contamination. Such work would build off of preliminary analyses done by the USGS with a focus on emerging contaminants in the upper Santa Cruz in Arizona.

- Water quality assessments including anthropogenic impairments

  Industrial and other contaminants originating in urban areas need to be assessed. Mining operations from Cananea and wastewater treatment from Ambos Nogales are important. Important riparian habitat (federally protected in the San Pedro) exists downstream of both the mining operations and wastewater treatment facility. Also, emerging contaminants need to be monitored, especially from sites such as the Nogales International Wastewater Treatment Plant, as many residential wells operate downstream from the Treatment Plant's discharge.

- Assessment of institutional asymmetries and binational cooperation frameworks

  Due to differing groundwater management strategies between the US and Mexico, it is imperative to understand how cross-border cooperation can best function. The binational agency, International Boundary and Water Commission does not regulate shared groundwater, thus federal-level management in Mexico vs. state-level management in the US is a primary linkage for binational cooperation. The Arizona-Mexico Commission has provided a useful venue for discussion of programmatic initiatives related to TAAP-A/S in the past.

- Improved linkages with international best practices (via ISARM)

  Continue engagement with global and regional (Americas) ISARM initiatives. Participate as a case study so as to provide other ISARM participants with information on TAAP-A/S as well as learning from other shared resource scenarios. UNESCO has developed draft articles on the law of transboundary aquifers, of which the final form will be discussed during the 66th session of the UN general assembly in 2011.

The Ecohydrology and Management of Pinus Ponderosa Forests in the Southwest

Basic Information

Title:	The Ecohydrology and Management of Pinus Ponderosa Forests in the Southwest
Project Number:	2009AZ297B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	AZ 001
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Management and Planning, Groundwater
Descriptors:	None
Principal Investigators:	George Koch, Lucy Penn Mullin

Publications

1. Dore S, T Kolb, MC Montes-Helu, SE Eckert, J Kaye, GW Koch, AJ Finkral, BW Sullivan, SC Hart, BA Hungate. 2010. Carbon and water fluxes from ponderosa pine forests disturbed by wildfire and thinning. Ecologial Applications, in press.
2. Montes-Helu MC, T Kolb, S Dore, B Sullivan, SC Hart, G Koch, BA Hungate. 2009. Persistent effects of fire-induced vegetation change on energy partititioning and evapotranspiration in ponderosa pine forests. Agricultural and Forest Meteorology. 149:491-500.

The Ecohydrology and Management of *Pinus ponderosa* Forests in the Southwest
Final Project Report – July 2010

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a. Problem and Research Objectives

Population growth and the climate warming and drying place increasing pressure on water resources in the Southwest. Forests dominated by ponderosa pine (*Pinus ponderosa*) are common in southwestern uplands, supplying 70-90% of annual streamflow and therefore are key controllers of watershed-atmosphere interactions (Troendle 1983). Prior to Euro-American settlement in the mid-1880s, low tree density and a well-developed herbaceous understory characterized these forests (Moore et al. 1999). Fire exclusion, heavy grazing, and high seedling recruitment over the last century have increased tree density and decreased herbaceous vegetation in today's southwestern ponderosa pine forests (Savage et al. 1996, Covington et al. 1997), structural changes that have greatly increased risk of stand-replacing fires. A common approach to reduce fire risk and restore ecological health of southwestern ponderosa pine is thinning and controlled burning (Covington et al. 1997, Allen et al. 2002). Given the planned implementation of widespread forest restoration thinning, there is a pressing need to understand the effects of this management practice on water use and potential water yield in southwestern forests**.** Therefore, this project has focused on how changes in forest structure associated with management influence water use by individual ponderosa pine trees.

Because canopy structure and species composition strongly influence whole-system water exchange (Hollinger et al. 1999, Baldocchi 1997), large-scale restoration treatments will likely alter landscape water fluxes and ultimately regional climate (Sellers et al. 1996). Although reduced water use by trees and increased water supply to local streams is a potential benefit of restoration (Covington et al. 1997), little is known about how restoration will alter the components of plant transpiration and soil evaporation (evapotranspiration, ET) and sources of plant-transpired water (Simonin et al. 2007). By influencing the relative contributions of plant transpiration and soil evaporation to total ET, thinning will likely affect site water balance. A companion to this project, the NAU Carbon Flux Project, has used the eddy covariance technique to document how restoration thinning affects the water, energy, and carbon balance of ponderosa pine forests in northern Arizona (Dore et al. 2008, Montes-Helu et al. 2009; Dore et al. 2010). These data can now be used for scaling water balance over landscapes of the Southwest.

The specific focus of the WRRC-supported research by graduate student Lucy Mullin has been to examine the extent to which trees in thinned and unthinned stands depend on winter vs. summer water inputs to support their transpiration demands. This information provides the basis for understanding how future changes in the balance of inputs from these water sources may interact with stand structure to alter forest hydrology and potential water yield from Arizona forests.

The research supported by this WRRC grant has augmented, and benefited from, research supported by grants from federal agencies including the National Science Foundation, the USDA Forest Service, and the Department of Energy. This external funding has supported the aforementioned research on stand-level CO_2, water, and energy fluxes in ponderosa pine forests under different management conditions (see Dore et al, 2008; Montes-Helu et al. 2009; Dore et

al. 2010). Although the eddy-covariance research was not supported by this WRRC grant, it provides valuable ecosystem-scale context for understanding the implications of the WRRC-funded research.

The research supported by this WRRC grant is ongoing, with field sampling, lab measurements, and data analyses in progress and scheduled for completion in 2011. The research that has been supported by the WRRC grant has involved a great deal of labor-intensive field sampling to collect soil and plant samples that are frozen prior to water extraction and subsequent water isotope analysis. The extractions are extremely time-intensive, requiring roughly an entire day to extract water from 12 samples, after which the samples are submitted to the Colorado Plateau Stable Isotope Laboratory for determination of deuterium/^{1}H (δ D) and oxygen $^{18}O/^{16}O$ ($\delta^{18}O$) ratios. To date, graduate student Lucy Mullin has processed nearly 2000 samples and is awaiting data back from the isotope lab on roughly half of these. The large workload for Ms. Mullin has precluded her planned involvement in the study of sapflow (whole tree water use) at the site of the eddy covariance studies of ecosystem water, energy, and CO_2 exchange (Dore et al, 2008; Montes-Helu et al. 2009; Dore et al. 2010). The sapflow measurements have been conducted by Dr. Mario Montes-Helu under the auspices of the NAU Carbon Flux Project. Ms. Mullin continues to interact with the Carbon Flux team because that study and her own have considerable conceptual overlap.

Given the realities of the Ms. Mullin's workload constraints, her research under this WRRC grant has focused on the following hypotheses about water use by ponderosa pine in relation to tree size and stand density. Preliminary results addressing these hypotheses are described in Section C., Principal Findings and Significance.

Hypotheses

1) During the most active growing season, water at greater depths in the soil profile is derived from winter snow while water at shallower depths is primarily derived from summer rain.
2) Soil in thinned stands has greater winter precipitation recharge than soil in unthinned control stands.
3) Thinned *P. ponderosa* stands rely more heavily on winter precipitation while dense stands rely more on summer precipitation.
4) Larger ponderosa pines rely more heavily on water deeper in the soil profile than do the smaller ponderosa pines that dominate unthinned stands.
4) *P. ponderosa* trees use heartwood as a water source when soil water is depleted.

b. Methodology

The bulk of the work under this grant has examined how tree size and stand density affect the use of summer and winter precipitation by ponderosa pine in northern Arizona. The methods for the related eddy-covariance study are detailed in Dore et al. (2008) and Montes-Helu et al. (2009).

The study sites were 10 km northwest of Flagstaff, AZ (N35°15'58",W111°42'1", elevation 2200m) in the Flagstaff Urban Wildland Interface (FUWI) located within the Fort Valley Experimental Forest (USDA Forest Service, Rocky Mountain Research Station). The forest is dominated by *P. ponderosa* and has three 17 ha control (unthinned) plots and three 17 ha heavily thinned plots. The basic study design involved 72 trees, 36 large (diameter at breast height, DBH, >60 cm) and 36 small (DBH 12 – 19 cm). The trees were evenly sampled from randomly chosen areas having a range of tree densities (stems per hectare) established by earlier

thinning treatments (Fulé et al. 1999, Skov et al. 2004). We measured plant and soil relative water content and the isotopic signature of water in precipitation, soil, the water conducting system of trees (branch and trunk xylem) in March, June, and August of 2009 and in April of 2010. Paired measurements of water isotopes in precipitation and the water used by trees have provided the opportunity to determine the importance of water inputs during different seasons and received from different atmospheric sources (Flanagan et al. 1992, Lin et al. 1996).

Hydrogen and oxygen stable isotope composition in water were measured using an Off-Axis Integrated Cavity Output Spectroscopy (ICOS) instrument (Los Gatos Research, Los Gatos, CA) at Northern Arizona University's Colorado Plateau Stable Isotope Lab (CPSIL). Precipitation (rain and snow) was collected during each major event. Soil samples were taken from three depths (0-5 cm, 20 - 25 and 40 – 45 cm) during each season and beneath the crown of each of the 72 study trees. Branch segments were collected with a pole pruner from the lower crown on the south side of each tree. Main trunk samples were collected with an increment corer, which also provided samples for planned cellulose oxygen isotope analysis (see below). Water was extracted from soils, branch, and main trunk samples using a cryogenic vacuum line.

Samples collected for analysis of tree ring oxygen isotopes in cellulose are in storage pending analyses to begin fall 2010. These measurements will allow reconstruction of the variation in water source over time in relationship to interannual precipitation variation and in response to thinning. For this analysis we will cross date cores and focus on the last 20 years of growth (ten pre-thinning years and ten post-thinning years).

c. Principal Findings and Significance

A principal finding from this ongoing research is that water isotope composition can be used to track inputs and use of seasonal precipitation in ponderosa pine forests. Figure 1 shows the pattern of hydrogen isotope composition (δD) in precipitation and soil water during late winter (March), late spring (June), and during the summer monsoon season (August). Precipitation inputs shift from highly depleted δD values (c. -100‰) in winter to less depleted values (c. -20‰) in summer, consistent with the different sources of regional moisture and storm temperature. Cold winter storms from the north Pacific are expected to have more depleted δD values than warmer summer rains that originate in the Gulf of Mexico. Soil water carries the isotopic signature of source precipitation, with some enrichment (becoming less negative) as a result of preferential evaporation of lighter isotopes. The deeper soil (40cm) shows little seasonal variation in isotopic composition, remaining around a value (c. -90‰) that reflects the dominant input of winter snow, which melts and infiltrates to recharge deep soils. Shallower soil layers (20 cm and surface) are more variable and generally more enriched (less negative δD values) as a result of evaporative fractionation and because they are influenced by inputs of the isotopically more-enriched summer precipitation. *These results support our hypothesis that during the most active growing season, water at greater depths in the soil profile is derived from winter snow while water at shallower depths is primarily derived from summer rain.*

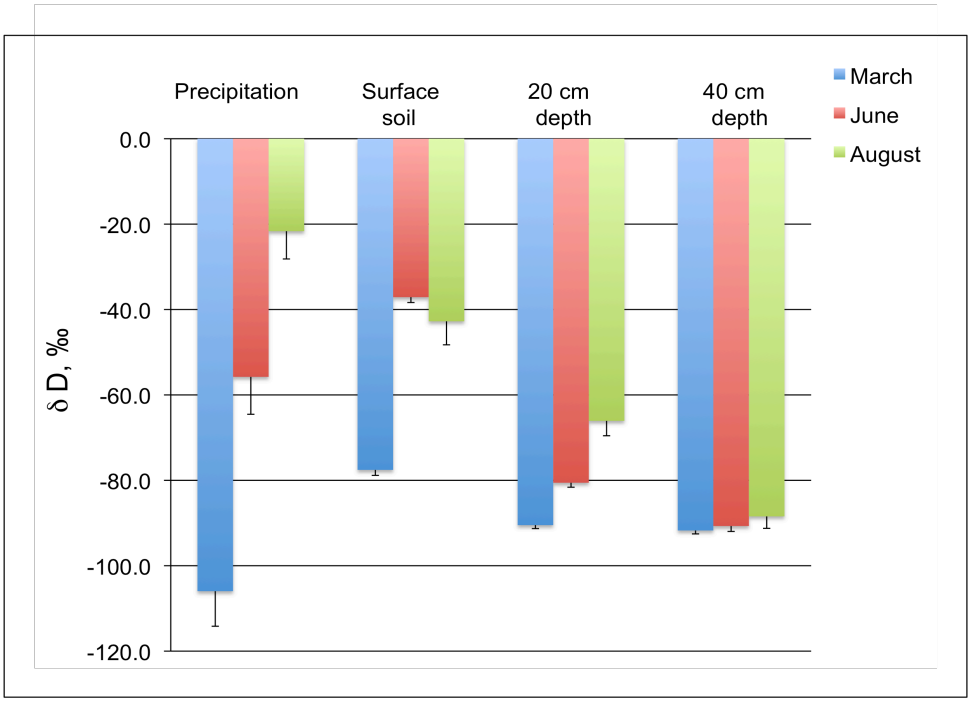

Fig. 1. Variation with depth and season in hydrogen isotope composition of precipitation and soil water during spring, summer and fall at the Ft. Valley ponderosa pine restoration site, northern Arizona. Note that deep soil water (40cm) has a stable isotopic composition while shallower water is more variable and reflects changing precipitation inputs. Values are means (± 1 s.e.) of 40 to 72 samples for each time period and measurement location.

A second principal finding of our research to date is that trees of different size classes (Figure 2) and in stands of different densities (Figure 3) rely primarily on winter rather than summer precipitation. The δD values of water in the conducting tissue (xylem) of trees ranged from about -84‰ to -96‰ across seasons and trees of different sizes (Figure 2A), values reflecting the winter precipitation inputs to deeper soil layers seen in Figure 1. Even during the monsoon season (August), water derived from winter storms is apparently the dominant source for ponderosa pines.

Although winter precipitation clearly dominates water used by ponderosa pine, there was some sensitivity of xylem water δD values to tree size (Figure 2) and the basal area density of neighboring trees (Figure 3). Smaller trees tended to have higher (less negative) δD values, (Figure 2), likely because they are more shallowly rooted and drawing water from intermediate soil layers (c. 20 cm) which have less depleted δD values (Figure 1). Trees in the lowest density stands (< 10 m^2 ha^{-1}) had significantly lower xylem water δD values than trees in all other basal area density classes (Figure 3A). Presumably, at low stand density there is less canopy interception of winter (and summer) precipitation, greater infiltration of precipitation, and less competition for soil water, factors that collectively drive xylem water toward values more similar to winter precipitation. These results are consistent with hypotheses 2, 3, & 4: *2) Soil in thinned stands has greater winter precipitation recharge than soil in unthinned control stands; 3) Thinned P. ponderosa stands rely more heavily on winter precipitation while dense stands rely more on summer precipitation*; *4) Larger ponderosa pines rely more heavily on water deeper in the soil profile than do the smaller ponderosa pines that dominate unthinned stands.* A more thorough test of hypothesis 2 awaits careful analysis of soil moist content, which will

complement the soil water isotope data and allow estimation of the dynamics of quantity of water, as well as its source, in different soil layers.

In the very densest stands xylem water δD was more negative than in stands of somewhat lower density, although not the lowest density stands (Figure 3A). We think that these trees in extreme high density conditions may use primarily winter precipitation because the closed canopy structure intercepts spring and summer precipitation, which then evaporates without adding significantly to plant accessible soil water. Thus, trees at very high and very low density may be more reliant on winter precipitation than the intermediate density stands.

Interestingly, the water content (% moisture) of the sapwood of larger trees (Figure 2B) and trees in the lowest density stands (Figure 3B) is *lower* than for smaller trees and trees in higher density stands. Although this could be interpreted as indicative of greater water stress in these trees, this would not be consistent with these trees' apparently greater access to more reliable, winter-derived soil moisture in the deeper soil layers. Instead, our current interpretation of this curious result is that the wood anatomy of these trees is such that smaller diameter conducting cells with a higher cell wall fraction are produced, resulting in lower water content per wood volume.

The mean hydrogen isotope composition (δD) of winter precipitation was -105‰, while summer precipitation averaged about -22‰. These two values provide the end points for a two-member mixing model to resolve the relative contribution of winter and summer precipitation to plants. Development of that model is underway and requires analysis of changes in water isotope composition as precipitation water infiltrates soils and is subject to evaporative enrichment.

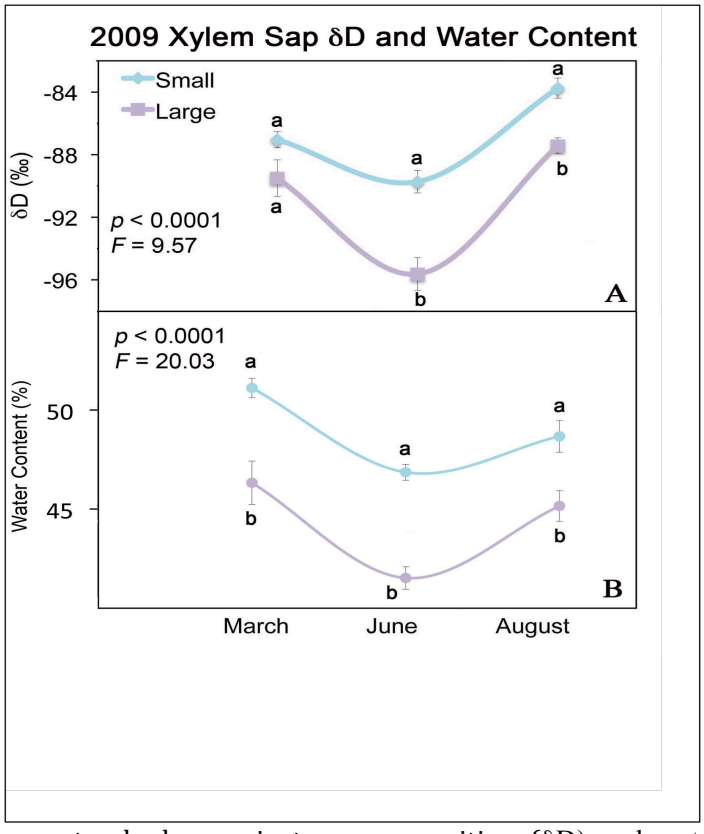

Figure 2. Xylem water hydrogen isotope composition (δD) and water content in large (> 60 cm diameter) and small (12 - 19 cm diameter) ponderosa pine trees at three seasonal sampling periods.

