Water Resources Research Center
Annual Technical Report
FY 2010

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 WRRA, the WRRC carries out research on water-related topics of policy interest to the State and beyond. 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. Three associated programs at the WRRC, the Watershed Steward Program, 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 provides support in the form of small "seed" grants for researchers at all three state universities in Arizona, through the WRRA, Section 104(b) research grant program. Each year, the WRRC typically funds three or four small projects to examine water issues of statewide importance. A wide range of projects have been funded over the years. In the last few 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 2010 through February 2011) the WRRC funded five project. One identified major sources of perflouronated compounds and perfluoro-octanoic acid in the Tucson Basin, in support of a broader investigation into the causes of and means for preventing PFOS/PFOA contamination of groundwater. A project investigating the sources of contamination from nitrogen complemented other work sorting out the roles of atmospheric and geologic sources for a suite of contaminants. Another project looked at biochar soil amendments with the purpose of increasing the water holding capacity of desert soils using a method with multiple benefits, including carbon sequestration and energy production. A fourth project investigated the efficacy of nano-scale, zero-valent Iron as a promoter of in-situ biochemical remediation of Uranium plumes in groundwater. An on-going project on Uranium contamination is using fish tissue to detect the presence of Uranium and Lead isotopes in the Lower Colorado River.

The WRRC also 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. Efforts made for this program led to an agreement on cross-border cooperation: the "Joint Report of Principal Engineers Regarding the Joint Cooperative Process United States and Mexico for the Transboundary Aquifer Assessment Program," signed by the Principal Engineers of both the Mexican and U.S. sections of the IBWC on August 19, 2009. Since then, two databases of border aquifer studies have been compiled and the results of the stakeholder engagement process and program research have been presented at multiple regional and international meetings.

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:	4/30/2011
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., et al. 2009. "Assessment of United States – Mexico Transboundary Aquifers Facing Climate Change and Growth in Urban Water Demand" Climate Change (in press)
4. 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.
5. 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/.
6. 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).
7. 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.

8. Vandervoet, Prescott L., 2009. "Transboundary Aquifer Assessment Program Arizona," Annual Meeting for the Association for Borderlands Studies. Albuquerque, New Mexico, April 16, 2009.
9. 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.
10. 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.
11. 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/.
12. 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).
13. 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.
14. Vandervoet, Prescott L., 2009, "Transboundary Aquifer Assessment Program Arizona," Annual Meeting for the Association for Borderlands Studies, Albuquerque, New Mexico, April 16, 2009.
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16. Browning-Aiken, A., C.A. Scott, R.Varady, S. Megdal, 2010, Spanning transboundary waters in North America (Atravesando las aguas transfronterizas en América del Norte, Traverser les eaux transfrontières en Amérique du Nord), Newsletter of International Network of Basin Organisations.
17. Scott, C.A., 2010, Groundwater, Encyclopedia of Geography, SAGE Publications, Thousand Oaks, California, <http://www.sage-ereference.com/geography/Article_n548.html>.
18. Scott, C.A., S. Dall’erba, R. Díaz-Caravantes, 2010, Groundwater rights in Mexican agriculture: spatial distribution and demographic determinants. Professional Geographer 62(1): 1-15.
19. Milman, A., C.A. Scott, 2010., Beneath the surface: intranational institutions and management of the United States – Mexico transboundary Santa Cruz aquifer. Environment and Planning C: Government and Policy 28: 528-551.
20. Norman, Laura M., Lainie Levick, Phillip D.Guertin, James Callegary, Jesus Quintanar Guardarrama, Claudia Zulema Gil Anaya, Andrea Prichard, Floyd Gray, Edgar Castellanos, Edgar Tepezano, Hans Huth, Prescott Vandervoet, Saul Rodriguez, Jose Nunez, Donald Atwood, Gilberto Patricio Olivero Granillo, Francisco Octavio GastelumCeballos,2010, “Nogales Flood Detention Study” U.S. Geological Survey Open File Report 2010-1261.
21. Vandervoet, P.L., S.B. Megdal, C.A. Scott, 2011, Los acuíferos transfronterizos Santa Cruz y San Pedro de Arizona y Sonora: Estado actual y creación de bases de datos (The Santa Cruz and San Pedro transboundary aquifers of Arizona and Sonora: Current status and database creation) In G. Cordova, J. Dutram, B. Lara, and J. Rodriguez (Eds.) Fortaleciendo el diálogo social: El desarrollo humano transfronterizo en la región Sonora-Arizona (Strengthening social dialogue: Transboundary human development in the Sonora-Arizona region) Universidad de Sonora. Hermosillo, Sonora, Revise and resubmit in process.