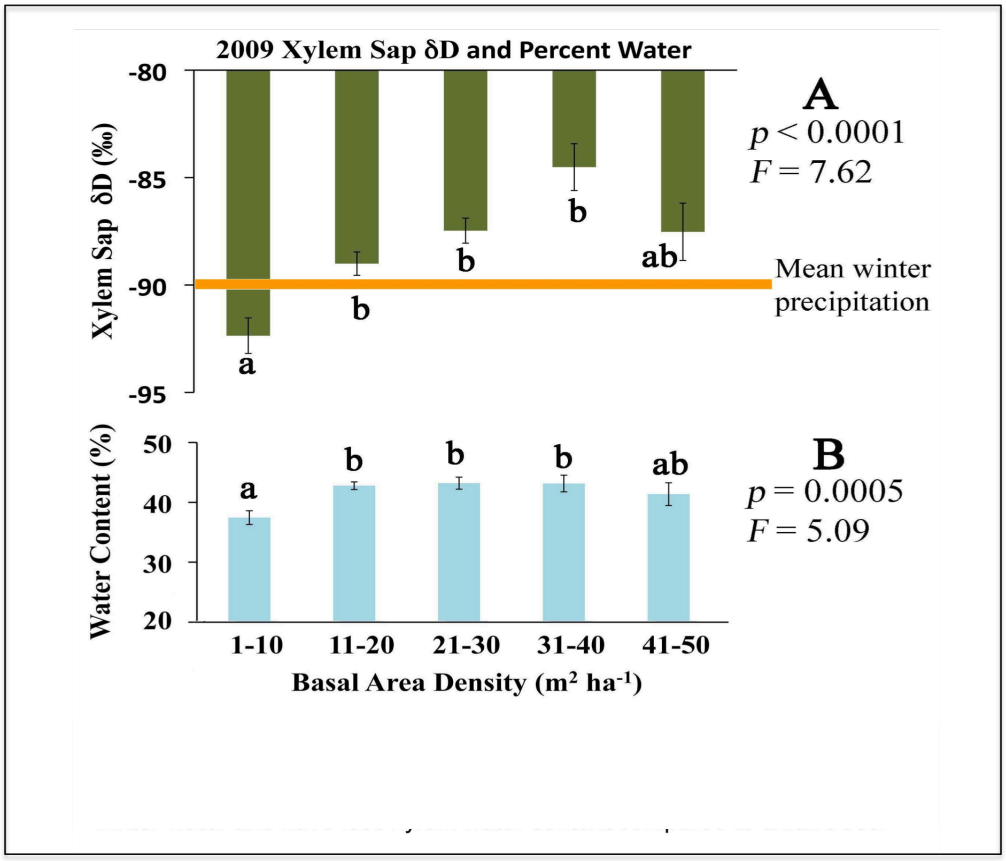

Figure 3. Xylem water hydrogen isotope composition (δD) and water content in ponderosa pine trees in stands of different densities. Note: recent analyses of additional precipitation data indicate that mean δD of winter precipitation averages about -105‰, lower than the c. -90‰ shown.

Significance. A major conclusion from the present study is that ponderosa pine trees in northern Arizona rely primarily on winter precipitation, regardless of the time of year. This implies that future climatic change that affects the amount, form, or timing of winter precipitation may be more influential in driving productivity changes than climatic shifts in summer precipitation. This conclusion is consistent with studies based on correlations between tree-ring growth patterns and climatic variables (e.g. Adams and Kolb, 2004). The stable isotope technique used in the present study has the advantage of definitively identifying the source of water that supports plant transpiration at any point in time. Although summer precipitation may be a minor quantitative source of moisture to ponderosa pine trees, it is important to note that the summer monsoon has a major effect of lessening atmospheric moisture stress by increasing the water vapor concentration of the air. Because vapor pressure deficit is a major influence of stomatal conductance and photosynthesis, the summer monsoon may in fact be critically important to the productivity of ponderosa pines even though it does not directly act as an important water source. In effect, the monsoon, by reducing vapor pressure deficity, likely acts to lessen transpiration rates, allowing higher stomatal conductance and photosynthesis than during periods of lower humidity, such as in the late spring (May, June) pre-monsoon period. Moreover, the monsoon, by providing some soil water input and increasing humidity, also

reduces the evaporation of the soil moisture derived from winter inputs. Thus, it is likely not correct to conclude that climatic change that brings less summer precipitation would have little influence over the growth of ponderosa pine.

d. Ongoing Work.

As mentioned, this project is ongoing, with considerable sample processing and data analysis yet to be completed. The analysis of cellulose oxygen isotope composition of tree rings, scheduled to begin fall 2010, will provide important insights to the past use of winter vs. summer precipitation. In combination with standard dendrochronological methods, these measurements will allow testing whether the apparent dependence on winter precipitation is seen consistently across years having different winter vs. summer precipitation.

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Transport and fate of mercury and other metals in Tucson’s urban metropolitan area: Role of watershed sources versus atmospheric deposition

Basic Information

Title:	Transport and fate of mercury and other metals in Tucson’s urban metropolitan area: Role of watershed sources versus atmospheric deposition
Project Number:	2009AZ312B
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End Date:	2/28/2010
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Congressional District:	8
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Surface Water, Sediments
Descriptors:	fate and transport, mercury, urban watershed, atmospheric deposition
Principal Investigators:	Kathleen Ann Lohse, Paul David Brooks, Jennifer McIntosh

Publications

1. Lohse, K.A., E. L. Gallo, and J. R. Kennedy, 2010, Possible tradeoffs from urbanization on groundwater recharge and water quality, Southwest Hydrology, 9 (1), 18- 19; 32.
2. Lohse, K.A., E. L. Gallo, P. D. Brooks, J.E.T. McLain, J. McIntosh, and T. Meixner, Influence of channel substrate type on storage and transport of urban storm runoff in a semi-arid environment, In preparation for Journal of Environmental Quality
3. Gallo, E.L. P.D. Brooks, K. A. Lohse, and J.E.T. McLain, Patterns and controls of storm runoff quality in semi-arid urban catchments, In preparation for Hydrologic Processes
4. Gallo, E.L. K.A. Lohse, and P.D. Brooks, Temporal variation in urban storm runoff and water quality, In preparation for Hydrologic Processes.
5. Carlson, M, 2010, Impacts of urbanization on groundwater quality and recharge rates in a semi-arid alluvial basin. “MS Thesis” School of Natural Resources and the Environment, University of Arizona, Tucson, AZ, p. 65.
6. Carlson, M., K.A. Lohse, J.C. McIntosh, Impacts of urbanization on groundwater quality and recharge rates in a semi-arid alluvial basin, In preparation for Journal of Hydrology.
7. Lohse, K.A. and A.M. Merenlender. 2009. Impacts of exurban development on water quality In G. McPherson and A. Esparza, editors. The Planner's Guide to Natural Resource Conservation: The Science of Land Development Beyond the Metropolitan Fringe. New York: Springer-Verlag, pp. 159-180.

TRANSPORT AND FATE OF MERCURY AND OTHER METALS IN TUCSON'S URBAN METROPOLITAN AREA: ROLE OF WATERSHED SOURCES VERSUS ATMOSPHERIC DEPOSITION

PROBLEM AND RESEARCH OBJECTIVES

Numerous studies have documented that urbanization increases runoff and the occurrence and loads of nutrients, metals and organic pollutants to surface and ground water that have negative consequences for aquatic life and drinking water (*Kolpin et al. 2002, Barber et al. 2006*). Despite this trend, water managers lack information on how the process of urbanization alters localized hydrologic processes and the subsequent transport and fate of different pollutants. In arid to semi-arid environments, such as Arizona, runoff from urban areas is often actively managed as a part of storm water management but also as active and/or focused recharge to groundwater. These activities result in a modified hydrologic template in which to understand water quality issues and raise concerns and questions about the tradeoffs between urban storm-recharge and water quality.

In particular, there is growing concern about the adverse effects of mercury and other metals in the environment. Human activities have dramatically accelerated the release of mercury and other metals into the environment via coal-fire combustion and mining of metals for industry. Due to specific concerns related to mercury, the Mercury Deposition Network was initiated in 1996 to monitor inputs of mercury in wet deposition; it currently has 100 sites in the United States. The network remains limited in the Southwest with only one site in Arizona despite the fact that relatively high concentrations have been observed at the sole monitoring site in Phoenix (25.8 ng/L).

An alternative means to evaluate potential human and wildlife exposure to atmospherically deposited mercury is to monitor concentrations of mercury in storm runoff. Preliminary data from a study initially funded by the Water Sustainability Program (WSP) (partial match for this grant) showed high concentrations of mercury (Hg) in the urban runoff across the sites. Average Hg concentrations were 6.47 ± 0.43 ug/L, exceeding ephemeral wash standards of 5.0 ug/L as dissolved Hg. These concentrations are 1000 times higher than concentrations observed in rainwater at the Phoenix site. High concentrations of Hg across all sites compared to other metals and pollutants suggested that atmospheric deposition was the dominant pathway. However, these averages only represented a small subset of the urban runoff samples from 2007 (37 out of 400). As such, questions remained about whether these samples are representative of different storm events and seasonal loads and/or whether they are biased towards peak concentrations.

In this study, we expanded our analysis of mercury and other metals in surface, ground waters and soils in the Tucson Basin, Arizona, a semi-arid urban environment. We addressed the following objectives posed here as questions: **How does urban land use influence storm transport and delivery of metals to surface and groundwater? What roles do soils in ephemeral washes play in retaining or removing these pollutants and controlling the rate at which pollutants are transported to regional groundwater?**

We hypothesized that metals derived from different land uses would vary with watershed characteristics. Alternatively, atmospheric derived metals would be similar across all watersheds. We predicted mercury concentrations would be high across watersheds whereas watersheds with higher impervious surface area such as commercial and high urban density

(HDH) would have higher concentrations of metals (Zn, Cu, Cd) in surface waters relative to lower urban density watersheds (LDH). We also hypothesized that naturally surfaced washes would act as a sink for metals compared to concrete line washes with the prediction that vegetated lined washes would retaining more metals than soil lined washes.

To address these objectives, we trained and supported two graduate students in field and laboratory procedures and analyzed runoff and soil samples from 2007 and 2008 campaigns for metals on an ICP MS to evaluate how metals and mercury (Hg) vary with land use. Lateral ephemeral washes contrasting in housing age and density along the Rillito River (a proposed site for artificial recharge) afforded us the opportunity to evaluate the relative importance of these controls on water quality. In addition, we sampled groundwater samples in 2008 and 2009 across the Tucson Basin and analyzed these samples for metals.

Approach, methods, procedures, and facilities -

Study Site The study was conducted in the Tucson Basin in southeastern Arizona, USA (Figure 1). Tucson metropolitan area (population 1,000,000) occupies the alluvium-filled valley and foothills. The basin is bounded by the Santa Catalina, Rincon, and Tucson Mountains, and the Santa Cruz River and its major tributaries, the Canada del Oro, the Rillito River, and the Pantano Wash flow intermittently toward the northwest. Tucson experiences hot summers and mild winters with two distinct rain seasons (total ~28 cm/yr): intense and localized summer-monsoon storms (accounting for 2/3 of the annual precipitation) and protracted, widespread winter rains.

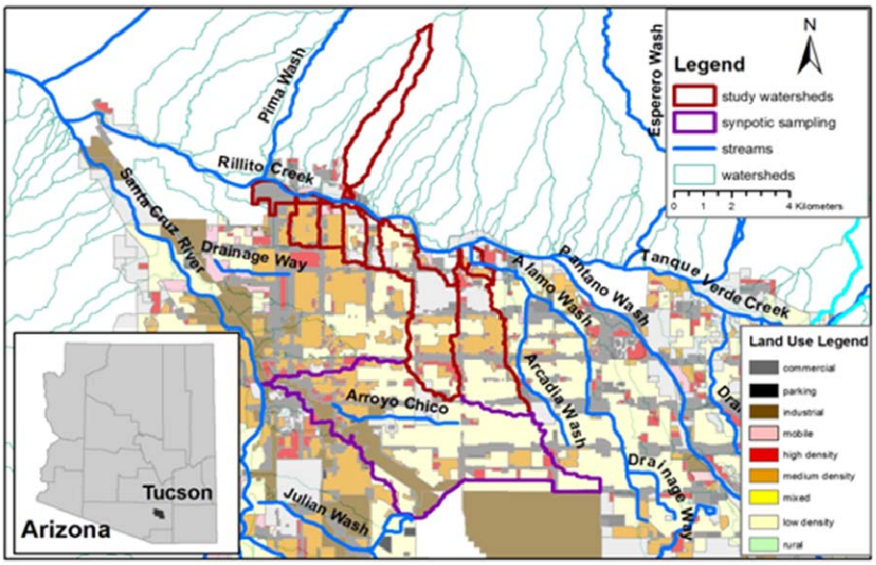


Figure 1: Tucson Basin showing study watersheds draining into the Rillito Creek and synoptic sampling watershed (Arroyo Chico) draining into the Santa Cruz.

We focused our study on urbanizing watersheds draining laterally into the Rillito River because water managers have identified sections of the Rillito as potential area of recharge, and recent studies indicate the transient flow conditions during summer monsoon flooding result in more infiltration that predicted from steady state conditions (Blasch et al. 2006). Moreover, the Rillito and lateral drainages are not impacted by any wastewater treatment plants (WWTP).

Surface Storm Runoff Procedures and Methods For this study, we used 5 previously established sites in the Tucson basin representing a range of urban land use watersheds (5 sites, commercial, high density housing, mixed density housing, highly engineered mixed density housing, low density housing). In June 2007, we installed 10 rain gauges within the study

watersheds and 5 automated storm water collectors with pressure transducers each in a culvert at the outlet of lateral sub-watershed draining into the Rillito Creek that vary in land use (Figure 1). We collected storm events over the course of the summer 2007 monsoon season to characterize the summer hydrograph and quantify nutrients, metals, organic pollutants, and bacteria. In addition, we installed 2 automated storm water samplers with pressure transducers along the Arroyo Chico in upstream and downstream positions. We then performed synoptic grab sampling of water from 12-15 sites along the Arroyo Chico over several storm events along with collections from the automated water collectors to evaluate possible sources and transformations in space and time, respectively. In total, we collected over 400 samples. In the summer of 2008, we collected a smaller set of runoff samples to evaluate year to year variability and fill gaps in data (~200 samples).

Groundwater sampling To examine the impacts of urbanization on groundwater quality and recharge rates, 40 groundwater samples were collected from water supply and monitoring wells operated by Tucson Water and the Winterhaven Living Community along the Rillito Wash in May 2008 and June 2009 (Figure 2). Groundwater wells were selected for access, proximity to the Rillito Creek and a shallow static water depth, as areas of focused channel infiltration and recent recharge tend to be closer to the surface (ranging from 10 to 50 m). Fifteen of the 40 groundwater wells were also sampled for CFCs, ^{3}H and noble gases to estimate recharge rates along the Rillito Creek. These wells were selected partially as they had been previously sampled by Eastoe et al. (2004) for ^{3}H in the 1990s. This study collected unfiltered aliquots for ^{3}H in sample-rinsed 1 L HDPE plastic bottles; care was taken to collect samples without any headspace. CFC samples were collected in 125 mL clear glass bottles with aluminum foil-lined plastic caps. In order to avoid atmospheric contamination, bottles were filled and capped in a bucket under water through copper tubing connected to the wellhead. The bottles were sealed with electrical tape and stored and shipped upside down. Duplicate CFC samples were collected at each site. Additional protocol details are available from the USGS CFC collection website (http://water.usgs.gov/lab/chlorofluorocarbons/sampling/bottles/).

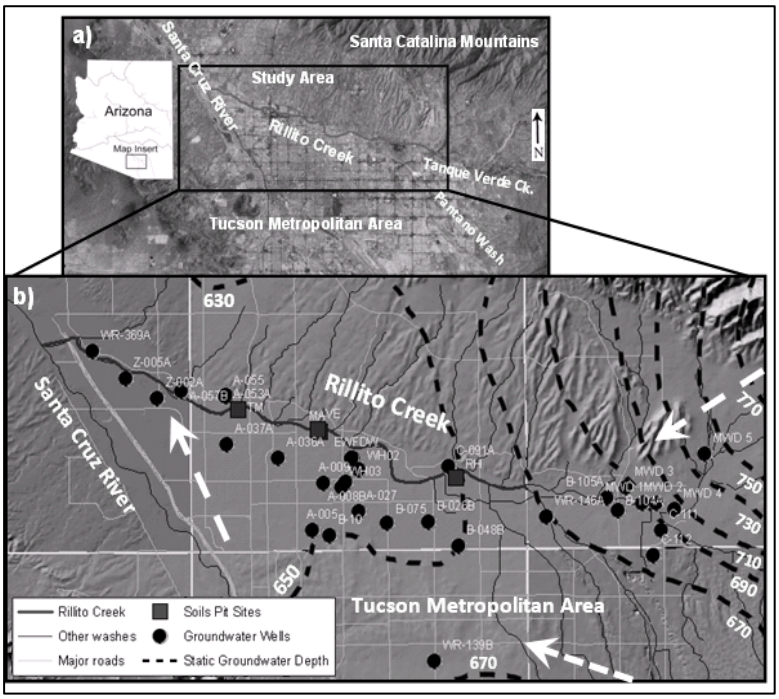


Figure 2. a) Location of study area and urban development in the Southern Arizona. b) Within the study area, location of the Rillito Creek and its tributaries, groundwater wells, soil pits and static groundwater depth contours (measured in meters above sea level). White arrows represent the direction of groundwater flow.

Soil Sampling Procedure and Methods In addition to sampling storm runoff in 2008, we also sampled soils in ephemeral washes and Rillito to evaluate the transport and fate of nutrient, organic pollutants and metals in soils. We collected tributary sediments to the Rillito before and after the monsoon for solute concentrations, organic matter content, and soil moisture status. In addition, we collected soils in Rillito Creek itself. The purpose of this approach is to be able to assess the reaction and transport of the metals and organic matter rich runoff as it propagates through the surface and subsurface hydrologic system. Due to the alluvial nature of the Tucson basin and the sandy texture of sediments, we collected surface soil cores (0-5 cm) at the outlet of the washes and at grab sampling points (defined by surface water sampling above) within the watershed before and after each monsoon season for the duration of this project (150 samples + blanks). We also collected sediment cores before and after each monsoon season from Rillito Creek at the outlets where we had established surface water sampling sites (Figure1). Two to three soil cores were collected in the Rillito to approximately 1 m depth (2-3 per site, 4 sites, 12 cores, 120 samples + blanks). We extracted soils in artificial rainfall water to evaluate those nutrients, pollutant and metals that could be readily exchanged and transported in runoff.

Metal analyses

Samples for analysis of metals in runoff and groundwater were collected in sterile amber glass vials and filtered them through 0.7 and 0.1 μm glass fiber filters. We preserved dissolved metals in amber glass vials with concentrated ultrapure nitric acid so that sample pH was below 2 and analyzed these samples on an ICP MS in the ALEC lab at the University of Arizona.

PRINCIPLE FINDINGS AND SIGNIFICANCE

Preservation and methodology challenges

Methodology for preservation of mercury (Hg) is inherently challenging. Debate exists as to how to preserve mercury, particularly mercury compounds in aqueous matrices. Factors affecting mercury stability include the form of mercury, the container material, the matrix, and the preservation techniques (EPA 2003). The currently accepted method for preservation of mercury samples is a 2% HNO_3 as preservative, with an allowed holding time of 26 days prior to instrumental analysis. However, studies have shown significantly low recoveries with 2% HNO_3 as a preservative. Other studies suggest that mercury ions bind to the high density polyethylene (HDPE) water sample containers. Finally, mercury vapor may be lost when the bottles are uncapped.

We analyzed 2007 samples preserved with HNO_3 in glass that had been shown to have high mercury (>5 ug/L Hg) and found that mercury concentrations were below detection limit. We hypothesized that low mercury

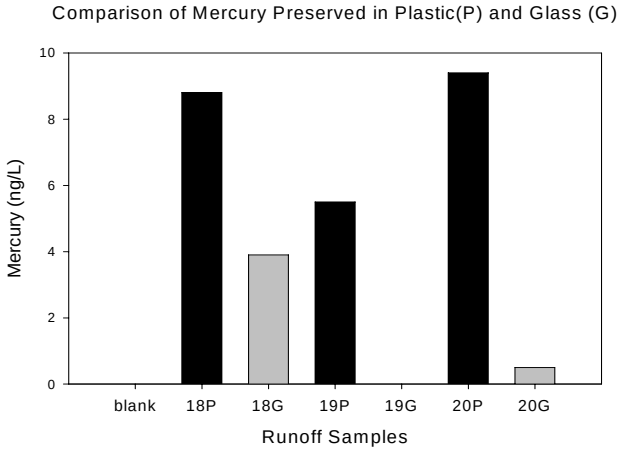


Figure 3: Comparison of mercury concentrations in water contained in plastic (#P) or glass (#G)

recoveries might be due to loss on glass or plastic containment, time of containment, or analytical problems on the ICP MS. We ran additional 2008 samples that had been contained for the same amount of time as those observed with high concentrations but also found that these at lower concentrations (ng/L) suggesting containment issues or analytical errors.

Plastic versus Glass Bottles for Containment We tested the effects of differences in containment (plastic versus glass) on 3 sets of samples contained in plastic or glass and analyzed them for mercury. We found higher recoveries of Hg in plastic compared to glass suggesting loss of Hg to binding on the glass or vaporization (Figure 3). However, concentrations in plastic were still an order or magnitude lower than expected (ng versus ug/L) suggesting loss of Hg or analytical errors. Other studies suggest that a 1 ppm solution of AuCl3 in HNO_3 is sufficient to preserve Hg but will not affect any other analytes or analytical techniques (EPA 2003). Prior collections of runoff for the 2007 and 2008 season were not solely oriented at measuring Hg so that a 2009 sampling campaign was organized to test whether observations of high Hg in runoff could be reproduced if the samples were preserved with $AuCl_3$ and then run immediately for Hg on the ICP MS.

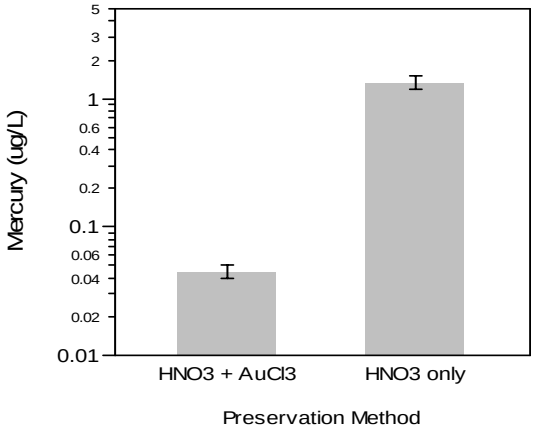


Figure 4: Comparison of preservation treatment

Comparison of Preservation with Gold Chloride ($AuCl_3$) Eight samples were collected during the 2009 monsoon runoff season, preserved with $AuCl_3$, and analyzed immediately for Hg analysis to eliminate preservation and containment issues. If runoff samples were high in runoff as observed across all sites in the 2007 season, we expected to observe high Hg in runoff samples. If the problem was analytical in nature (i.e. ICP MS not calibrated correctly or dilutions incorrect), we expected to observe low levels of Hg. Indeed, we found low levels of Hg in runoff samples preserved with gold chloride relative to preliminary analyses suggesting possible analytical mis-calibration contamination or other spurious error (Figure 4). Interestingly, concentrations in runoff samples preserved with nitric acid alone were higher (1 ug Hg/L) relative to those preserved with nitric acid and gold

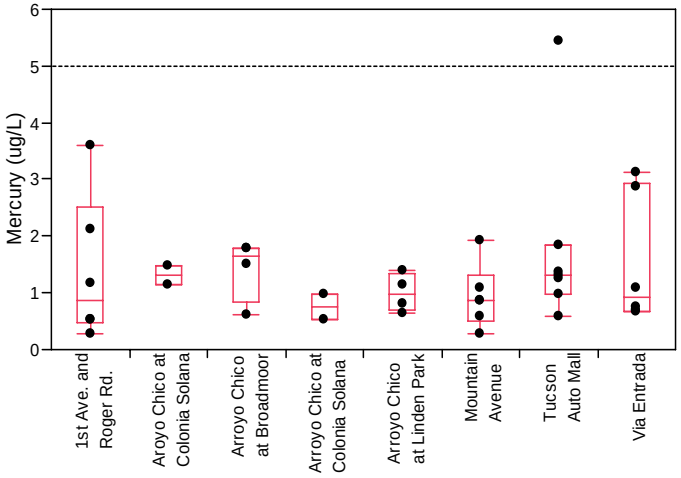


Figure 5: Concentrations of mercury in storm runoff across the Tucson Basin (n=37 samples) and ephemeral wash standard of 5 µg/L m (dashed line).

chloride. Hg concentrations were also much higher than those observed in Phoenix rainfall concentrations (25. 8 ng/L) suggesting that high concentrations in runoff may be real but extreme precaution and a study solely devoted to tracking Hg may be warranted.

Reanalysis of ICP MS data To attempt to address possible analytical issues, we requested re-analysis and recalibration of our samples on the ICP MS. Post-analysis showed that the average Hg concentrations declined relative to preliminary analyses. Average concentrations were 1.35 ± 0.17 ug/L, still 530% greater than those observed at the Phoenix monitoring site, and one sample exceeded the ephemeral wash standards of 5.0 ug/L as dissolved Hg (Figure 5). From this study we concluded that we could not reproduce high Hg concentrations observed in preliminary analyses and suspect that calibration issues affected our analyses as well containment issues. We also concluded that Hg concentrations appear to be high relative to the Phoenix monitoring site and that further research should be devoted solely to Hg analyses. For the remaining samples that we ran on the ICP MS, we analyzed samples for other metals and not Hg.

Data set enhancement with metal analysis for 2008 monsoon

An additional objective of metal analysis for a second monsoon season was to complement our 2007 runoff quality data set.

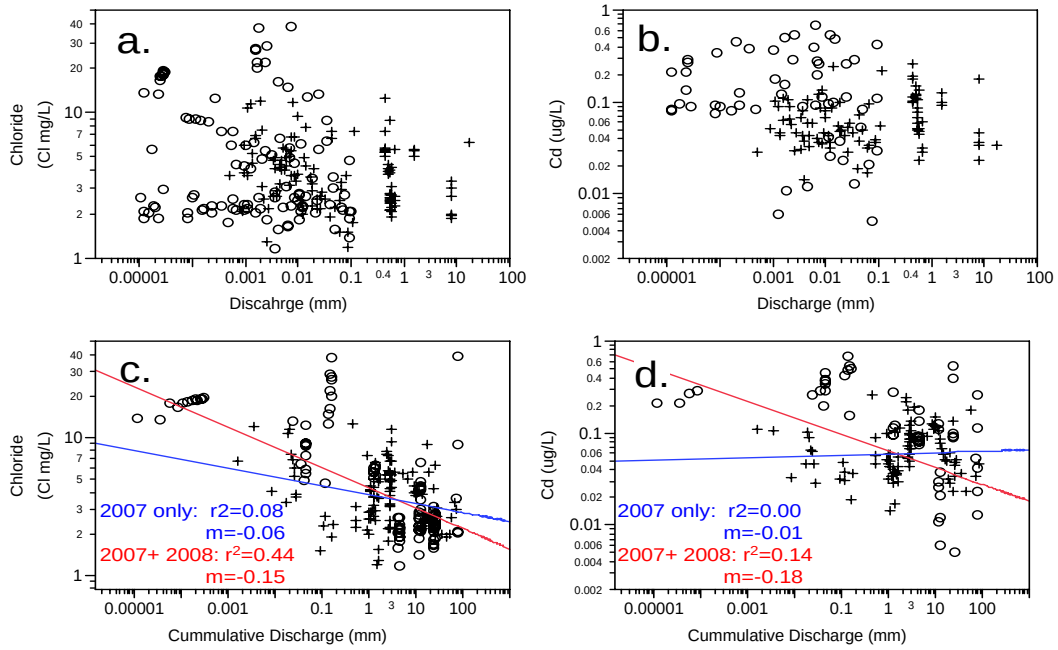
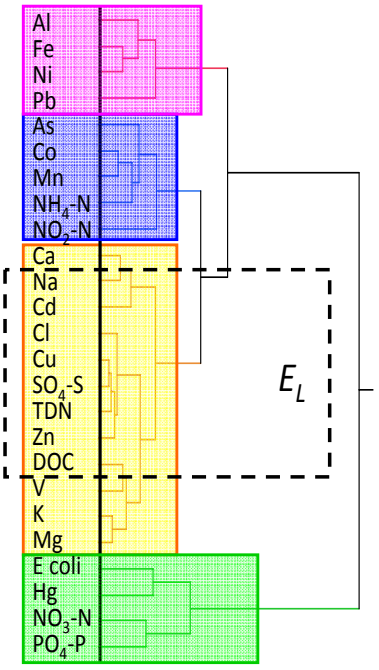


Figure 6 – Chloride and cadmium concentrations for the 2007 (crosses) and 2008 (open circles) monsoon against discharge magnitude (panels a and b) and cumulative discharge (panels c and d). Solute concentrations for 2008 plot along a wider range of discharge and cumulative discharge values, and enhance temporal trends thus illustrating the importance of additional analysis to complementing our data set.

We enhanced our existing data by analyzing metal concentrations of 2008 monsoonal runoff samples that were collected over a wider range of discharge magnitudes, and which were more evenly distributed throughout the monsoon. For example, panels a and b in Figure 6 show chloride

and cadmium concentrations, respectively, against discharge for the 2007 (crosses) and 2008 monsoons (open circles). The 2008 chloride (Cl) and cadmium (Cd) data plot along smaller discharge events and show that chloride concentrations are highly variable at small discharges whereas cadmium concentrations are higher during smaller runoff magnitudes. Panels c and d in Figure 6 show chloride and cadmium concentrations, respectively, for both monsoons plotted against cumulative discharge. Given that cumulative discharge increases as the monsoon season progresses, we can use cumulative discharge as a time variable that can help us identify temporal trends in runoff quality. Panel c and d show that for the 2007 season, chloride concentrations significantly decreased as the season progressed ($r^2 = 0.08$, $p = 0.001$); whereas cadmium concentrations did not ($r^2 = 0.00$, $p = 0.61$). However, a clearer image emerges when the 2007 and 2008 data are combined and concentrations across a wider range of cumulative discharge values are added. The combined data set shows that chloride and cadmium concentrations decrease as the season progresses and cumulative discharge increases ($r^2=0.44$, $p < 0.001$ for chloride, $r^2=0.14$, $p <0.001$ for cadmium), however, the weaker correlation of cadmium with cumulative discharge suggests that the mechanisms impacting runoff quality vary among solutes. Specifically, the impact of time since the onset of monsoonal runoff is greater for chloride than cadmium. The seasonally distributed chemistry data enhances our ability to identify dominant runoff quality trends over space and time. The impact of runoff vs. the impact of land cover can therefore be better addressed by a data set containing 2 years of data (Gallo et al, manuscript in revision, Gallo et al. in preparation).

How does urban land use influence storm transport and delivery of metals to surface water?
Land use and discharge alone were not good predictors of metal concentrations across all of our sites. Surprisingly, metals including aluminum, arsenic, iron, nickel, lead and zinc; and the cations calcium, sodium and potassium exhibit chemostasis where concentrations vary independently of discharge, rather than inversely with discharge, suggesting that these solutes are constantly sourced during runoff events. This may occur due to a very large reservoir of solute stored in the watershed, or to a constant input of solute into our study sites via weathering of geologic



1 – Land Use
- Only varies with Q at least impervious non-piped site
- potential sourcing - stormwater routing system and building materials

2 – Antecedent rainfall
- May require wetting and change in redox for mobilization
- or larger contributing area

3 – Solute mobilization
- vary with Cl and Q -
- vary with E_L – highest at homogeneous
- Reservoirs depleted more rapidly

4 – Particulate sourcing and atmospheric deposition
- not correlation with Cl or Q
- not significantly different among sites
- continuously sourced

Figure 7 – Cluster analyses showing dominant sources of metals and other solutes

and urban construction materials, or atmospheric deposition.

A cluster analysis of mean solute correlations identified factors that appear to largely impact concentrations of different metals in urban runoff (Figure 7). We identified 4 major controls on the runoff quality of urban runoff: 1) land cover characteristics, 2) antecedent rainfall conditions and catchment wetting 3) hydrologic transport of solutes with finite sourcing and reservoirs and 4) constant particulate sourcing and atmospheric deposition. Cluster 1 (pink) included aluminum, iron, nickel and lead. Regressions against land cover attributes, including road density, stormwater routing piping density and land cover types (e.g. percent low density residential), suggest that these solutes are mainly sourced from weathering of land cover components such as pipes and roofing materials. Cluster 2 includes arsenic, copper, manganese, nitrate-nitrogen and nitrite-nitrogen, the mobility of which is closely associated with a change in redox conditions. The high correlation of concentrations of these solutes with antecedent rainfall conditions suggests that these solutes are likely sourced from stream channels. Cluster 3 is the largest of the clusters and includes the hydrologic tracer chloride and solutes that were highly correlated with rainfall frequency, duration and discharge magnitude, suggesting that as the amount of catchment wetting increases, these solutes are mobilized and flush out of our study sites. Finally, cluster 4 included nitrate-N, phosphate-p, mercury and *E. coli* and is indicative of solutes that are constantly sourced to the catchment either via atmospheric deposition or through land use practices. These solutes do not correlate with discharge, but do correlate with the amount of parks, open land and low density residential housing at our study sites, suggesting that a coupling of land use practices and atmospheric sources control their concentrations in runoff.

How does urban land use influence storm transport and delivery of metals to groundwater? All measured trace metal concentrations were below U.S. EPA standards (Carlson 2010). However, groundwaters located near commercial land use (well A-037), the western landfill site (Z-002) and agricultural plots (DW-001) had relatively high concentrations of Ni, Zn, Cu, and Fe indicating possible point source contamination. Although unrelated to any known point source of anthropogenic contamination, some groundwaters also showed high variability among wells. Measured groundwaters furthest from the Santa Cruz River along the eastern edge of the study site (well C-112), for example, had some of the highest concentrations of Ni (4.6 μg/L), Pb (>0.8 μg/L), As (2.5 μg/L) and Cu (>1.5 μg/L).

In contrast to our expectations of using chlorofluorocarbons (CFC) for groundwater dating, we found that CFC concentrations were anomalously high across the basin. Non-point source pollution in runoff and/or leaky infrastructure was identified as the most plausible source of this contamination (Carlson 2010). Interestingly, CFCs were strongly and positively correlated to nitrate (r^2=0.77) and mobile trace metal, nickel (r^2=0.71) suggesting that that solutes were sourced from a similar source. This statistical analysis was based on non-point source contamination, excluding effluent dominated wells, known to have high CFCs. Groundwater concentrations of Cu and Fe showed similar spatial variation to Ni, however the correlations

were relatively weak for Ni and Fe (r^2=0.24, p=0.13) and Ni and Cu (r^2=0.18, p=0.19).

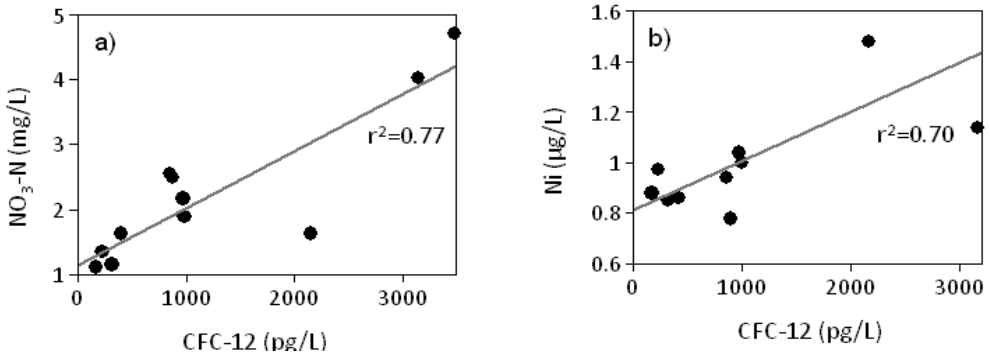


Figure 8. Groundwater concentration of a) NO3-N and b) Ni versus dissolved groundwater concentration of CFC-12.

What roles do soils in ephemeral washes play in retaining or removing these pollutants and controlling the rate at which pollutants are transported to regional groundwater? We measured upstream-downstream concentrations of solutes and metals to evaluate the role of soils in retaining or removing metals. We used chloride as an inert hydrologic tracer and compared observed to predicted downstream solute concentrations, based on the product of upstream solute concentrations and the ratio of the downstream to upstream Cl concentrations during flow recession. We found that observed concentrations of metals such as Cu and Zn in runoff were much lower than predicted concentrations in most of the grass-lined reaches compared to gravel-lined reaches suggesting that grass-lined channels are retaining more metals than gravel-lined reaches during transport (Figure 9). Little modification or retention of solutes and metals appears to be occurring in gravel lined washes. Our findings suggest that urban waterways that are lined with grass may provide ecosystem function services of removing metals and possibly other nutrients and pollutants, similar to those observed in constructed basins. Higher amounts of soil organic matter and cation exchange capacity in grass-lined systems are likely factors explaining the enhanced retention of metals and other constituents in these reaches. Additionally the finer texture of stream bed composition in the grass-lined reaches indicated increased surface area availability for adsorption of metals such as Cu and Zn.

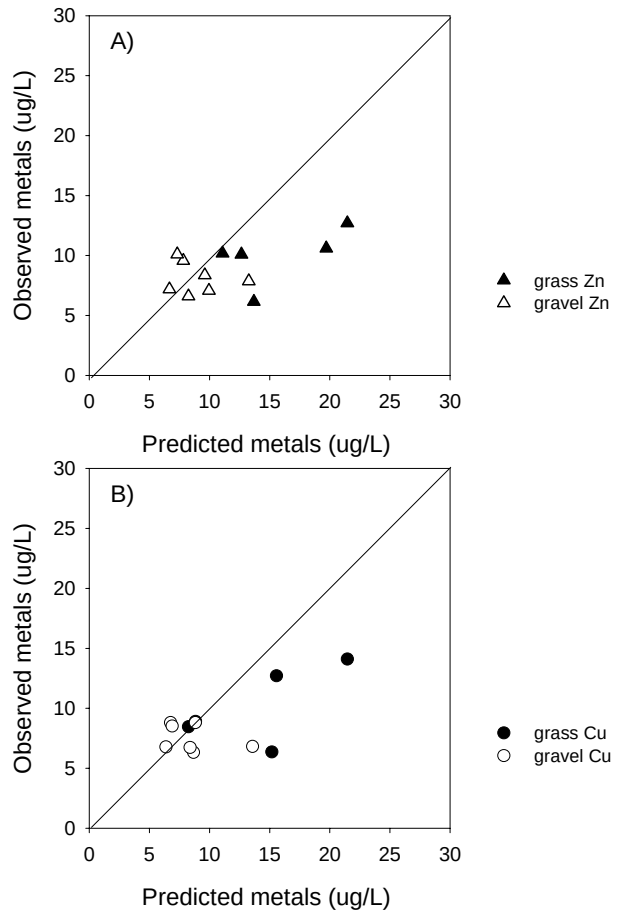


Figure 9: Observed versus predicted metals in runoff

Training and Education: Funding provided matching support for training and research support through Peace Corp Fellowship work study program for 1 MS graduate student (Mark Carlson) and research funding for 1 PhD student student (Erika Gallo) and 1 undergraduate (Shane Clark). This research has been integrated into several courses by Lohse (UNVR 195a: Water Quality and the Environment, WSM 468/568:Wildland Water Quality [guest lecture]). Graduate student (Erika Gallo) attended several local and national conferences in December 2009, and PI's and graduate students are preparing manuscripts for peer-reviewed articles. Some of these findings have recently been published in *Southwest Hydrology* and resulted disseminated to the public, stakeholders at City of Tucson Transportation and Water Departments, and science community. In addition, a layman discussion of the impacts of urbanization and exurban development on water quality has been published in Lohse and Merelender (2009).