Summary

The Transboundary Aquifer Assessment Program (TAAP) originates from U.S. Public Law 109-448, signed into law by the President of the United States on December 22, 2006 as the U.S.-Mexico Transboundary Aquifer Assessment Act. The Act applies to the states of Texas, New Mexico, and Arizona where four transboundary aquifers have been designated for priority assessment. These aquifers include the Hueco Bolson and Mesilla Basin aquifers in the greater El Paso / Ciudad Juárez region and the Santa Cruz and San Pedro aquifers across the Arizona – Sonora border (see map). TAAP is designated to operate for 10 years, with $50 million authorized for appropriation over that time period. Appropriations to date include $500,000 each for fiscal years 2008 and 2009 and 1 million for 2010.

TAAP-A/S (Arizona/Sonora) conducts assessments of aquifers shared by Arizona and Sonora as a collaborative effort between the United States Geological Survey (USGS) and the University of Arizona, by way of the Water Resources Research Center (WRRC) and the Udall Center for studies in Public Policy. A variety of other U.S. and Mexican stakeholders participate in the priority-setting for the assessment process. TAAP-A/S (which studies the transboundary Santa Cruz and San Pedro aquifers) has participated in the UNESCO Internationally Shared Aquifer Resource Management (ISARM) Programme, which has led to TAAP participation in international conferences and a wider range of scientific resources.

During the November 2009 international TAAP workshop, the Transboundary Aquifer Assessment Program- Arizona and Sonora component developed a work plan for activities to be carried out during the 2010-11 program year. These activities were divided between responsibilities falling under the supervision of the Arizona Water Science Center of the USGS and those by the Water Resources Research Center (WRRC) and Udall Center for Studies in Public Policy (Udall), both at the University of Arizona. Activities carried out by the WRRC and Udall are classified under the heading of "vulnerability assessment" as they are focus on issues more closely related to groundwater use by and related to human populations. Activities supervised by the USGS come under the heading of "hydrological modeling framework", as the work tends to focus on the purely hydrological and geological aspects of aquifers in question. The vulnerability assessment items (listed below in bold) aim to involve a varied socio-economic set of stakeholders that affect and depend upon groundwater resources located within the bi-national upper Santa Cruz and San Pedro river basins.

The evolving vulnerability related to groundwater use by urban centers such as Cananea, Sierra Vista, and Ambos Nogales, as well as surrounding rural communities, is a significant issue for transboundary aquifers, given the proximity of aforementioned cities to the international boundary as well as their near total dependence on groundwater. Some of the issues particular to these areas include groundwater recharge deficit in the Sierra Vista subwatershed, over-allotment of groundwater rights in the Mexican section of the San Pedro, storm runoff and wastewater (conveyance and treatment) infrastructure in Nogales, Sonora, and uncertainty regarding groundwater bearing and defining geological units around Nogales, Arizona well fields. Given these, as well as other unique regional issues, the vulnerability assessment for the TAAP-A/S work plan for project year 2010-11 focused on the following activities:

A. **Data collection of land use, zoning, economic and population growth, infrastructure, etc.**
B. **Urban growth characterization and effect on watershed land use and hydrology**
C. **Bi-national water balances and supply / demand analysis**
D. **Groundwater Vulnerability Assessment**
E. **Water quality assessments including anthropogenic impairments**
F. **Assessment of institutional asymmetries and bi-national cooperation frameworks**
G. **Improved linkages with international best practices (via ISARM)**

A. Data collection of land use, zoning, economic and population growth, infrastructure, etc.

Activity description (2010-11 work plan): Develop profiles and corresponding pressures on groundwater resources originating from focal urban and rural areas by 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.