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Table 1 – Solute concentrations (Mean (SE), [minimum – maximum]) at our Tucson Basin study sites. Solutes with the same superscript are not significanlty distinct from each other ($p \leq 0.05$)

Solute (units)	Solute Type	Low Density	Medium Density	High Density	Mixed	Commercial
Cl (mg L^{-1})	Hydrologic Tracer	7.0 (3.7), [1.2 - 19.2]^{b}	4.0 (2.7), [1.4 - 12.5]^{c}	2.6 (0.1), [1.3 - 5.7]^{c}	3.4 (0.2), [1.2 - 6.6]^{c}	10.5 (1.2), [1.8 - 38.7]^{a}
Ca (mg L^{-1})	Major Cation	14.5 (1.4), [8.0 - 38.8]^{ab}	14.6 (13.1), [7.7 - 30.4]^{ab}	13.8 (0.6), [10.6 - 17.8]^{ab}	12.7 (0.5), [7.9 - 20.6]^{b}	17.4 (2.0), [6.0 - 63.9]^{a}
Mg (mg L^{-1})	Major Cation	1.4 (0.2), [0.6 - 3.9]^{ab}	1.6 (1.3), [0.8 - 3]^{a}	1.2 (0.1), [0.8 - 1.7]^{ab}	1.1 (<0.1), [0.6 - 2]^{b}	1.5 (0.2), [0.4 - 5.8]^{ab}
K (mg L^{-1})	Major Cation	4.1 (0.5), [1.6 - 12.6]^{a}	4.7 (3.5), [2 - 12.1]^{a}	2.7 (0.1), [2 - 3.9]^{a}	3.7 (0.3), [1.4 - 9.1]^{a}	4.1 (0.4), [1.3 - 13.9]^{a}
Na (mg L^{-1})	Major Cation	5.7 (0.9), [2.5 - 20.9]^{b}	4.0 (3.6), [2.3 - 8.3]^{b}	3.6 (0.2), [2.4 - 4.9]^{b}	3.7 (0.2), [2 - 7.4]^{b}	10.5 (2.1), [2.1 - 74.1]^{a}
Al (ug L^{-1})	Metal	441 (370), [192 - 1100]^{ab}	567 (421), [172 - 1739]^{a}	419 (69), [160 - 942]^{ab}	497 (39), [156 - 1120]^{ab}	388 (39), [46 - 1190]^{b}
As (ug L^{-1})	Metal	1.4 (1.3), [0.2 - 2.9]^{a}	1.7 (1.6), [0.9 - 3.6]^{a}	1.9 (0.1), [1 - 2.7]^{a}	1.9 (0.2), [0.9 - 6.6]^{a}	1.7 (0.2), [0.6 - 4.7]^{a}
Cd (ug L^{-1})	Metal	0.1 (0.1), [nd - 0.3]^{bc}	0.1 (0.1), [nd - 0.5]^{ab}	<0.1 (<0.1), [nd - 0.1]^{c}	<0.1 (<0.1), [nd - 0.3]^{c}	0.2 (<0.1), [nd - 0.7]^{a}
Co (ug L^{-1})	Metal	1.0 (0.7), [0.1 - 3.1]^{ab}	1.6 (1.2), [0.1 - 4.6]^{a}	0.9 (0.1), [0.6 - 1.4]^{ab}	0.9 (0.1), [0.2 - 2.4]^{b}	1.3 (0.3), [0.2 - 9.2]^{ab}
Cu (ug L^{-1})	Metal	20.3 (17.7), [3.7 - 61.3]^{b}	16.2 (14.1), [3.9 - 48.7]^{bc}	7 (0.6), [4.5 - 15.5]^{c}	9.9 (1.2), [3.1 - 33.9]^{c}	28.8 (2.6), [8.7 - 69.5]^{a}
Fe (ug L^{-1})	Metal	692 (446), [193 - 7725]^{a}	571 (576), [305 - 1090]^{a}	504 (20), [374 - 633]^{a}	471 (28), [211 - 1202]^{a}	527 (45), [80 – 1237]^{a}
Pb (ug L^{-1})	Metal	1.2 (0.8), [0.1 - 3.4]^{a}	2.9 (1.2), [0.2 - 39.2]^{a}	0.7 (0.3), [0.2 - 5.2]^{a}	1.1 (0.1), [0.2 - 5.1]^{a}	1.5 (0.5), [0.1 - 17.6]^{a}
Mn (ug L^{-1})	Metal	108 (18), [2 - 440]^{a}	106 (24), [3 - 423]^{a}	8 (3), [2 - 58]^{b}	25 (5), [2 - 163]^{b}	64 (16), [1 - 493]^{ab}
Hg (ug L^{-1})	Metal	1.5 (0.9), [0.7 - 3.1]^{a}	1.4 (0.9), [0.3 - 3.6]^{a}	n.a.	0.9 (0.2), [0.3 - 1.9]^{a}	1.8 (0.6), [0.6 - 5.4]^{a}
Ni (ug L^{-1})	Metal	5.6 (3.7), [1.1 - 16.7]^{a}	8.3 (5.8), [1.3 - 50.7]^{a}	6.9 (2.4), [1.6 - 41.6]^{a}	6.1 (0.9), [0.8 - 22]^{a}	7.3 (1.1), [1.4 - 37.9]^{a}
V (ug L^{-1})	Metal	5.6 (3.9), [2.1 - 15.7]^{abc}	6.5 (6.1), [2.3 - 17.4]^{ab}	3.3 (0.1), [2.5 - 4.4]^{c}	4.5 (0.3), [2.2 - 10.8]^{bc}	7.7 (1.0), [2.8 - 31.1]^{a}
Zn (ug L^{-1})	Metal	57.3 (25.6), [5.0 - 248.5]^{b}	51 (30.7), [6.3 - 370.1]^{bc}	9.4 (0.9), [3.8 - 19.1]^{bc}	14.5 (2.3), [4.7 - 59.9]^{c}	112.2 (16.1), [22.6 - 467.9]^{a}

Mercury Source Fingerprinting in Arid Lands Aquatic Ecosystems

Basic Information

Title:	Mercury Source Fingerprinting in Arid Lands Aquatic Ecosystems
Project Number:	2009AZ313B
Start Date:	3/1/2009
End Date:	12/31/2009
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Focus Category:	Geochemical Processes, Sediments, Water Quality
Descriptors:	None
Principal Investigators:	Paul Terry Gremillion, Michael Ketterer

Publication

1. Hermosillo, Edyth, 2010, “Variations in Mercury Bioaccumulation in Fish Along the River Continuum of Four Arizona Freshwater Ecosystems,” MS Dissertation, Department of Environmental Sciences and Policy, Northern Arizona University, Flagstaff, AZ.

Mercury Source Fingerprinting in Arid Lands Aquatic Ecosystems

Problem and Research Objectives

Mercury (Hg) is well-known as a global pollutant; its main source is coal combustion, and deposition of Hg into aquatic systems and landscapes produces subtle neurotoxic effects in vertebrates at low concentrations. Identifying Hg sources and unraveling their relative contribution to the Hg inventories in water, soil, sediment, and biota remains an elusive problem despite decades of environmental studies of Hg. Recent work by several groups, however, indicates that Hg exhibits small variations in its stable isotope compositions. This variation is at least partially source-related and can potentially be used to understand sources, transport, and biogeochemical cycling of Hg. Research in Hg isotopes is not well developed, but is the subject of intense interest among several research groups.

The principal investigators have been working to build the capability at Northern Arizona University to track the movement of Hg through ecosystems in order to understand the sources of Hg and mechanisms by which some fisheries in arid lands ecosystems are impaired by Hg and others are not. This project supplements an award from the Technology and Research Initiative Fund (TRIF) at NAU, titled "Developing the Capacity to Trace Sources of Mercury in the Environment Using Hg Stable Isotopes". The TRIF award permits the investigators to address the instrumental challenges in perfecting the technique of detecting Hg isotope ratios. Funding from the Water Resources Research Institute, through WRRA enabled us to fund a graduate student to apply this technique for her master's thesis work.

The specific objectives of this project were to (1) acquire an instrument to analyze total Hg (T-Hg) and establish a laboratory and protocols to support this instrument; (2) develop the capability to track the movement of Hg through aquatic food webs using a variety of stable isotope techniques; and (3) collaborate with an external Hg isotope expert to develop the capability to measure Hg isotope ratios.

Methodology

Our first objective involved measurement of T-Hg in solid and semi-solid samples (as opposed to aqueous or other liquid samples). We acquired a Teledyne/Leeman Hydra-C analyzer. This

instrument is designed to analyze specifically for Hg by combusting samples, accumulating Hg by amalgamation onto gold-coated sand, releasing the Hg vapor by heating the gold sand, and detecting the Hg by cold-vapor atomic absorption spectrometry. This technique corresponds to EPA Method 245.5 (USEPA, 1993). This instrument can detect greater than about 2 ng Hg. For sediment samples of about 200 mg, this corresponds to a detection limit of about 0.4 ng/g Hg.

Our second objective involved tracing the movement of Hg through aquatic food webs. This was the subject of the master's student funded through this research. She selected three stream reaches in the upper Verde River of northern Arizona (Figure 1). The project consisted of sampling algae, biofilm, leaves, and fish at upstream and downstream locations in each stream. Samples were analyzed for T-Hg; nitrogen-15 isotope ratios ($\delta^{15}N$) to detect the trophic position in the food web; and carbon-13 ($\delta^{13}C$) and organic-matter deuterium (δDorg) isotope ratios to detect carbon sources. Hermosillo (2010) provides a complete description of field and laboratory methods.

Our third objective was to make measurements of Hg isotope ratios for inorganic and biotic samples. We used a modification of the technique described by Foucher and Hintelmann (2006). Samples were digested in *aqua regia* (HNO_3/HCL 9:1 v/v) and diluted to about 5 ng/mL Hg. Samples were introduced to a multi-collector inductively coupled plasma mass spectrometer (MC ICPMS) using an apparatus that provided a continuous flow of stannous chloride ($SnCl_2$) for Hg reduction, injection of a thallium (Tl) solution of known isotopic composition an internal standard, and a moisture separation device which uses argon gas to separate moisture from the cold Hg vapor. The ICPMS was operated in multi-collector mode, with Faraday collectors tuned to detect the Mass 198, 199, 200, 201, and 202 isotopes of Hg and the Mass 203 and 205 isotopes of Tl.

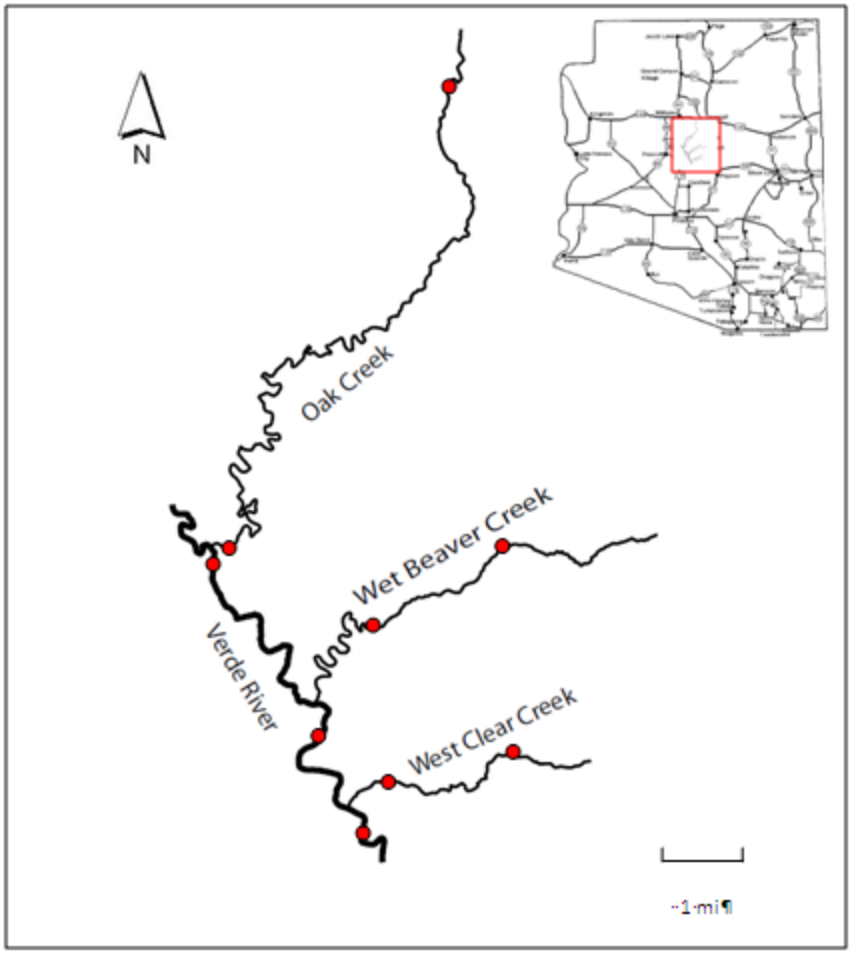

Figure 1. Study Location for Food Web Study in Arizona.

Principal Findings and Significance

We were able to complete our first two objectives, which were to establish a laboratory for environmental Hg analysis and developing the techniques to detect movement of Hg in aquatic food webs. We also made significant progress on the third objective, which was to make accurate measurements of Hg isotope ratios.

Objective 1. Establish a Laboratory for Environmental Mercury

Pooling a variety of funding sources, which included this project, enabled us to acquire and make operational a Teledyne/Leeman Hydra-C total Hg analyzer. Table 1 provides a summary of the performance of the instrument over an operational period of about a year. The materials analyzed were standard reference materials (SRMs) from certified sources and selected to reflect the

composition of the materials we analyze most commonly: sediments, plant material, and fish tissue. DORM-3 and MESS-3 are from the National Research Council Canada, Institute for National Measurement Standards; IAEA-336 is from the International Atomic Energy Agency in Seibersdorf, Austria; and SRM 1547 and SRM 2702 are from the US National Institute of Standards and Technology. Shown in the table are the standard deviation of the mean (Stdev); relative standard deviation (RSD), which is the standard deviation divided by the mean and reported as a percent; and error, which was the arithmetic difference between the certified and mean measured valued divided by the average of the two values and reported as a percent.

Table 1. Analyses of Standard Reference Materials for Total Hg.

SRM	Material	n	Mean (ng/g)	Stdev (ng/g)	RSD	Certified (ng/g)	Error
DORM-3	Fish Protein	5	410	18.8	4.3%	382	7.1%
IAEA-336	Lichen	6	187	17.7	8.5%	200	6.5%
MESS-3	Marine Sediment	22	91.6	5.9	5.4%	91.0	0.7%
SRM 1547	Peach Leaves	19	37.2	6.3	11.7%	31.0	18.2%
SRM 2702	Marine Sediments	40	422	83.5	18.4%	445	5.1%

Instrument performance was excellent or acceptable for all materials except SRM 1547. Additionally, 10 to 20 percent of samples were analyzed in duplicate and duplicate precision was generally better than five percent relative percent difference (calculated same as error in Table 1). This instrument was used for measuring T-Hg for all samples in Objectives 2 and 3. We consider the instrument and laboratory fully operational, but are concerned about the relatively high error in the analysis of SRM 1547. In response, we continue to analyze high numbers of duplicate samples and SRMs to verify accuracy in measurements.

Objective 2: Track Mercury in Aquatic Food Webs

This objective was pursued by a graduate student in the Environmental Sciences and Policy program at NAU. The student worked closely with the stream ecosystem research group in Jane Marks's laboratory at NAU. Her objective was to evaluate differences in bioaccumulation of Hg in terms of the River Continuum Concept (RCC). This phenomenon in stream ecology considers shifts in energy sources from upstream to downstream in river continuums. RCC theory predicts that upstream regions should be dominated by decomposing leaf matter and other allochthonous

material as primary carbon sources. Downstream reaches should be dominated by the autothonous carbon sources of primary producers. Traditional carbon isotope ($\delta^{13}C$) and more innovative deuteurium isotope (δDorg) measurements were used to determine energy source in food webs, along with more direct measurements of leaf litter and mass of algae and biofilm at sampling locations.

More relevant to this report however, is the capability provided by this project to use the combination of T-Hg and nitrogen stable isotopes ($\delta^{15}N$) to infer bioaccumulation. Nitrogen isotopes have become recognized as reliable indicators of trophic position, or the position in a food web occupied by individuals (e.g., Fry, 2006). Table 2 summarizes the Hg and isotopic data collected as part of the graduate thesis work supported by this project.

Table 2. Food Web Data Collected in Arizona Stream Ecosytems.

	Hg (ng/g)			$\delta^{13}C$ (‰)			$\delta^{15}N$ (‰)			δD (‰)		
	n	Mean	Stdev	n	Mean	Stdev	n	Mean	Stdev	n	Mean	Stdev
Algae	32	30.8	9.1	29	-29.1	5.0	29	4.2	3.5	29	-229.1	25.3
Biofilm	10	22.6	4.3	10	7.3	4.4	10	0.5	0.5	10	-137.1	25.2
Leaves	40	56.3	5.5	40	-29.0	0.9	40	-0.2	1.5	40	-137.6	7.9
Ambloplites rupestris – Rock bass	6	482.9	156.3	6	-24.0	1.0	6	14.7	1.2	6	-142.0	12.1
Pomoxis annularis -- Crappie	2	214.0	42.3	2	-25.2	0.7	2	11.4	0.2	2	-178.7	6.7
Ictalurus punctatus – Channel catfish	1	420.5	-	1	-23.3	-	1	12.7	-	1	-135.4	-
Lepomis cyanellus – Green sunfish	15	496.3	251.1	15	-22.6	0.5	15	9.5	0.9	15	-119.3	10.6
Lepomis macrochirus – Bluegill sunfish	18	536.9	259.7	18	-23.0	10.3	18	9.9	5.2	18	-141.0	39.2
Micropterus dolomieui – Smallmouth bass	69	384.0	266.1	67	-23.4	1.6	67	11.0	2.3	67	-143.5	15.9
Micropterus salmoides – Largemouth bass	5	737.3	281.9	5	-23.6	1.1	5	13.0	1.2	5	-127.9	24.6
Oncorhynchus mykiss – Rainbow trout	12	73.9	7.2	10	-17.9	1.2	10	11.1	0.4	10	-116.6	10.1
Pylodictis olivaris – Flathead catfish	19	606.3	415.3	19	-24.3	0.9	19	11.4	2.4	19	-160.5	23.5
Salmo trutta – Brown trout	12	138.0	138.0	12	-25.4	-25.4	12	10.9	10.9	12	-149.8	-149.8

A complete analysis of the data are provided in Hermosillo (2010), however an important result of this research was that differences in Hg bioaccumulation between nearby ecosystems were revealed. Figure 2 shows plots of T-Hg versus $\delta^{15}N$ for the downstream sampling locations in two of the streams sampled. The data show that in both systems Hg concentrations increase with trophic position, providing at least partial confirmation that the ultimate Hg sources are diffuse, rather than point sources. Point sources of Hg, such as mines or industrial waste, would likely result in high concentrations of Hg without systematic increases with trophic position.

More importantly though, the data show that the food web in Oak Creek concentrates less Hg at high trophic positions than in Wet Beaver Creek. With relevance to fish specifically, for a given trophic position, there are lower concentrations of Hg in fish from Oak Creek than from Wet

Beaver Creek. It is not yet clear whether this difference is due to differences in the supply of Hg to the streams, differences in the methylation of Hg between the streams, or differences in the trophic structures of the streams.

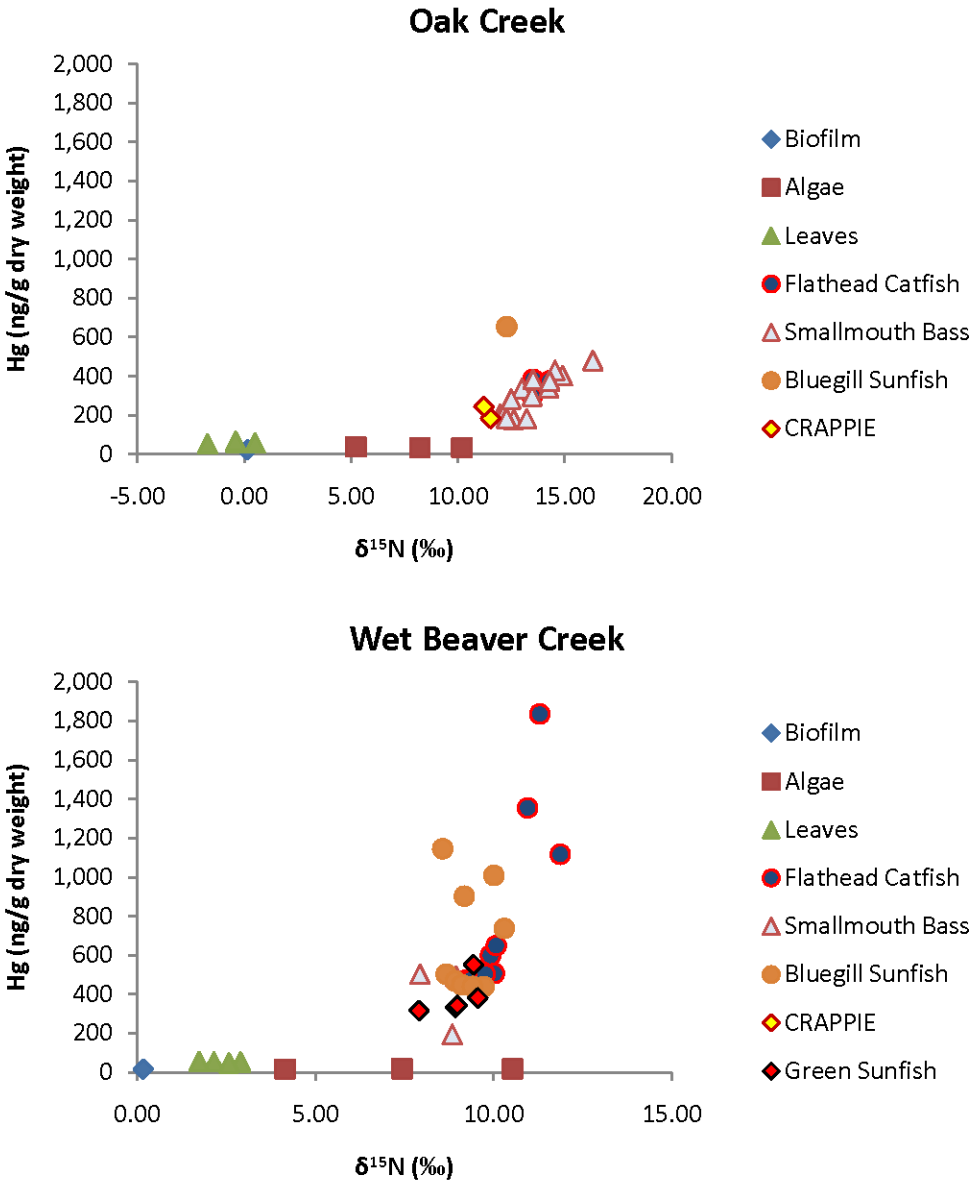

Figure 2. Mercury Concentration (T-Hg) Versus Nitrogen-15 ($\delta^{15}N$) for Food Webs in Two Arizona Streams (From Hermosillo, 2010).

Much work has yet to be done with these data, however this study does demonstrate that we have developed the techniques to detect relationships between trophic position and Hg

bioaccumulation in arid lands aquatic ecosystems. An important next step is to be able to address more directly the question of Hg sources.

Objective 3: Measure Mercury Stable Isotopes

Little debate remains that the major source of Hg in fish in most aquatic ecosystems is atmospheric (Grigal, 2003), yet the ability to detect the relative contributions of Hg from different sources has been elusive. Because Hg is volatile and readily forms Hg vapor in combustion sources, the potential exists for global transport of Hg. Indeed, coal-fired power plants in rapidly developing Asian countries have been blamed for Hg deposition in the western United States (e.g., Hope, 2006). Mercury stable isotopes may provide a direct indication of sources, if the various sources of Hg in the environment, for example the native geologic material, coal used by local sources, and coal used by more distant sources, have sufficiently distinctive isotopic ratios.

Mercury has seven stable isotopes: ^{196}Hg, ^{198}Hg, ^{199}Hg, ^{200}Hg, ^{201}Hg, ^{202}Hg, and ^{204}Hg. Instrumentation and methods now exist to measure all seven of these isotopes simultaneously for a given sample. Our objective was to adopt these techniques, acquire the apparatus necessary to introduce the samples into the MC ICPMS at NAU, and make isotope ratio measurements at NAU. To date we have worked with colleagues at Trent University in Onario, Canada. At their laboratory, the principal investigators were able to make measurements on samples collected from two Arizona ecosystems. Table 3 shows quality assurance data for the sample runs.

Table 3. Quality Assurance Data from Hg Isotope Analytical Runs.

Almaden	δ^{199}Hg (‰)	δ^{200}Hg (‰)	δ^{201}Hg (‰)	δ^{202}Hg (‰)
Sample 1	-0.08	-0.25	-0.42	-0.63
Sample 2	-0.20	-0.35	-0.56	-0.64
Mean	-0.14	-0.30	-0.49	-0.63
Blum and Bergquist (2007)	-0.14	-0.27	-0.44	-0.54
RPD	2.2%	9.5%	11.4%	16.1%

The reference material, Almadén, was an in-house reference material currently in use at the University of Michigan laboratory of Dr. Joel Blum. In the absence of certified reference materials, it is used as an uncertified reference material in the Hg isotope community. Precision was good or acceptable, except for the δ^{202}Hg observations.

The notation for Hg stable isotopes uses the customary *del* notation and in most current literature is expressed relative to the Mass-198 isotope (^{198}Hg). The standard being adopted for comparison in the del notation is NIST 3133 (Bergquist and Blum 2007) using the following formula:

$$\delta^{xxx}Hg = \left\{\left[\left(\frac{^{xxx}Hg}{^{198}HG}\right)_{unknown} / \left(\frac{^{xxx}Hg}{^{198}HG}\right)_{SRM\ 3133}\right] - 1\right\} x1000$$

Table 4 shows a summary of analytical results. Total Hg (T-Hg) was analyzed in our laboratory at NAU. Isotopic analyses were conducted in the Hintelmann laboratory at Trent University, Ontario, Canada.

Table 4. Hg Isotopic Analysis of Inorganic and Biotic Material from Arizona Ecosystems.

	T-Hg (ng/g)	δ^{199}Hg (‰)	δ^{200}Hg (‰)	δ^{201}Hg (‰)	δ^{202}Hg (‰)	Δ^{199}Hg (‰)	Δ^{200}Hg (‰)	Δ^{201}Hg (‰)
Upper Lake Mary - Upper Core	207	-0.31	-0.71	-1.12	-1.57	0.08	0.07	0.04
Upper Lake Mary - Mid Core	92	-0.30	-0.67	-1.05	-1.43	0.09	0.07	0.08
Parker Canyon Lake	101	-0.43	-0.48	-1.05	-1.18	-0.14	0.11	-0.17
Parker Canyon Soil 104-A	43	-0.12	-0.20	-0.50	-0.63	0.04	0.10	-0.01
Parker Canyon Soil 104-B	28	-0.36	-0.54	-0.97	-1.14	-0.06	0.03	-0.10
Parker Canyon Soil 104-D	17	-0.24	-0.42	-0.73	-0.85	-0.02	0.01	-0.08
Upper Lake Mary Fish 28	2,337	1.84	0.03	1.36	-0.07	1.87	0.07	1.43
Upper Lake Mary Fish 34	897	1.79	0.13	1.37	0.02	1.80	0.13	1.38
Upper Lake Mary Fish 63	747	1.61	0.17	1.34	0.16	1.57	0.09	1.22

An important aspect in the study of stable isotopes is the concept of *fractionation*. This is a change an isotopic ratio due to a physical or biological process. In heavy isotopes, such as strontium (Sr) and lead (Pb), as well as Hg, there is a fractionation process associated with the mass of the isotope itself. This is known as *mass-dependent fractionation* (MDF) and can be accounted for as essentially a data processing step. Researchers have discovered that for the Hg isotopic system, a second fractionation process occurs, but only in the odd numbered isotopes (^{199}Hg and ^{201}Hg). This has been termed mass-independent fractionation (MIF).

MIF can be calculated as the difference between the observed isotope ratio and the theoretical MDF (Blum and Bergquist, 2007):

$$\Delta^{xxx}Hg = \delta^{xxx}Hg - \left(\delta^{202}Hg\ x\ F\right)$$

Where xxx is the mass of the isotope and F is a fractionation factor (See Blum and Bergquist (2007) for a listing of these factors.

These separate phenomena have the potential to increase the power of Hg stable isotopic analysis in making inferences regarding sources and processes of transfer and transformation, but require levels of control on sampling and analytical procedures. The samples from Table 4 are consistent with values reported for similar materials in other studies. The phenomenon of mass-independent fractionation is particularly evident as Hg moves through food webs and can be seen in the fish samples. This can be seen in Figure 3, which plots δ^{199}Hg (a MIF isotope) versus δ^{202}Hg (a MDF isotope).

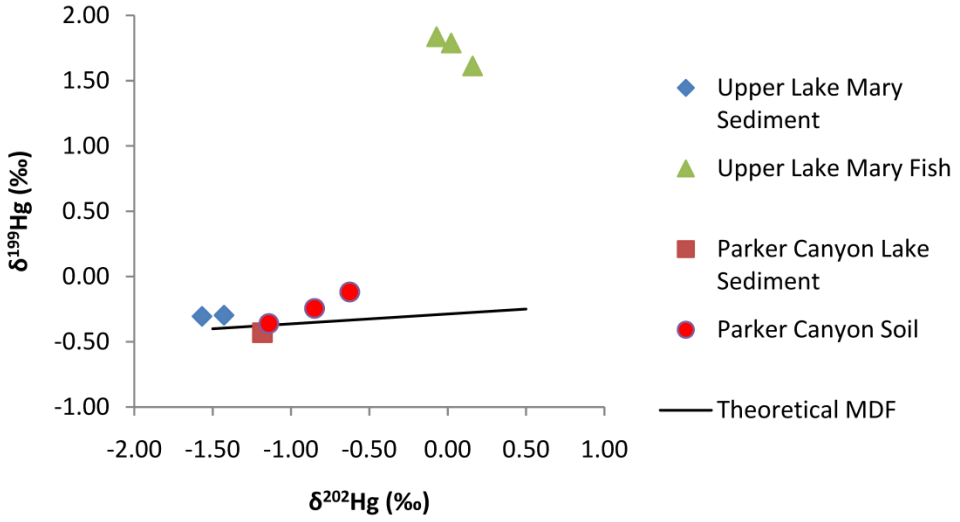

Figure 3. Mercury Stable Isotope Analysis of Soils, Sediments, and Fish from Arizona Ecosystems.

The solid line in Figure 3 shows the theoretical MDF. The fish show a distinct departure from the theoretical MDF value. The cause of this fractionation is not yet well understood, but in a study in the Arctic, Gantner and others (2009) found that the magnitude of the departure of the MDF from the theoretical value was consistent across a region and that an offset could be applied to estimate the isotope ratios of Hg in lower trophic level and the sediment. This has the potential value of being able to use Hg isotopic ratios from fish tissue alone to infer sources, rather than reconstructing isotopic ratio studies of entire food webs.

At this point we have successfully applied techniques for analyzing Hg stable isotopes and have reasonable, but limited, data from Arizona ecosystems. We have acquired a specialized apparatus for introducing samples into the MC ICPMS at NAU, but have not yet tested it.

In summary, this project, in conjunction with research funded by TRIF, and in close cooperation the stream ecosystem group led by Jane Marks at NAU, have enabled NAU to develop the capability to track Hg movement through aquatic ecosystems in arid lands. We now have all of the laboratory instrumentation necessary to make further investigations in total Hg and Hg stable isotopes and have developed strong research collaborations both with a leading Hg isotope laboratory as well as within NAU among the Chemistry, Environmental Engineering, Biology, Environmental Sciences faculty. Importantly, this project enabled funding for a master's student to develop skills in aquatic ecology, while providing crucial initial data for our research effort.

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Information Transfer Program Introduction

The WRRC at the University of Arizona is recognized for its strong information transfer program. The WRRC has established itself as a primary link among the academic community; local, state and federal government; and the private sector for the exchange of water knowledge, providing timely and relevant information on water and related resource management issues statewide through its publications, functions and research reports.

The WRRC's information transfer program draws on its research portfolio for substantial input to its newsletters and other publications; conference, seminar series and other events; and postings on its web site. WRRC staff reaches out to targeted communities through presentations and lectures, service on boards, committees and panels, written articles and research activities.

The Information Transfer program targets three audiences: water managers and decision makers; the academic community of students, water researchers and outreach professionals; and the public with an interest in water affairs. The WRRC also reaches out to policy makers who are less informed about water issues and to a wider public to improve their water knowledge. Involvement in WSP Education and Outreach ensures robust exchanges of information within UA's water and sustainability communities. Teachers and school age students are reached by Arizona Project WET, and Arizona NEMO carries water information to groups dispersed throughout the state.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2009AZ338B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	AZ-007
Research Category:	Not Applicable
Focus Category:	Law, Institutions, and Policy, Management and Planning, Economics
Descriptors:	water policy, stakeholder engagement, best practices, research applications
Principal Investigators:	Sharon Megdal, Susanna Eden

Publications

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2. Artiola, Janick, Kathryn Farrell-Poe, and Kristine Uhlman, 2009, "Water Facts: Home Water Treatment Options", University of Arizona Cooperative Extension [Az1498].
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18. Uhlman, Kristine (Ed.), 2009, "Rapid Watershed Assessment Fort Pearce (Utah,Arizona, Nevada)", USDA Natural Resources Conservation Service.
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WRRC STAFF INFORMATION TRANSFER RELATED ACTIVITIES

During the project year the WRRC professional staff included Sharon Megdal, Director; Kerry Schwartz, Director Arizona Project WET; Holly Thomas-Hilburn, Arizona Make a Splash with Project WET Water Festival Program Coordinator; Jackie Moxley, Water Sustainability Program Coordinator; Kristine Uhlman, Director Arizona NEMO; Susanna Eden, Applied Research Coordinator; Joe Gelt, Editor; Terry Sprouse, Erin Westfall and Carie Deatherage, Senior Research Specialists; and Joanna (Bate) Nadeau, Research Analyst.

Sharon Megdal is the C.W. and Modene Neely Endowed Professor for Excellence in Agriculture and Life Sciences. In addition to serving as WRRC Director, Prof. Megdal is the Water Sustainability Program Director. She is also a professor/specialist in the UA Department of Agricultural and Resource Economics and the Department of Soil, Water and Environmental Science, and holds courtesy appointments with the UA School of Government and Public Policy and School of Geography and Development, the Planning Degree Program, College of Architecture and Landscape Architecture and The College of Public Health. She is a member of the Arid Lands Resource Sciences Graduate Interdisciplinary Program and the Institute of the Environment. In addition, Dr. Megdal was elected in November 2008 to the Central Arizona Water Conservation District Board of Directors, which oversees the Central Arizona Project. She was selected to serve on the Governor's Blue Ribbon Panel on Water Sustainability and in January 2010, received the University Distinguished Outreach Faculty award.

During the reporting period, Prof. Megdal gave numerous presentations on the topic of water management and planning, around the state. She also published articles, reports and commentary based on her water policy research. She participated in the CAST study to examine Water Availability for Agriculture in the United States using the impacts, regulations, challenges, and policies of specific U.S. states as examples; she was lead author on the study report and presented its results at three seminars in Washington, D.C. at the U.S. Department of Agriculture and on Capitol Hill. She spearheaded collaborative development and implementation of a bi-national research plan as part of the U.S.-Mexico Transboundary Aquifer Assessment Program. She led a study on water conservation for environmental enhancement that has resulted in a proposal for a prototype "Conserve to Enhance" program generating considerable interest from conservation planners, municipalities and other water providers. In addition, she continues to teach her popular graduate-level water policy course and is the author of a water policy column for the WRRC's newsletter.

Prof. Megdal has encouraged the growth of international collaborations, maintaining an affiliation with the newly established UMI center on Water, Environment, and Policy, a research partnership between the UA and the French National Center for Scientific Research. She was invited to present a paper on the U.S.-Mexico Transboundary Aquifer Assessment Program at the World Water Week in Stockholm in August 2009. In addition, she led the cooperative development of an international symposium and workshop held August-September 2009 in Tucson, with participation from Israeli, Palestinian and U.S. water policy experts and government officials; she is co-editor of a book based on workshop presentations that will be published by UNESCO Press.

As the Director of the Arizona Project WET (Water Education for Teachers) Program, **Kerry Schwartz** runs a comprehensive statewide water education program that is expanding to more school districts, teachers, and students each year and now reaches tens of thousands of individuals. As an Associate Specialist with the Department of Agricultural Education, she

combines her knowledge of water resource management and hydrogeology with an ability to engage adults and students in learning. Formative and summative evaluation of education programs is ongoing. Ms. Schwartz administers grants from federal, state, county, city public/private entities, and expanded during the reporting period to a funding relationship with the Abbott Fund. In addition, she meets weekly with an APW staff team of eight with an advisory council bi-monthly to guide the APW program. The 150 page School Water Audit Program curriculum was peer-reviewed and published on the Arizona Project WET website during the reporting period. Ms. Schwartz was co-Recipient (with an ACE colleague) of the 2009 Governor's Regional and Rural Development Conferences' Excellence in Economic Development – Future Leaders Award for the Cottonwood Middle School Water Audit.

As Program Coordinator for the Arizona Make a Splash with Project WET Water Festivals, **Holly Thomas-Hilburn** manages a program that supports local communities in organizing standards-driven water education events for fourth graders. This includes supporting local communities who sponsor and host these events with technical support, equipment and trainings for teachers and volunteers as well as working in new areas to establish local Water Festival coordinators and committees. Additionally, Holly collaborates on other direct student outreach programs including the Sweetwater Wetlands Water Festival program (for third graders in the Tucson area) and the Earth Camp Program, a collaboration between Arizona Project WET and the Arizona-Sonora Desert Museum.