Summary of Activities Completed:

- Prichard, Andrea. MA Thesis (in progress)- Interbasin water transfers at the US-Mexico border city of Nogales, Sonora: implications for aquifers and water security. Expected defense in December 2011. School of Geography and Development. University of Arizona.
- Vandervoet, Prescott. TAAP-A/S Santa Cruz Database. MS Access/MS Excel/PDF Format. Location: http://www.cals.arizona.edu/azwater/taap
- Vandervoet, Prescott. TAAP-A/S San Pedro Database. MS Access/MS Excel/PDF Format. Location: http://www.cals.arizona.edu/azwater/taap
- Scott. C.A. 2010. Groundwater overdraft in Mexico: climate, energy, and population drivers. *Toward Sustainable Groundwater in Agriculture – An International Conference Linking Science and Policy.* Univ. California - Davis and the Water Education Foundation, San Francisco, June 15-17, 2010.
- (for a complete list of TAAP publications and other output, see Annex A)

Graduate Research Assistant and MA Candidate in the School of Geography and Development, Andrea Prichard, has collaborated with municipal authorities in the city of Nogales, Sonora to better understand the planning and management of potable water supply and delivery as well as sewerage. The municipal-level *Organismo Operador Municipal de Agua Potable, Alcantarillado, y Saneamiento de Nogales, Sonora* (OOMAPAS-NS) and the *Instituto Municipal de Investigacion y Planeacion de Nogales, Sonora* (IMIP) have been crucial partners in the effort to characterize the city's ability to provide both drinking water and wastewater infrastructure to residents. A recent development (though a re-occurring regional theme, given that the USEPA issued a FONSI for Border 2012 support of a treatment plant in 1999) has been the start of construction on a wastewater treatment facility located to the south of the city of Nogales, Sonora. Currently, the city's wastewater is treated in Arizona at a facility operated by the International Boundary and Water Commission located in Arizona approximately 9 miles north of the international border. Given that wastewater deliveries from Nogales, Sonora to the bi-national facility frequently surpass the agreed upon quantities, and that the city continues to grow (primarily to the south), the need for additional treatment is clear.

Another pertinent issue studied by Ms. Prichard is the inter-basin transfer of drinking water, as well as the proposed conveyance of sewage for treatment. These supply transfers include approximately 339 liters per second (7.74 MGD) of groundwater from the Los Alisos basin aquifer into the city of Nogales, Sonora which overlies (and pumps from) the transboundary Nogales Wash aquifer, as well as an anticipated 220 lps (5 MGD) of wastewater to be conveyed from Nogales, Sonora to the forthcoming treatment plant located within the Los Alisos basin, from which the potable water is pumped (see Figure 1). These transfers raise questions about sustainability, both for growing populations sharing aquifer resources on both sides of the border, and for the riparian ecosystem downstream of Rio Rico, Arizona, which benefits from treated effluent released by the Nogales International Wastewater Treatment Plant in Arizona, of which a portion belongs to and can be reclaimed by Mexico. Ms. Prichard has also been involved in recent studies related to management of urban flooding as a result of summer storm events in the region of Nogales, Sonora.