Jackie Moxley, Coordinator for the Water Sustainability Program (WSP), manages all aspects of the program under the direction of Sharon Megdal, WSP director, and the WSP Executive Committee. Funding for the program is allocated to a Recruitment and Research Initiative, a Student Fellowship Program, an Education & Outreach Program, a Competitive Grants Program (recently suspended due to budget cuts) and to the five water centers that serve as the management core. Ms. Moxley also coordinates the Water and Environmental Sustainability Program, which combines WSP and the Translational Environmental Research initiative into one reporting unit for the Arizona Board of Regents. She oversees staff in Maricopa County working with Cooperative Extension in Phoenix to help develop and deliver WSP education and outreach programs to the state's largest population center. Ms. Moxley writes the WSP Newsletter, a periodic electronic newsletter on WSP that communicates current news on funding opportunities, notice of new grants and honors, and events for the UA water community. She also wrote the WSP Water Centers, Spring 2009 insert published in *AWR*, which also serves as a stand-alone fact sheet. She was instrumental in organizing a workshop on emerging pathogens in water, as part of the series of WSP Education and Outreach workshops. Development of a new website, brochure and other promotional materials for WSP were part of her responsibilities over the last year as well as meeting and event planning.

As an Assistant Area Agent with Cooperative Extension, **Kristine Uhlman** is working with several Arizona counties on projects addressing water resources. She continues her role as the Arizona NEMO (Non-point Education for Municipal Officials www.ArizonaNEMO.org) Program Director and is responsible for the development of watershed-based planning documents and educational outreach to land-use decision makers on non-point source pollution issues. Other projects include developing volunteer watershed and river monitoring programs for watershed partnerships across the state (NEMO Wet/Dry); development of a predictive MODFLOW groundwater model of groundwater resources in the central part of the State; isotope analysis of numerous water supply wells to determine groundwater age; a key-word searchable photo archive of historic photographs provided by the Bureau of Land Management;

and a series of county-based water resource fact sheets for domestic well owners. In addition, as Principal Investigator for a grant with the Natural Resources Conservation Service (NRCS), Ms. Uhlman leads a team developing Rapid Watershed Assessments (RWA) for four watersheds surrounding the Grand Canyon in Arizona, Utah, and Nevada. An important focus of effort over the past year was the organization of the Coordinated Resource Management Workshop representing the state and federal resource management agencies across the state. Working with campus faculty and County Extension Agents across the state, she has also developed a new outreach program addressing domestic well operation, maintenance, and water quality sampling. Over the past year, seven "Arizona Water Well Workshops" have been conducted in five counties. This new program coincides with the publication of *Arizona Well Owners' Guide to Water Resources* (Artiola and Uhlman) and includes sampling and analysis of domestic water wells. Ms. Uhlman was appointed to the Enforcement Advisory Committee by the State Board of Technical Registration, the entity responsible for registration of professional engineers and geologists for Arizona. Ms. Uhlman continues her appointment to the Pima Association of Governments Watershed Subcommittee Chair position.

Susanna Eden, Coordinator, Applied Research, is responsible for managing the WRRA Section 104(b) competitive grant program for the WRRC, and she was responsible for assembling the WRRC's 5-year evaluation report. She initiated and manages the annual summer internship at the WRRC for students interested in writing about water for the general public. The 2009 intern, **David Newman**, a Masters student in Chemical and Environmental Engineering, was selected by competition and worked at the WRRC providing background research and initial composition for the *Arroyo* newsletter on the topic of the water-energy nexus. Dr. Eden also implemented a parallel initiative: a writing contest for undergraduate at the three Arizona universities. Prizes for the three winning entrants were awarded in January 2010. She provided synthesis and reporting on WSP-funded research into the role of irrigation districts in the development of water markets and collaborated on an Arizona Water Institute research project to assess incentives for water reuse in Arizona. She also was a member of the planning committee for both the 2009 and 2010 annual conferences and contributed to organization of the conferences. In addition, she presented a paper on Arizona-Mexico transboundary water issues at the Arizona-Israeli-Palestinian Water Management and Policy Workshop and is co-editing a book based on the presentations at that workshop.

Joe Gelt has a major role in the production of the two WRRC newsletters. He writes and edits the *Arizona Water Resource*, published four times per year, and edits and co-authors the *Arroyo,* an annual publication. He prepared a special edition of the *AWR* newsletter reporting on the Arizona-Israeli-Palestinian Water Management and Policy Workshop, an international conference organized by the WRRC. He also had a role in conducting a summer writing internship and statewide contest for student writers. Partially retired, Mr. Gelt works half time and will be fully retired in midsummer 2010.

Terry Sprouse, Research Specialist Senior, worked with Project NEMO to produce Rapid Watershed Assessment Reports and Watershed-Based Plans for watersheds in Arizona. He collaborated on training watershed groups to do Wet/Dry Mapping of their watershed, and has helped in GIS mapping seminar presentations. Dr. Sprouse is also coordinating an update of the popular Arizona Water Map Poster, and he manages the NEMO webpage.

Erin Westfall, Research Specialist Senior, applied her expertise in GIS and cartography on work for Arizona NEMO. Ms. Westfall created cartographic products for reports and other published material, and assists with compiling and editing watershed-based plan reports for the

Arizona Department of Environmental Quality (ADEQ). In addition, she carried out public outreach activities, including training volunteers for the Arizona NEMO Wet/Dry Mapping. She was co-author on several publications with Arizona NEMO Program Director, Kristine Uhlman. This position is now held by **Carie Deatherage**.

Joanna B. Nadeau is a Research Analyst as of January 2010, having spent the past 2.5 years working as a Graduate Research Assistant to Dr. Megdal. Continuing work started during her graduate program, Ms. Nadeau's current work involves outreach and partner development towards implementation and evaluation of pilot programs of Conserve to Enhance, an innovative strategy to connect water conservation with environmental enhancement projects. She works in collaboration with non-profits and local municipal water professionals in several Western communities to establish Conserve to Enhance programs tailored to local communities. Joanna provides outreach for the Conserve to Enhance project, including presentations to regional audiences and writing a progress report intended for use by interested communities. She is also working on a one-year statewide assessment of Arizona's environmental water needs, funded by the Nina Mason Pulliam Charitable Trust. The assessment will assemble and analyze information from ongoing and completed efforts to quantify the water requirements of Arizona's riparian areas and aquatic ecosystems. Ms. Nadeau oversees communication with the assessment's Advisory Committee, which is composed of environmental flows experts and key environmental stakeholders in the state.

A list of presentations by WRRC professional staff is appended.

WRRC PUBLICATIONS

Arizona Water Resource Newsletter

The Arizona Water Resource is a 12-page newsletter focusing on state and regional water issues. Published 4 times during the project year, it was sent free of charge to more than 2,700 people on the mailing list and distributed to more than 200 others via email. The newsletter has wide distribution; the majority of its readers are from Arizona, but it also is mailed to other states and foreign countries. The publication regularly includes a feature article, a guest view, news briefs, and items of timely interest including special projects, book reviews and legal news. Each issue also includes a public policy column written by the WRRC Director, as well as announcements and publication notices. Most issues of the newsletter include a four-page special supplement inserted as a center fold.

Requests are often received to use material from the AWR in various ways. For example, during this period Wholly H2O, a California Reuse Integrated Management Center, requested to use material from an Arroyo focusing on graywater use and Ritsumeikan University (Kyoto, Japan) requested permission to an AWR article titled "Global Water Shortage Looms In New Century," to be used as part of an English exam for admission to Ritsumeikan University.

AWR Feature Articles 2009-2010:
Spring 2009

- Q & A with Benjamin Grumbles, New AZ Department of Environmental Quality Chief
- Golf Courses Go Green With Less Green - Two Approaches

Summer 2009

- Q & A With Commissioner Salmon, Mexico-United States International Boundary and Water Commission
- Green Roofs, A Heads-Up Way of Providing Urban Environmental Benefits - Water resource advantages number among green roof benefits

Fall 2009

- Arizona, Middle East Water Issues Focus of WRRC Workshop
- Common Concerns of Arizona, Israel and Palestinian Territories Prompt Cooperative Efforts

Winter 2010

- Decentralized Treatment Promises More Delivery and Use of Recycled Water
- Raising High-Rise Crops

WRRC Director's Public Policy Columns 2009-2010:

- "Payoffs From Water-Saving Practices May Have Down-the-Line Costs," Arizona Water Resource, Spring 2009.
- "AZ water planning, a glass both half filled and half empty," Arizona Water Resource, Summer 2009.
- "Organizing international workshop provides much behind-the-scenes learning," Arizona Water Resource, Fall 2009.
- "Now's the Time to Fit Together the Pieces of an Arizona Water Plan," Arizona Water Resource, Winter 2010

Sponsors of the newsletters usually contribute material for the special supplements, recognizing the AWR as a primary vehicle for reaching their audience. This year major sponsors have been the U.S. Geological Survey and the UA Water Sustainability Program. USGS has been prominent as a supporter of the WRRC newsletters contributing $2,500 toward publications this project year.

AWR Supplements 2009-2010

- Spring 2009: Water Sustainability Program: Innovation, Collaboration, Education and Policy
- Summer 2009: USGS, National Water-Quality Assessment Program, Southwest Principal Aquifers Regional Ground-Water Quality Assessment
- Winter 2010: USGS, National Water-Quality Assessment Program, Dissolved Solids in Basin-Fill Aquifers and Streams in the Southwestern United States — Executive Summary

<u>Arroyo Newsletter</u>

The 2009 edition of the *Arroyo*, an annual newsletter focusing on a single topic of timely interest to Arizona, was published in April. Titled "Once Shunned, Wastewater Now Viewed as a Valuable Resource," it provides a comprehensive overview of wastewater reclamation and use in Arizona, including history, regulation, treatment, and uses of reclaimed water, along with the latest results of relevant university research projects. It explores public policy issues relating to treatment and distribution costs, incentives, and the protection of public health with reclaimed water for various uses, including potable reuse. **Claire Landowski**, the student awarded the WRRC summer writing internship in 2008 worked as a team member with Joe Gelt and Susanna

Eden on the reuse Arroyo. Highly commended, the reuse Arroyo was used as a basic document for the Governor's Blue Ribbon Panel on Water Sustainability assembled by Arizona Governor Jan Brewer in January 2010.

Work on the 2010 *Arroyo* began with selection of the 2009 summer writing intern. Planned for publication in early spring, the *Arroyo* will deal with the emerging issues surrounding the use of water in energy production and the use of energy in the production and provision of water. *Arroyo*'s coverage of this "hot topic" will provide explanations of basic concepts, data on water and energy use, description of the legal context, discussion of emerging issues, and a glimpse of cutting-edge research and technology.

WRRC PRODUCTS

Arizona Water Map

The Arizona Water Map was completely redesigned and revised with up-to-date information. The new map was published and made available for distribution in the spring of 2010. The map was produced in two formats: a full-sized (31.5" X 41") color poster suitable for framing and classroom use and a folded map with accompanying curriculum guide for teachers, providing in-depth explanations and supplemental information.

Layperson's Guide

The Layperson's Guide to Arizona Water, published by WRRC in collaboration with the Water Education Foundation in 2007, is still regarded as the primary informational resource throughout the state on Arizona water. Aimed at a general audience, the Guide describes Arizona's water resources and their uses, the history of water development, water law and the management framework, and discusses the major water issues confronting the State. The Guide can be downloaded free of charge from the WRRC website or purchased in hardcopy form from WEF.

CONFERENCES, SEMINARS AND LECTURES

Annual Conference

The 2009 Annual Conference "Best Practices for Stakeholder Engagement in Water Resources Planning," was held March 17 at the UA Student Union. The conference, organized in collaboration with the Morris K. Udall Foundation and the Arizona Water Institute, developed a dialogue across a broad spectrum of interests on concepts and strategies to promote stakeholder participation in water resources planning. Former U.S. Assistant Secretary of the Interior for Water and Science, Elizabeth Rieke gave the keynote address and U.S. Representative Gabrielle Giffords provided a video message to the conference audience. The conference included a poster session and three concurrent interactive workshops. Arizona NEMO and Watershed Steward Program facilitated participation by watershed groups across the state. Approximately 250 people attended from 35 communities across Arizona and the Southwest. After the conference the speakers' PowerPoint presentations were made available on the WRRC web site: http://ag.arizona.edu/AZWATER/.

Work began on planning the 2010 Annual Conference in the summer of 2009. A committee that included representatives from the Morris K. Udall and Stewart L. Udall Foundation, the Flinn Foundation, the UA Water Sustainability Program and Arizona Project

Wet was assembled to develop plans for a highly interactive, diverse and multi-generational meeting on the subject of water and environmental leadership. The conference was scheduled to take place at the UA Student Union on June 9-10, 2010.

Brown Bag Seminar Series

The WRRC's brown bag seminar series offers information and opportunities for two-way dialogue and for community-university interaction. The seminars focus on topics with broad appeal to academics from multiple disciplines, members of the water community and interested citizens. This year seminars attracted mixed audiences of about 36 people on average, roughly 47 percent from the campus and 53 percent from the wider community. Seminars in the period March 2009 through February 2010 are listed in the table below.

- Monday, April 6, 2009; Chad Staddon, Senior Lecturer in Geography, Department of Geography and Environmental Management, Chair of the "Bristol Group for Water Research" and "Rural Sustainability" research groups and Regional Committee Member for the Consumer Council for Water, Central Region; *The English Water Sector: 20 years on from Privatization*
- Monday, April 13, 2009; Sid Wilson, Central Arizona Project; *Prospects for Operating the Yuma Desalting Plant;* Karl Flessa, Dept. of Geosciences, University of Arizona; *Nature's fair share: Opportunities for Habitat Restoration on the Colorado River Delta in Mexico*
- Friday, May 1, 2009; Robert Glennon, Morris K. Udall Professor of Law and Public Policy, University of Arizona; *Unquenchable: Americas Water Crisis and What To Do About It*
- Thursday, September 10, 2009; Theresa Crimmins and Katherine Waser, Arid Lands Information Center, University of Arizona; *Simple Techniques for Backyard Water Harvesting: An Online Instruction Module*
- Friday, October 2, 2009; Mark Holmes, Water Manager, Town of Chino Valley; *Achieving True Water Sustainability: A Case Study of Chino Valley's Efforts within the Prescott AMA*
- Wednesday, October 21, 2009; Chris Scott and Stephen Yool, School of Geography and Development, University of Arizona; *Urban Heat Island Effect: Impact on Vegetation*
- Friday, November 13, 2009; Stanley Leake (Fred Tillman), Arizona Water Science Center, U.S. Geological Survey; *Regional Ground-Water Conditions in the Southwestern United States: Assessment Tools*
- Wednesday, November 11, 2009; Diane Boyer and Robert Webb, U.S. Geological Survey; *Damming Grand Canyon: The 1923 USGS Colorado River Expedition*
- Wednesday, November 18, 2009; Mary Hansel, Carollo Engineers; *Bio-mimicry – Learning from Nature's Consummate Engineers*
- Tuesday, January 19, 2010; Will Focht, Director, Oklahoma Water Resources Research Institute; *Water Planning: The Oklahoma Experience*
- Wednesday, January 20, 2010; Linda Stitzer and Kelly Mott Lacroix, Arizona Department of Water Resources; *The Arizona Water Atlas*
- Tuesday, February 16, 2010; Richard Holmes, Director of Environmental Resources, Southern Nevada Water Authority; *The Pursuit of Sustainable and Reliable Water Supplies in the Desert - The Las Vegas Story*
- Friday, February 26, 2010; Roberto Salmón-Castelo, Commissioner, International Boundary and Water Commission, Mexico; *U.S.-Mexico Transboundary Water Issues*

Other Seminars, Workshops and Events

In addition, the WRRC sponsored or co-sponsored meetings, lectures and other events for students, the campus community and the public.

Reception for Sid Wilson at the WRRC

Friday, March 6, 2009, the WRRC hosted a reception to celebrate the more than 40 years of accomplishments by Sid Wilson, the General Manager of the Central Arizona Project, on the occasion of his retirement. Members of the Arizona water community and others joined us in honoring a state leader in water management and a long-time friend of the WRRC.

Unquenchable Author's Presentation and Book Signing

UA James A. Rogers School of Law Professor, Robert Glennon, spoke about his recently published book, *Unquenchable: America's Water Crisis and What To Do About It,* April 24, 2009, in the Sol Resnick Conference Room at the WRRC. Prof. Glennon's book received considerable national notice and this presentation provided the university and local community to hear first-hand some of the stories that had attracted the attention of the national media.

WSP Student Fellowship Presentations and Reception

On Friday, April 17, 2009, the WRRC hosted research presentations by the 2008-2009 Water Sustainability Program, Student Fellowship recipients. Four graduate students and four undergraduate students gave brief presentations on the results of their research over the academic year.

Geography and Development Colloquium

The WRRC is a regular supporter of the annual colloquium series presented by the School of Geography and Development

International Workshop on Water Management and Policy

The *Arizona, Israeli, and Palestinian Water Management and Policy Workshop: Economic, Environmental, and Community Implications of Expanding Reuse and Desalination for Future Water Supplies.* August 31- September 2, 2009, was co-organized by the UA WRRC, Arizona Center for Judaic Studies, Center for Middle Eastern Studies, and Udall Center for Studies in Public Policy, with major funding from the U.S. National Science Foundation; U.S.-Israel Binational Science Foundation; University of Arizona Foundation; University of Arizona Water Sustainability Program. The three day workshop and evening community program brought together researchers and policy experts representing the three regions to identify solutions to water management challenges in arid and semi-arid lands.

WRRC Co-Sponsors Arizona-Sonora Aquifer Assessment Workshop

The U.S.-Mexico Transboundary Aquifer Assessment, Program Workshop: Developing a Work Plan for the Assessment of the Santa Cruz and San Pedro Aquifers was held in Tucson, AZ, November 3-4, 2009. Scientists and stakeholders from federal, state, and local agencies, non-governmental organizations, and universities on both sides of the border met over two days to review progress of the Arizona-Sonora component of the TAAP and confirm or modify priorities in the draft work plan that will guide assessment of the Santa Cruz and San Pedro aquifers.

IBWC Commissioners Address Students and Community Members

Roberto Salmón-Castelo, Commissioner, International Boundary & Water Commission, Mexico, addressed Professor Megdal's water policy seminar class on Friday, February 26, 2010, in the morning and presented a general discussion of U.S.-Mexico Transboundary Water Issues

at a Brown Bag Seminar in the afternoon. Edward Drusina, the newly appointed IBWC Commissioner for the United States, surprised the class by dropping in on the seminar and joining the discussion. Both Commissioners addressed the audience at the afternoon Brown Bag, with Commissioner Drusina presenting informal remarks. Presentations were followed by a question and answer session that provided an unusual opportunity to hear first-hand from the leaders of this important cross-border organization.

WRRC WEB PRESENCE AND ELECTRONIC COMMUNICATIONS

The Internet is an effective outreach vehicle, and the WRRC endeavors to make effective and extensive use of our web site. The site was redesigned to update its look and improve its navigability and continues to be reviewed and revised on a regular basis. In addition to WRRC news and events, the site carries *AWR* and *Arroyo*, as well as papers, presentations and other research and public information publications. Staff profiles and information about WRRC products are posted, along with links to many other water sites. The Annual Conference registration is handled on-line through the WRRC website and conference presentations are posted following the event. Access to the WRRA Section 104 institute program information is also provided through the site.

Information Transfer Program funds have supported a web specialist, **Santiago Samorano**, for work at the WRRC since April 2009. He continually monitors the WRRC site and implements improvements and design enhancements to it make more useful and attractive. He also has been involved in developing and maintaining a web site for the Arizona Transboundary Aquifer Assessment Program (TAAP).

Electronic Mailing Lists

Another component of WRRC information transfer program is to provide timely notice of activities, events and products of interest to the water community. To keep researchers at the three Arizona universities apprised of funding opportunities and upcoming events, the WRRC maintains an up-to-date listing of research faculty and other research scientists. Notices of WRRC's education and outreach activities and products are sent regularly to listserv managers, media outlets and individuals on campus and in the wider community. The WRRC maintains several targeted email lists for these notices, as well as for forwarding announcements and notices received from a wide range of other institutions and organizations.

ASSOCIATED PROGRAMS

The WRRC houses several programs with important university and statewide missions in water research, education and information transfer. WRRC staff members have major responsibilities for directing and coordinating these programs and the WRRC provides them administrative support. The association of these programs has a synergistic effect, greatly enhancing the reach and impact of each.

THE UA WATER SUSTAINABILITY PROGRAM

The Water Sustainability Program (WSP) is a university-wide collaboration of researchers and educators working to leverage The University of Arizona's world renowned expertise in water resources to develop innovative solutions to real-world water resource challenges. This is accomplished through inter-disciplinary research, education and outreach initiatives under the direction of five coordinating water centers, including the WRRC, each bringing unique strengths to the program in water quality, supply, management and policy. The program is delivered through a number of components: a broad, internally competitive grants program; student fellowship program; an education and outreach program; water center directed initiatives and activities support; and strategic recruitment and research initiatives.

Funded through the state Technology and Research Initiative Fund (TRIF), WSP has approximately $2.4 million for one more year in the current cycle of funding to allocate to UA water projects and programs. A program evaluation process, underway as of the end of February 2010, will help determine funding levels for the next five-year cycle. WRRC continues to play a pivotal role in implementing, developing, and managing program components, under WSP and WRRC director, Sharon Megdal.

WSP Co-Sponsored Forums and Workshops

- WRRC Annual Conference 2009, *Best Practices for Stakeholder Engagement in Water Resources Planning*. March 17, 2009.
- WSP Distinguished Speaker & Poster Session. Dr. Jeanne VanBriesen, Carnegie Mellon University, *Intelligent Water Infrastructure.* April 16, 2009.
- Robert Glennon, talk and book signing, *Unquenchable: America's Water Crisis and What To Do About It.* April 24, 2009.
- WRRC Conference, *Arizona, Israeli, and Palestinian Water Management and Policy Workshop: Economic, Environmental, and Community Implications of Expanding Reuse and Desalination for Future Water Supplies.* August 31- Sept 2, 2009.
- SAHRA Annual Meetings, Water and Land Cover Changes in a Non-Stationary World, WSP-WRRC sponsored panel on *Water Planning in a Non-Stationary Environment,* facilitated by Sharon Megdal. September 23-24, 2009.
- School of Geography and Development Speaker Series. Annual seminar series, academic year 2009-2010.

WSP is also a collaborator for the WRRC Conference 2010, June 9-10, *Creating New Leadership for Arizona's Water and Environment in a Time of Change.*

Competitive Grants

One of the key components of the WSP has been the Competitive Grants Program. Beginning in FY2004 approximately $1 million was allocated to UA faculty and staff to fund projects relevant to critical Arizona water issues that served to: stimulate collaborative research; move the knowledge base forward on many fronts; expand education and outreach activities; and provide research opportunities for students. However, due to budget shortfalls, funding was cut back in 2009; the program was suspended for FY2010; and no new projects were funded. Fourteen projects were completed by June 2009 and four two-year projects will wrap up June 2010. Summaries of all projects funded through the program are available on the new WSP web site,

www.wsp.arizona.edu, under Research. Projects completed June 2009, with WRRC staff participation or those hosted by the WRRC, included the following:

1. Ground Water Age Dating for Water Budget Development in the Show Low Watershed, Navajo County, AZ, $4,800 – 1 year, Kristine Uhlman, Water Resources Research Center, Chris Eastoe, Department of Geosciences, and Steve Campbell, Navajo County, Cooperative Extension. Partners: Arizona NEMO (Nonpoint Education for Municipal Officials), Arizona Department of Water Resources and Show Low Creek Watershed Enhancement Partnership.
2. Science Education That Makes a Difference - through Inspired Teacher Leaders, $34,479 – 1 year, Kerry Schwartz, Water Resources Research Center. Partners: ASU Polytechnic Science Education Program, and Arizona Foundation for Resource Education.
3. Yuma Desalting Operations, Water Quality and Vegetation Distribution in the Cienega de Santa Clara, $30,895 – 1 year, Karl Flessa, Department of Geosciences. Partners: Central Arizona Project and Centro de Investigación en Alimentación y Desarollo (CIAD).
4. Optimum and Minimum Irrigation Requirements of Landscape Trees, $20,959 – 1 year, Ursula Schuch, School of Plant Sciences, Ed Martin, Maricopa Agricultural Center and Rick Gibson, Pinal County, Cooperative Extension. Partners: Arizona Landscape Contractors Association, Pinal County Master Gardeners and the City of Maricopa.
5. Estimating Water Use: Monitoring Rural Domestic Wells with Low-cost, Near-real Time Water Metering, $58,970 – 2 years, Susan Pater, Kim McReynolds, Cado Daily, Cochise County Cooperative Extension, Gary Woodard and Ramon Vazquez, SAHRA, Department of Hydrology & Water Resources, Sharon Megdal and Susanna Eden, Water Resources Research Center. Partners: Cochise County and Badger Meters.

<u>WSP Funded WRRC Directed Initiatives</u>

In addition to the WSP projects conducted in-house or hosted by the WRRC, WSP funding has provided opportunities for the WRRC to strengthen educational programs, support new and continuing projects, and expand ties to other departments and colleges in the area of water policy and management. Faculty in the College of Law, the School of Geography and Development in the College of Social and Behavioral Sciences, and the Department of Soil, Water & Environmental Science in the College of Agriculture and Life Sciences received funding through the WRRC on a number of recruitment incentives. WSP Director Megdal has also been instrumental in building and supporting the Water Resources and Policy research emphasis in the School of Geography and Development.

The WRRC used WSP Directed Initiative funds to hire a graduate research assistant to do the groundwork for an international water workshop, *Arizona, Israeli, and Palestinian Water Management and Policy Workshop,* hosted by WRRC in August 2009. WSP-WRRC funding was leveraged into workshop grants from NSF, the U.S.-Israel Binational Science Foundation and the UA Foundation, leading to additional partners and sponsorship. Similarly, WRRC was also able to make use of a small kernel of initial federal funding and TRIF funding to develop the stakeholder framework for the Arizona portion of the U.S.-Mexico Transboundary Aquifer Assessment Program. This federally authorized program is carried out in partnership with the U.S. Geological Survey. The Arizona-Sonora portion of the program has been accepted as a case study of the International Hydrologic Program's Internationally Shared Aquifer Resources Management (ISARM) Program. WSP-WRRC funds were also used to develop the new Water,

Society and Policy Master's Degree in Science program based in the School of Natural Resources and the Environment that evolved from the Water Policy Certificate program initiated by Dr. Megdal.

Graduate students have been supported though WSP-WRRC funding on many projects including the "Conserve to Enhance" project, a concept that enables water users to apply conservation gains to environmental use; the Tucson Regional Water Planning Perspectives Study; and a project evaluating golf course water conservation policies. Joanna Bate Nadeau, the graduate student working on the "Conserve to Enhance" project, graduated and became a WRRC Research Analyst for the project funded through a grant from the Nina Mason Pulliam Charitable Trust.

Arizona Project WET and Arizona NEMO, programs in WRRC have received WSP-WRRC funding for special projects. WSP-WRRC funding was directed to a NEMO project to assess drought vulnerabilities for rural Arizona communities.

At the WRRC, Susanna Eden's position as WRRC Applied Research Coordinator is funded through WSP-WRRC. WSP funds also helped to support WRRC publications, including the *Layperson's Guide to Arizona Water*, and the *Arizona Water Resource* newsletter.

ARIZONA PROJECT WET

Arizona Project WET Water Education Program

Arizona Project WET is a comprehensive water education program with a twelve-year history of successful teacher/educator training. The Arizona Project WET program uses nationally recognized educator guides to deliver water education programs that meet Arizona Academic Standards. Water Education Workshops, developed with local education and water specialist partners, meet grade level specific instructional goals and bring relevancy to the subject of water education for each audience. Water resource materials used to develop workshops cover all water topics from the physical and chemical properties of water to something as specific as Central Arizona Project's junior priority status for Colorado River water. Program coordinators in Maricopa, Pinal and Yavapai Counties are part of the Arizona Project WET team. The Arizona Project WET program is guided by an advisory council, which meets bi-monthly. The Council members are water specialists and stakeholders from statewide government agencies and private entities.

Teacher workshops and other Arizona Project WET activities are funded by grants from federal, state, county, city and public/private entities, as well as foundations. Grant funds support on-going program evaluation to assess impact and expand appropriately. During the reporting period, 587 teachers participated in at least one of 38 six to sixteen-hour water education workshops held in 18 cities across Arizona. These participating teachers report reaching 29,712 students each year with water education. To the statement, "*The workshop was excellent - one of the best I have ever attended,"* 90 percent agree or strongly agree. To the statement, "*The workshop was relevant and improved my knowledge,"* 95 percent agree or strongly agree. Finally, to the statement, "*I intend to become a better water steward as a result of this workshop*," 93 percent agree or strongly agree.

After a thorough philanthropic review process by the Abbott Fund, Arizona Project WET received $100,000 to begin the Pinal County Arizona Project WET program. This initiative was begun to develop a water conservation ethic and a community investment in the environment

focusing on Casa Grande and lay the groundwork for the Pinal County Water Education Program.

The School Water Audit Program (SWAP) was developed in response to an expressed need to provide K-12 institutions with action education projects tied to state standards and education programs that meet the nationwide call for inquiry-based Science, Technology, Engineering and Math (STEM) education. Research shows that real-world project-based education can interest students in learning and be a catalyst for learning and understanding the STEM. Also, research shows that students can be conduits to educate parents and guardians and even local decision makers about water stewardship. With both the youth and adult audiences in mind, the SWAP was developed with the motto "SWAPping Water Waste for Water Efficiency." A 12-unit (150-page) School Water Audit Program (SWAP) curriculum based on teaching the inquiry process through relevant learning was developed, peer-reviewed and posted at http://cals.arizona.edu/arizonawet/teachersupport/swap.

One case study, completed during the reporting period, involved 120 7th graders from Cottonwood Middle School, two teachers, 18 volunteers and in-kind donations of 270 aerators, 72 catch cans, and 250 dye tabs. Student data analysis resulted in a projected water savings at Wilson K-8 of 250,000 gallons/year (a 53% savings on bathroom and classroom faucets) through the installation of faucet aerators. The annual financial savings through Cottonwood Middle School retrofits is about $1,400 using an assumed rate of $3.58/Ccf or $.00479/gal. Finally at Cottonwood Middle School students' homes, through installation of aerators and use of dye tablets that detected leaks in 16% of the toilets, an estimated 3,340,480 gallons of water and $10,355.49 will be saved annually (using a water rate $3.10/1,000 gallons and toilet savings calculations based on loss of 200 gallons/day for leaky toilets). APW nominated Cottonwood Middle School SWAP for the 2009 Excellence in Economic Development Award for Future Leaders and it was presented to them by the Governor at the Governor's Regional and Rural Development Conference in August 2009. Four SWAP teachers presented the program at the National Science Teacher Association conference in Phoenix in December 2009 and continue to teach with and promote the SWAP.

APW Workshops and Professional Development

- "School Water Audit Program, Volunteer Training," Yavapai County Building, Cottonwood, Arizona, April 1, 2009.
- "Arizona Water Festival Volunteer Training," Global Water, Maricopa, Arizona, April 2, 2009.
- "Arizona Water Festival High School Volunteer Training," Maricopa Agricultural Center, Maricopa, Arizona, April 14, 2009.
- "Water Champions" 2-day workshop, PERA Club at Stewart Mountain Dam, Arizona, April 17-18, 2009.
- "Macroinvertebrates as Water Quality Indicators," Hohokam Middle School's Youth in the Wilderness Camp, Las Cienegas National Conservation Area, April 23, 2009.
- "School Water Audit Program with 120 7th Grade Students," Cottonwood Middle School, Cottonwood, Arizona, April and May 2009.
- "Arizona Project WET Water Education for 5th grade Teachers," Maricopa High School, Maricopa, Arizona, May 6, 2009.
- "All School Water Education - Training and Festival Day," San Simon, Arizona, May 18 & 19, 2009.

- "Yuma K-8 English Language Learner Vocabulary Development Using Arizona Project WET," Yuma District 1, Yuma, Arizona, June 9, 2009.
- "Arizona Conserve Water," Deadhorse Ranch State Park, Cottonwood, Arizona, June 11, 2009.
- "An Advanced Water Education Workshop: The Energy Water Nexus," ASU Decision Center for a Desert City, Tempe, Arizona, June 16-17, 2009.
- Middle School Laurel Clark Earth Camp, Tucson, AZ, June 8-20, 2009.
- High School Laurel Clark Earth Camp, Tucson, AZ and Moab, UT, July 7-17, 2009.
- "Water Education for STEM Subjects using the Inquiry Process," B-2 Institute, Arizona Center for STEM Teachers Summer Institute, Biosphere 2, Oracle, Arizona, July 17, 2009.
- "Energy & Environmental Science 6th Grade Unit," Tucson, Sunnyside and Flowing Wells Unified School District, Mansfield Middle School, Tucson, Arizona, August 3 & 4, 2009.
- "Family Science Night focused on Water," Abbott Employees, Abbott, Casa Grande, Arizona August 6, 2009.
- "Energy & Environmental Science 6th Grade Unit," Tucson, Sunnyside and Flowing Wells Unified School District, UA Environmental Research Lab, Tucson, Arizona, September 22 & 29, 2009.
- "Full Option Science System Integrated Water Kit Training," Tucson, Sunnyside and Flowing Wells Unified School District 3rd Grade Teachers, Tucson, Arizona, September 24 & October 1, 2009.
- "School Water Audit Program Teacher Training," Casa Grande Middle School, Arizona, October 29, 2009.
- "School Water Audit Program Volunteer Training," Pinal County Cooperative Extension Office, Casa Grande, Arizona, October 29, 2009.
- "Energy & Environmental Science 6th Grade Unit," Tucson, Sunnyside and Flowing Wells Unified School District, UA Environmental Research Lab, Tucson, Arizona, January 12 & 19, 2010.
- "Full Option Science System Integrated Water Kit Training," Tucson, Sunnyside and Flowing Wells Unified School District 3rd Grade Teachers, Tucson, Arizona, January 14 & 21, 2010.
- "School Water Audit Program Professional Development," Mesa Unified School District, Mesa, Arizona, February 6 & 20, 2010.

<u>Arizona Makes a Splash with Project WET Water Festivals Program</u>

Arizona Make a Splash with Project WET Water Festival program supports local communities in organizing standards-driven water education events for fourth graders. Arizona Project WET developed the Arizona Water Festival Program in 2000. These 4th grade standards-based water education events have now engaged and instructed nearly 40,000 students and 1385 teachers throughout Arizona. This reporting period water festivals reached 5,680 students, and 213 teachers. Lessons were conducted by 482 trained volunteers, representing a total of 2892 volunteer hours, including training and delivering instruction to students. During this reporting period, the Arizona Water Festival Summative Program Evaluation was completed and published. This assessment showed that students who participate in Water Festivals show significant gains in their understanding of water concepts, and that further, those whose teachers

attend Arizona Project WET workshops learn even more. This assessment data has led to the submission of an article for publication. Communities regularly holding festivals include Tucson, Yuma, Sierra Vista, Safford, Payson, Cottonwood and Nogales. New festivals were established as annual events this year in Casa Grande and Apache Junction.

The following is a list of Water Festivals during the reporting period:

April 21, 2009	Maricopa	Maricopa Agricultural Center, Maricopa, AZ
April 29, 2009	Santa Cruz	Nogales High School, Nogales, AZ
May 18, 2009	San Simon	San Simon School, San Simon, AZ
May 27, 2009	Chandler	Central Arizona Community College, Chandler, AZ
September 17, 2009	Payson	Jacobs Park, Payson, AZ
October 2, 2009	TucsonAgua	Caliente Park, Tucson, AZ
October 20, 2009	Sierra Vista	Veteran's Memorial Park, Sierra Vista, AZ
October 22, 2009	Verde Valley	Dead Horse Ranch State Park, Cottonwood, AZ
November 5, 2009	Yuma	Yuma Crossing Park, Yuma, AZ
February 25, 2010	Casa Grande	Mesquite Elementary School, Casa Grande, AZ

ARIZONA NEMO (Nonpoint Education for Municipal Officials)

Arizona NEMO is a program to provide technical support and educational outreach to communities and land use decision-makers in Arizona. With a strong focus on water quality concerns, Arizona NEMO watershed based planning documents characterize each watershed with GIS mapping and includes predictive numeric modeling to simulate watershed response and to predict nonpoint source transport. The Arizona NEMO program has developed watershed based planning documents for each of the watersheds across the state with funding provided through Federal Clean Water Act, Section 319, under the direction of the Arizona Department of Environmental Quality. Planning documents, maps, and a manual of Best Management Practices (BMPs) can be found at the NEMO website (www.AirzonaNEMO.org). ADEQ renewed the Arizona NEMO contract through 2012 to complete finer-scale modeling and mapping of six smaller watersheds targeted by EPA because of water quality impairments. In addition, the new scope of work includes upgrading of the NEMO Internet Mapping Service (IMS) to provide state-wide coverage of GIS maps, hydrologic data, and water quality information. Under this new scope the NEMO team will be providing workshops across the state on IMS tools, Best Management Practices (BMPs) to improve watershed health, as well as supporting the development of Watershed Implementation Plans.

MASTER WATERSHED STEWARDS PROGRAM

Since the summer of 2008, the office of Arizona's Master Watershed Stewards Program has been located at the WRRC. Administered within UA Cooperative Extension and the School of Natural Resources and the Environment, and funded by the U.S. Environmental Protection Agency and Arizona Department of Environmental Quality, the program educates and trains citizens across the state of Arizona to serve as volunteers in the protection, restoration, monitoring, and conservation of their water and watersheds. Association with this program extends WRRC's information and education outreach through this statewide network. Cooperative activities, such

as facilitating the participation of watershed groups in the WRRC's annual conference, provide mutual support, multiplying the benefits to the served communities.

PRESENTATIONS

Resulting from 104(b) and 104(g) research grants

1. Gallo, E. L., P. Brooks, K. A. Lohse, 2009, Controls on Monsoonal Storm Runoff Magnitude and Quality of Urban Catchments in the Tucson Basin, El Dia de Agua, Hydrology and Water Resources, University of Arizona, March 31, 2010. First place presentation.
2. Gallo, E. L., P. Brooks, K. A. Lohse, 2009, Controls on Stormwater Runoff Quality and Quantity in Semi-arid Urban Catchments. AGU, Fall Meeting, H12D-05.
3. Lohse, K.A., E.L. Gallo, P. Brooks, J. McLain, J. McIntosh, T. Meixner, 2009, Sustaining water resources in an arid to semiarid urban ecosystem: Influence of wash substrate of in-stream processing and water quality. Invited speaker at ESA, August 4, 2009.
4. Carlson, M., E. Gallo, K. A. Lohse, J. McLain, J. McIntosh, 2009, Impacts of Urbanization on Groundwater Recharge and Quality in the Tucson Basin. SAHRA Annual Meeting, October 23-24, 2009 (poster).
5. Clark, S., E. Gallo, K. A. Lohse, and P. Brooks, 2009, Using Citizen Science to Gain Knowledge of the Chemistry and Spatial Variability of Monsoonal Precipitation within the Tucson Basin, October 23-24, 2009 (poster).
6. Gallo, E. L., P. Brooks, K. A. Lohse, 2009, Controls on Stormwater Runoff Quantity and Quality of Urban Catchments in Southern Arizona, SAHRA Annual Meeting, October 23-24, 2009 (poster).
7. Gallo, E. L., P. Brooks, K. A. Lohse, 2009, Spatial and temporal variability in runoff chemistry across an arid urban ecosystem gradient, ESA. August 3-7, 2009.
8. Mullin, Lucy, 2010, presentation, ARCS Foundation Awards Banquet, Phoenix, April 30, 2010.
9. Ketterer, Michael E., Gremillion, Paul T., and Moan, Matthew R, 2010, Sources and Spatial Distribution of Metal Pollutants in Soils near the El Paso Smelter: A Forensic Study with Pb and Pu Isotopes, in Proceedings of the Annual Symposium of the European Geophysical Union, Vienna, Austria, May, 2010.