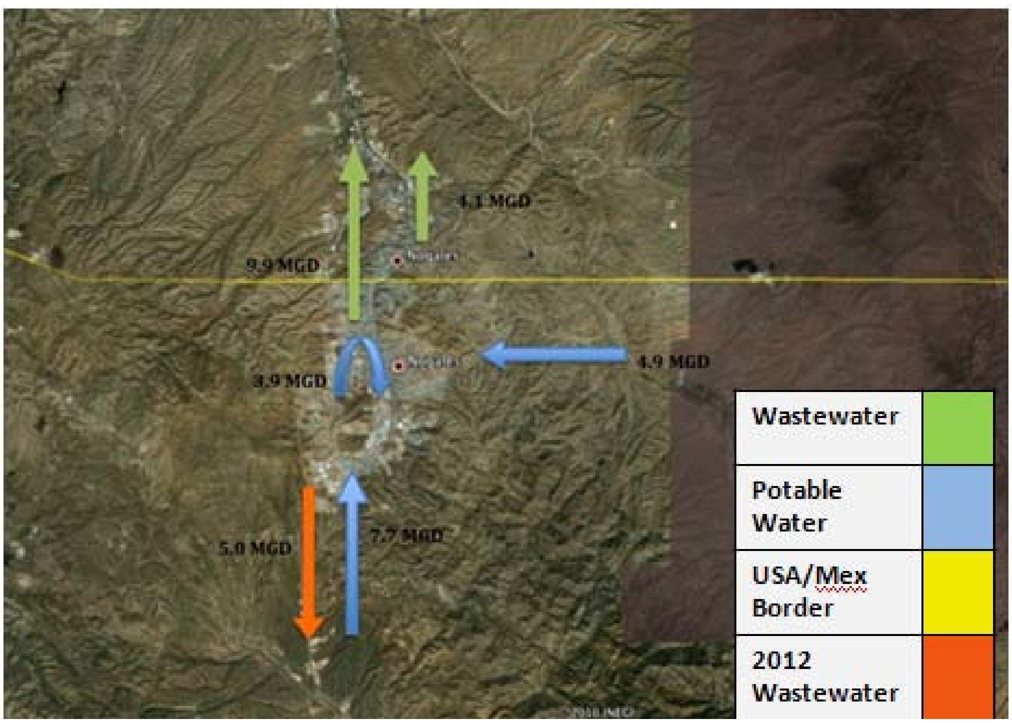

Figure 1. Transboundary and Inter-basin current and projected flows of potable and wastewater.

Ms. Prichard has compiled a database of well information from public records in the Santa Cruz, San Pedro, and Nogales Wash aquifers and created GIS maps according to the usage attributes of the wells. She has assisted Dr. Scott in calculations of projected recharge rates of Mexican aquifers based on IPCC projections of future precipitation and temperature scenarios for the next century. Using international climate scenario datasets and Mexican federal shapefiles, she displayed these aquifers and attributes in GIS maps. She is also conducting a multi-temporal remote sensing NDVI analysis of the riparian vegetation along and downstream of the Los Alisos wellfield, which provides around half of the municipal water to the city of Nogales, Sonora. As part of the data collection process on land use and infrastructure, and under the overarching theme of groundwater resources, Prescott Vandervoet has developed two databases that 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 150 (Santa Cruz) and 130 (San Pedro) reference materials each from various sources. Database elaboration falls under a mandated activity of the Transboundary Aquifer Assessment Act, Section 4(b)(B) which calls for "evaluating all available data and publications as part of the development of study plans for each priority transboundary aquifer". The creation of such databases, in addition to providing a valuable source of information for future research and data gathering on the Santa Cruz and San Pedro River aquifers, 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 and 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 y Cananea, Sonora
- City of Nogales; Nogales, Arizona
- Bureau of Reclamation; Tucson, Arizona
- Comisión Nacional del Agua, Comisión de Cuenca del Noroeste; Hermosillo, Sonora
- Upper San Pedro Partnership; Sierra Vista, Arizona
- University of Sonora; Hermosillo, Sonora
- College of Sonora; Hermosillo, Sonora
- University of Arizona; Tucson, Arizona

For an example of database entries and information compiled, see Annex 1 (Santa Cruz) illustrating five selected fields (Principal Author- Last Name, Principal Author- First Name, Other Authors, Year Published, and Title of Material) from the Santa Cruz database for all entries. The Santa Cruz and San Pedro databases can be accessed via the TAAP-A/S webpage that is located at http://www.cals.arizona.edu/azwater/taap.

B. Urban growth characterization and effect on watershed land use and hydrology

Activity description (2010-11 work plan): Land use change, primarily in the form of urban growth, may have a strong effect upon basin hydrology. This has resulted in increased runoff, increased sediment entrainment in surface flow, and decreased infiltration. The way in which populations grow and urban area expands, including evolving usage of groundwater resourced, are important issues to be analyzed.

<u>Summary of Activities Completed</u>:

- "Nogales Flood Detention Study" 2010. Norman, Laura M.; Levick, Lainie; Guertin, D. Phillip; ***Callegary, James***; Guardarrama, Jesus Quintanar; Anaya, Claudia Zulema Gil; ***Prichard, Andrea***; Gray, Floyd; Castellanos, Edgar; Tepezano, Edgar; Huth, Hans; ***Vandervoet, Prescott***; Rodriguez, Saul; Nunez, Jose; Atwood, Donald; Granillo, Gilberto Patricio Olivero, Ceballos, Francisco Octavio Gastelum. U.S. Geological Survey Open File Report 2010-1261.