Presented by WRRC professional staff

1. Eden, Susanna, "Take home messages from Water Resources Research Center's 2009 Annual Conference on Stakeholder Engagement," Watershed Planning Committee, Pima Association of Governments, May 18, 2009.
2. Eden, Susanna, "Water Transfers in Arizona, the role of irrigation districts," Little Colorado River Plateau RC&D, Thursday Luncheon Lecture Series, Pinetop-Lakeside Town Hall, May 15, 2009.
3. Hilburn, Holly, "Arizona Water Festivals: Student Learning Through Community Engagement" Watersmart Innovations Conference, Las Vegas, NV, October 8, 2009.
4. Hilburn, Holly, "Casa Grande Water Festival Report" Casa Grande School Board Meeting, Casa Grande, AZ March 9, 2010.
5. Megdal, Sharon, "Arizona Water Planning," Dept. of Hydrology and Water Resources Seminar, University of Arizona, March 4, 2009.

6. Megdal, Sharon, “Water Management in the Tucson Region,” Graduate Club, Tucson, AZ, March 11, 2009.
7. Megdal, Sharon, “Stakeholder Engagement in Water Planning,” Water Resources Research Center Annual Conference, Tucson, AZ, March 17, 2009.
8. Megdal, Sharon, “U.S.-Mexico Transboundary Aquifer Assessment Program”, Water Resources Research Center Annual Conference, Tucson, AZ, March 17, 2009.
9. Megdal, Sharon, “Is Water the New Oil? Challenges in Water Resource Planning,” 18th Annual Conference of the International Association of Attorneys and Executives in Corporate Real Estate, Scottsdale, AZ, April 23, 2009.
10. Megdal, Sharon, “Long-Term Water Planning”, Maricopa County Cooperative Extension, Phoenix, AZ, April 29, 2009.
11. Megdal, Sharon, “ISARM Case Study: Santa Cruz and San Pedro Aquifers,” Sixth Meeting of the U.S. National Committee for UNESCO IHP, Washington, DC, May 11, 2009.
12. Megdal, Sharon “Project Update, U.S.-Mexico Transboundary Aquifer Assessment Program in Arizona,” presented during public comment, Water Committee of the Arizona-Mexico Commission, Scottsdale, AZ, June 5, 2009.
13. Megdal, Sharon, “Arizona Water Management,” Student and Faculty from Arid Lands Institute at Woodbury University, Tucson, AZ, June 9, 2009.
14. Megdal, Sharon, “Arizona Water Management,” International Water Agency Professionals from the Middle East, hosted by the U.S. Department of State, Tucson, AZ, June 15, 2009.
15. Megdal, Sharon, “Arizona Water Management,” Humphrey Fellows program at the Center for English as a Second Language, Tucson, AZ, July 8, 2009.
16. Megdal, Sharon, “Challenges to Sustainable Water Management,” Udall Foundation Scholars Orientation, Tucson, AZ, August 7, 2009.
17. Megdal, Sharon, “The US-Mexico Transboundary Aquifer Assessment Program: The Arizona-Sonora Portion as a Case Study,” Sharing an Invisible Water Resource for the Common Good: How to Make Use of the UN General Assembly Resolution on the Law of Transboundary Aquifers Seminar, World Water Week, Stockholm, Sweden, August 20, 2009.
18. Megdal, Sharon, “Best Management Practices, Conservation and Smart Water Policy,” Arizona Investment Council Conference on Meeting Arizona’s Water Needs Today & Tomorrow, Tucson, AZ, August 28, 2009.
19. Megdal, Sharon, “Water Pricing Theory and Practice in Israel and Arizona,” with Yoav Kislev, Arizona-Israeli-Palestinian Water Management and Policy Workshop, Tucson, AZ, September 1, 2009.
20. Megdal, Sharon, “Arizona Water Management,” Greater Tucson Leadership, Tucson, AZ, September 11, 2009.
21. Megdal, Sharon, Panel Organizer/Moderator, “Water Planning in a Non-Stationary Environment”, SAHRA Center Annual Meeting, Tucson, AZ, September 23, 2009.
22. Megdal, Sharon, “Challenges Associated with Water Management,” U.S. Forest Service Southwestern Regional Leadership Team Meeting, Tucson, AZ, October 7, 2009.
23. Megdal, Sharon, “Growth, Water Planning, and the Environment,” Tucson Citizens Water Advisory Committee, Tucson, AZ, October 7, 2009.
24. Megdal, Sharon, “Water Management in the Greater Tucson Area: A Look at the Issues,” Good Shepherd’s Church, Green Valley, AZ, October 11, 2009.

25. Megdal, Sharon, “Food for Thought” Dinner, Women in Science & Engineering (WISE) campus group, University of Arizona, October 11, 2009.
26. Megdal, Sharon, “Securing Water for the Environment,” World Wildlife Fund and Coca Cola Enterprises field trip group, El Paso, Texas, October 13, 2009.
27. Megdal, Sharon, “Securing Water for the Environmental Purposes,” Water Conservation Information Sharing Group, Phoenix AZ, October 30, 2009.
28. Megdal, Sharon, TBreak Environmental Group Breakfast Meeting, Tucson, AZ, November 5, 2009.
29. Megdal, Sharon, “Thirsting for Water, based on Water, People and the Future: Water Availability for Agriculture in the United States,” Stakeholder, Media and Public Seminar, Washington, DC, November 9, 2009.
30. Megdal, Sharon, “Thirsting for Water, based on Water, People and the Future: Water Availability for Agriculture in the United States,” U.S. Department of Agriculture “Diverse Voices in Agriculture” Series, Washington, DC, November 9, 2009.
31. Megdal, Sharon, “Thirsting for Water, based on Water, People and the Future: Water Availability for Agriculture in the United States,” National Coalition for Food and Agriculture (NC-FAR) “Lunch ‘n Learn” Seminar, Washington, DC, November 9, 2009.
32. Megdal, Sharon, “Challenges to Sustainable Water Planning in Arizona,” Mining and Geological Engineering Seminar, University of Arizona, Tucson AZ, November 16, 2009.
33. Megdal, Sharon, “Working to Resolve Transboundary Water Conflicts,” Tucson Council on Foreign Relations, January 20, 2010.
34. Megdal, Sharon, “Challenges to Water Sustainability in Arizona,” International Learning in Retirement Program, February 13, 2010.
35. Megdal, Sharon, “Water for Agriculture,” Watershed Planning Subcommittee Meeting, Pima Association of Governments, February 22, 2010.
36. Megdal, Sharon, “Connecting Water Research and Water Management: The Importance of Engagement,” WaterSMART Kickoff Workshop, Las Vegas, NV, February 24, 2010.
37. Megdal, Sharon, “The Challenges to Sustainable Water Management in Arizona,” Biosphere 2 Science Saturdays, February 27, 2010.
38. Megdal, Sharon and Joanna Nadeau, “Conserve to Enhance” Conservation Info Sharing Group in Phoenix, AZ, Oct. 30, 2009.
39. Megdal, Sharon and Joanna Bate (Nadeau), “Securing Water for the Environment: Establishing Pilot Programs,” WaterSmart09 Innovations Conference, Las Vegas, NV, October 8, 2009.
40. Moxley, Jacqueline, “UA Water Sustainability Program,” Academy Village, Tucson, AZ. March 11, 2009.
41. Nadeau, Joanna, “Conserve to Enhance,” Tucson Water Commercial Conservation group March 25, 2009.
42. Nadeau, Joanna, Lecturer, “Securing Water for the Environment: WRRC Research Efforts” UA Arizona Water Policy Seminar, Tucson, March 26, 2010.
43. Nadeau, Joanna, “Conserve to Enhance,” for potential Las Cruces pilot partners (SW Environmental Center; LC Water Conservation Coordinator), Las Cruces, NM, April 28, 2010.
44. Nadeau, Joanna, “Conserve to Enhance,” Arizona Water Association, Glendale, AZ, May 6 2009.

45. Nadeau, Joanna, “Conserve to Enhance,” Watershed Planning Subcommittee meeting, Pima Association of Governments, Tucson, May 18, 2009.
46. Nadeau, Joanna, “Conserve to Enhance: El Paso C2E pilot” via conference call with Mark Briggs, and other WWF and Coca Cola Company representatives, September 4, 2009.
47. Nadeau, Joanna, “Conserve to Enhance” Pre-Launch of Tucson Pilot Program, September 10, 2009.
48. Nadeau, Joanna, “Conserve to Enhance” Presentation via conference call to Scott River Trust, December 7, 2009.
49. Nadeau, Joanna, “Conserve to Enhance,” SEWNA Advisory Committee meeting, Tucson, AZ, February 9, 2010.
50. Nadeau, Joanna, “Conserve to Enhance,” for potential Prescott pilot partners (Prescott Creeks, City of Prescott Conservation Coordinator, City of Prescott Parks Dept staff) February 17, 2010.
51. Nadeau, Joanna, “Conserve to Enhance,” Verde Watershed Association, Prescott, AZ, February 17, 2010.
52. Schwartz, Kerry, “Arizona Project WET Water Education Program in Pinal County,” Abbot Team Meeting, March 23, 2009.
53. Schwartz, Kerry, “Arizona Project WET & Water Reuse Education” for the Arizona WateReuse Conference, Flagstaff, Arizona, July 30, 2009.
54. Schwartz, Kerry, “Managing Water Resources for Tomorrow,” at the Arizona Hydrological Society Annual Symposium, Tucson, Arizona, August 31, 2009.
55. Schwartz, Kerry, “Arizona Water Festival Events,” WaterSmart Innovations Conference, Las Vegas, Nevada, October 8, 2009.
56. Schwartz, Kerry, “School Water Audit Program,” WaterSmart Innovations Conference, Las Vegas, Nevada, October 8, 2009.
57. Schwartz, Kerry, “Incentivizing the Use of Water Efficient Technologies in Arizona Communities” for the Arizona Water Conservation Info Share Group, Phoenix, October 30, 2009.
58. Schwartz, Kerry, “STEAM Education and Arizona Project WET” for the Arizona Department of Education Title I section MEGA Conference: Education Innovation powered by STEAM, Wigwam Resort & Conference Center, Litchfield Park, Arizona, November 18, 2009.
59. Schwartz, Kerry, “Water Resources in Tucson,” Tohono Chul Docent Training Class, Tucson, Arizona, February 10, 2010.
60. Uhlman, Kristine, “Where Does Your Water Come From,” keynote, Pioneer Day - Colossal Cave, Tucson, AZ, March 28, 2009.
61. Uhlman, Kristine, “GIS for Watershed Stakeholder Participatory Processes” WRRC Annual Conference, Tucson, March 17, 2009.
62. Uhlman, Kristine, “NEMO - Wet/Dry Volunteer Mapping Training Workshop,” Portal March 20, Duncan April 16, Cordes Junction April 18, and Black Canyon City April 30, 2009.
63. Uhlman, Kristine, “Mapping of the Agua Fria on June 20, 2009,” Agua Fria Watershed, June 20, 2009.
64. Uhlman, Kristine, “Water Resources of Arizona,” Arizona Riparian Institute, Gilbert, AZ, June 2, 2009.

65. Uhlman, Kristine, “Where Does Your Water Come From?” Science Saturday, Santa Rita Experimental Station, Green Valley, AZ, June 6, 2009.
66. Uhlman, Kristine, “Water Well Workshop,” Graham County Extension, Solomon, AZ, June 10, 2009.
67. Uhlman, Kristine, “Population Pressures and Watershed Planning,” Taylor municipal officials, June 11, 2009.
68. Uhlman, Kristine, “ NEMO Expeditionary Workshops” with Arizona Rural Water Association, June 29 to July 1, 2009.
69. Uhlman, Kristine, “NEMO Internet Mapping Service (IMS),” Workshops: ADEQ Phoenix, June 17, 2009; Northland Pioneer College, Show Low, July 9, 2009; UA Udall Center for Studies in Public Policy, September 16, 2009; Blue Ridge High School, Lakeside, October 29, 2009.
70. Uhlman, Kristine, “Arizona Well Owner s Guide to Water Supply,” Arizona Hydrologic Society Conference, Scottsdale, AZ, September 1, 2009.
71. Uhlman, Kristine, “NEMO Program,” Rio De Flag Partnership, Flagstaff, October 1, 2009.
72. Uhlman, Kristine, “Water Resources in Gila County,” Star Valley Sewer and Water Commission, Gila County, October 5, 2009.
73. Uhlman, Kristine, “WELL, What Do We Know?” Workshop Series, with Janick Artiola and the Arizona Water Well Association, for domestic well owners in Yavapai County (with Edessa Carr, October 26 in Prescott, October 27 in Cottonwood) and Gila County (with Chris Jones in Young, December 16, 2009.
74. Uhlman, Kristine, “Well, What Do We Know?” Snowflake community, November 5, 2009.
75. Uhlman, Kristine, “Water Resources,” Patagonia State Park Science Lecture Series, Patagonia, AZ, November 19, 2009.
76. Uhlman, Kristine and Chris Eastoe, “Water Resources,” Arivaca Water Co-Op and Arivaca Watershed Education Taskforce – AWET, invited lecture Arivaca, AZ, May 2, 2009.
77. Uhlman, Kristine, and Chris Eastoe, “Ground Water Age Dating,” Arivaca Water Co-Op and Arivaca Watershed Education Taskforce – AWET, invited lecture, Arivaca, AZ, June 24, 2009.
78. Uhlman, Kristine, Erin Westfall and Terry Sprouse, “Arizona NEMO Wet/Dry Mapping of the Agua Fria River,” NGWA Conference, Tucson, April 20, 2009.
79. Uhlman, Kristine, and Tauhid Rahman “Predicting and Mapping Ground Water Vulnerability to Nitrate in Arizona,” Tucson, April 20, 2009.
80. Varady, Robert G., Roberto Salmón-Castelo and Susanna Eden, “Key issues, institutions, and strategies for managing transboundary water resources in the Arizona-Mexico border region,” Arizona, Israeli, and Palestinian Water Management and Policy Workshop: Economic, Environmental, and Community Implications of Expanding Reuse and Desalination for Future Water Supplies, August 31 – September 2, 2009, Westward Look Resort, Tucson, AZ.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	9	0	0	0	9
Masters	3	0	0	1	4
Ph.D.	4	0	0	2	6
Post-Doc.	0	0	0	1	1
Total	16	0	0	4	20

Notable Awards and Achievements

Sharon Megdal received the University Distinguished Outreach Faculty award in January 2010. This award recognizes outstanding contributions to outreach at the University of Arizona, the State of Arizona and the nation. It is the highest honor in this area offered by the University of Arizona. Dr. Megdal received this award for demonstrating sustained excellence in the University's outreach mission.

Sharon Megdal was appointed to the Arizona Governor's Blue Ribbon Panel on Water Sustainability in December 2009. The panel of representatives from state and local government, water experts and key stakeholders is charged with recommending pathways for improving statewide water sustainability through increased water recycling, conservation and other promising strategies.

Kerry Schwartz was co-Recipient (with an ACE colleague) of the 2009 Governor's Regional and Rural Development Conferences' Excellence in Economic Development – Future Leaders Award for the Cottonwood Middle School Water Audit. The School Water Audit Program (SWAP) engages students in the real-world exercise of auditing their school's water use. In the process, it teaches standards-based content and empowers students to learn through discovery and develop or strengthen their sense of responsibility for efficient water use.

An interview with Kristine Uhlman was featured in "Life After People", a series on the History Channel looking at the fate of the built environment over time. The May 19, 2009 episode, "investigates how long it might take for groundwater levels and desert rivers to recover with people no longer diverting them...and will specifically look at Phoenix, an oasis created with, and maintained by, ever increasing amounts of water." (UA News article by Jeff Harrison: http://uanews.org/node/25647) Interviews with Uhlman and other scientists and visually compelling computer simulations depict the fate of the nation's fifth largest city - Phoenix.

In June 2009, Kristine Uhlman made a presentation, "Where Does Your Water Come From?" before the Citizens Water Advisory Group in Yavapai County, which was filmed for broadcast on Prescott local access TV - http://www.vimeo.com/5239467.

The WRRC held its first annual photography contest in conjunction with its co-sponsored "Arizona, Israeli, and Palestinian (AzIP) Water Management and Policy Workshop: Economic, Environmental, and Community Implications of Expanding Reuse and Desalination for Future Water Supplies," August 31 – September 2, 2009. The enthusiastic response to this event was apparent from the more than 200 entries we received. Three winning photos and six runners-up were selected. The selected photographs were on display at the AzIP Workshop and announced at the Community Evening Program held on the second evening of the workshop on Tuesday, September 1, 2009.

In the Fall semester of 2009, the WRRC inaugurated its first annual writing contest for undergraduate students at The University of Arizona, Arizona State University and Northern Arizona University. Eric Betz, a student in the Department of Physics and Astronomy and the Department of Communication at Northern Arizona University won the Grand Prize of $100.00, for an article on El Niño's effect on water supplies. The panel included the publisher of Southwest Hydrology magazine, the Environment, Water and Climate reporter for The Arizona Republic, a reporter for The Daily Courier the Prescott area newspaper. The contest was a unique opportunity for student writers to see their work published. The winning articles were published in the Spring issue of AWR.

Students supported by research grant 2009AZ312B received multiple grants and awards related to their research. These include: -2010 1st place talk, Erika Gallo, El Dia de Agua, Department of Hydrology and

Water Resources -2009 1st place, Erika Gallo, SAHRA Annual Meeting -2009 IE Travel Grant, Erika Gallo -2009 AZ Water Scholarship, Mark Carlson -2009 GSA Research Grant, Mark Carlson -2009 GSA Research Grant, Erika Gallo -2009 2nd Place Poster, Erika Gallo, El Dia de Agua. In addition, after publication of the research findings in Southwest Hydrology, the USEPA office in Washington DC contacted PI Lohse and colleagues for their recommendations on water management in the southwest.

Ms. Lucy Mullin, the Ph.D. student support on 2009AZ297B, received two additional grants to support her continuing study of water use by ponderosa pine. First, she received a $7,000 ARCS (Achievement Rewards for College Scientists) Fellowship in the Spring of 2010. Also in Spring 2010, Ms. Mullin was awarded a prestigious new Department of Energy Office of Science Graduate Fellowship for her research into the ecohydrology of ponderosa pine forests. Of more than 3200 applicants nationwide, only 150 (< 5%) received awards. The fellowship provides $50,000 per year for three years and includes a stipend, tuition, and research support.

Conserve to Enhance, an innovative strategy to connect water conservation with environmental enhancement projects conceived and developed at the WRRC, is being adopted by several communities in Arizona for pilot testing. Joanna Nadeau is conducting outreach and partner development towards implementation and evaluation of pilot programs. Working in collaboration with non-profits and local municipal water professionals in Tucson, Prescott, and several other Western communities, she has succeeded in developing Conserve to Enhance pilot programs tailored to local communities. The on-going evaluation of pilots will result in a report for use in expanding the program to more communities.

Publications from Prior Years