TAAP-A/S Research Analyst Prescott Vandervoet and Graduate Research Assistant Andrea Prichard contributed to the USGS study on land surface and rainfall runoff conditions in the Nogales, Sonora urban area (Norman et al., 2010). Their work involved compiling data on evolving population statistics within the upper Santa Cruz River basin and Nogales Wash areas in Arizona and Sonora, as well as site visits to map, measure, and document the flood detention features in place. The bi-national urban conglomeration of Nogales, Arizona and Nogales, Sonora, located within the Nogales Wash watershed is an important case study due to its development and dependence on regional groundwater.

The manner in which rainfall runoff occurs in the Sonoran city is of great importance to its northern neighbor, Nogales, Arizona as both cities share the same drainage gradient, with the Arizona side being located downstream. Intense precipitation events are frequent in summer months and tend to be concentrated in specific areas over short amounts of time, frequently dropping close to 1 inch of rain within one hour.

Urbanization trends within the City of Nogales, Sonora have exacerbated the effects of such rainfall. Natural vegetation has been replaced by cleared land, and natural drainages have been covered by asphalt and are used as roads. In light of this urban transformation within Nogales, Sonora, the city's current runoff drainage infrastructure is often incapable of handling large, intense rainfall drainage. Due to altered land surface on the surrounding hillsides, high amounts of sediment are brought into the storm drain infrastructure, which leads to clogging. Similarly, sediment can be introduced via manholes to the sewerage drain system, causing its clogging and overflow into storm drainage channels, thus mixing untreated sewage into surface water drainage. Sediment is considered a contaminant for water quality, and the aforementioned scenario of sediment clogging leading to mixing of untreated sewage has forced the city of Nogales, Sonora to chlorinate surface runoff flows. Additionally, Nogales, Arizona (downstream) must deal with untreated sewage introduced into the bi-national storm-drain conveyance, which is in open channels in sections of either sister city.

Population figures have been recently updated due to federal census counts from 2010 in the US and Mexico. While the City of Nogales, Arizona has not illustrated significant growth over the previous two decades, the peripheral suburban area to the north, referred to as Rio Rico, has grown substantially. The City of Nogales, Sonora has also exhibited high growth rates over previous decades, though, due to informal residential development on the city's fringes, official population counts may underestimate total city residents. As such developments tend to occur without municipal oversight, preferential surface-water drainage control may not occur. Similarly, formal access to the city potable water supply and sewerage grids may not occur for years, increasing the likelihood of informal connections, which add additional strain to such infrastructure.

C. Bi-national water balances and supply / demand analysis

Activity description (2010-11 work plan): Urban and rural development rates and climate change have important effects on groundwater usage. The evolving mix of agricultural, industrial, and residential water 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 users.

Summary of Activities Completed:

- Scott, C.A., S. Megdal, L.A. Oroz, J. Callegary, P. Vandervoet (In Review). *Assessment of United States – Mexico Transboundary Aquifers Facing Climate Change and Growth in Urban Water Demand*. Climate Research (special issue on US-Mexico Border Climate Change).

- Scott, C.A. and P. Vandervoet. 2010. Transboundary Aquifer Assessment, Management and Policy. Double session organized and moderated at the annual symposium of the Arizona Hydrological Society. September 3-4, 2010. Tucson, Arizona.

- Vandervoet, P.L., S.B. Megdal, C.A. Scott. Revise and resubmit in process. Los acuíferos transfronterizos Santa Cruz y San Pedro de Arizona y Sonora: Estado actual y creación de bases de datos (The Santa Cruz and San Pedro transboundary aquifers of Arizona and Sonora: Current status and database creation) In G. Cordova, J. Dutram, B. Lara, and J. Rodriguez (Eds.) Fortaleciendo el diálogo social: El desarrollo humano transfronterizo en la región Sonora-Arizona (Strengthening social dialogue: Transboundary human development in the Sonora-Arizona region). Universidad de Sonora. Hermosillo, Sonora.

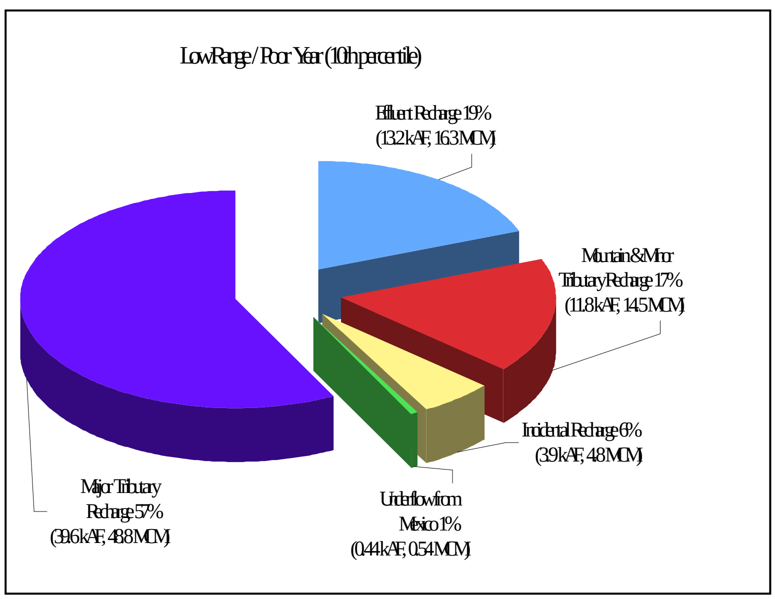

Figure 2. Estimated recharge & inflow for Santa Cruz AMA, low precipitation

Authors Christopher Scott, Sharon Megdal, Lucas Oroz, James Callegary, and Prescott Vandervoet, have submitted the study titled, "Assessment of United States – Mexico Transboundary Aquifers Facing Climate Change and Growth in Urban Water Demand" for review in the journal Climate Research for a special edition dedicated to US-Mexico border climate change. The following graphics (Figures 2 and 3) illustrate one of the points brought out by in this paper related to variability in water resource supply in the upper Santa Cruz River basin in Arizona. The data for this analysis, provided by the Santa Cruz Active Management Area, illustrates variability of precipitation on various drivers of demand within the upper Santa Cruz River basin in Arizona.

Thematic issues relating to bi-national water balances and supply / demand analysis have been addressed during two recent research events: 1) the Arizona Hydrological Society's annual symposium entitled "Dryland Hydrology: Global Changes, Local Solutions", held September 3-4, 2010 in Tucson, Arizona, and 2) the University of Sonora's colloquium entitled "Agua, salud y pobreza urbana en Nogales, Sonora: herramientas para la acción local (translation: Water, Health, and Urban Poverty in Nogales, Sonora: Tools for Local Action), held May 27, 2010 in Nogales, Sonora.

Research for the previously mentioned presentations focused on a regional outlook of groundwater availability in the bi-national upper Santa Cruz and San Pedro river basins. Aside from the physical conditions and groundwater recharge levels, the varied management scenarios both between nations, as well as between the two river basins, create unique cases for understanding the factors that affect water demand and availability.

It is important to visualize groundwater use within the upper basins of the Santa Cruz and San Pedro Rivers in a regional context, including each upper basin on either side of the international border. Due to the fact that the basins border each other, it is possible to generalize to a certain extent in terms of regional geography and climate. The bed of the San Pedro River at the international border is located at 1276 meters above sea level, while the Santa Cruz River bed is located 1128 meters above sea level at its location near the USGS-operated Nogales gage. The standard for defining the separation between upper and middle or lower basins for each river valley is created by the Arizona Department of Water Resources and the United States Geological Survey. For the Mexican portions of the river drainages, each basin is included in its entirety.

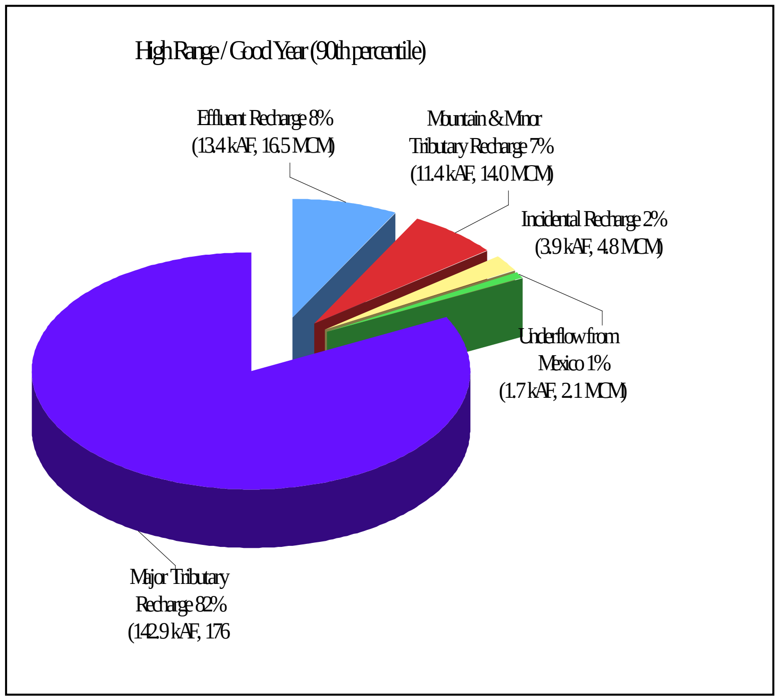

Figure 3. Estimated recharge & inflow for Santa Cruz AMA, high precipitation

The upper San Pedro River basin in Mexico has an area of 1750 km^2 (CNA 2009a) and the Sierra Vista subwatershed (as defined by the US Geological Survey) has an area of 2460 km^2 (Coes and Pool 2005) and extends approximately 43 kilometers north of the International border. In the Santa Cruz River basin, the San Rafael valley in Arizona, where the river begins, has an area of 445 km^2 (Towne 2003), while the extension of the river basin in Mexico has a surface area of 952 km^2 (CNA 2010b). The Nogales Wash, classified in Mexico as a separate basin from that of the Santa Cruz River, has an area of 120 km^2 (CNA 2007). The basin of the Santa Cruz River in Arizona, as covered by the Santa Cruz Active Management Area of the ADWR has an area of 1854 km^2 (ADWR 2010). In total, the area of both upper binational basins of the Santa Cruz and San Pedro Rivers covers 7581 km^2.

When a comparison is made between groundwater use in each shared basin (upper Santa Cruz River and upper San Pedro River), it is interesting to see that the quantity of water used is very similar. Yet, the uses of water are very different in the respective basins. In the Santa Cruz (both sides of the border) there is a significant quantity of water destined towards agriculture, while in the San Pedro, the Sierra Vista subwatershed has almost no water destined towards this use. In the Mexican portion of the basin, 5.1 hm^3 (23% of total) is destined towards agricultural use (CNA 2009b).

The analysis of annual recharge for both sides of the aquifers, in addition to data on groundwater withdrawals, provides useful information regarding the water balance in each administrative region of the two basins. The recharge figures do not include information related to groundwater exiting each basin, nor that of evapo-transpiration (important, given the riparian vegetation in each river). In this aspect, it is not necessarily the precise quantity that is used to determine availability when regulatory agencies consider water concessions. The intent of the following graphic (Figure 4) is to present the quantity destined towards human consumption (public-urban, agriculture, etc.) as a share of the total availability (CNA 2009a, CNA 2009b, ADWR 1999, USPP 2007).

	Santa Cruz (kAF)	**San Pedro (kAF)**
Recharge Volume (US)	48.8 – 176	22.2
Extraction Volume (US)	26.0	20.9
Recharge Volume (Mexico)	38.1	41.0
Extraction Volume (Mexico)	26.4	22.3

Figure 4. Estimated binational water budgets

D. Groundwater Vulnerability Assessment

Activity description (2010-11 work plan): 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.

Summary of Activities Completed:

Lincicome, Alexis; M.S. Thesis- in progress; Soil, Water, and Environmental Science Department, University of Arizona; Dr. Mark Brusseau, advisor.

Graduate Research Assistant Alexis Lincicome of the Soil, Water, and Environmental Science department is using a tool known as DRASTIC (Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone media, and hydraulic Conductivity of the aquifer) to ass the potential for groundwater in the Santa Cruz and San Pedro basins to become contaminated by surface pollution sources. The study area for this project includes the entire upper basins of the Santa Cruz and San Pedro rivers in Arizona. A variety of data sets are being collected and processed to construct a detailed analysis of surface and groundwater interaction, which provides a better understanding of the potential movement of surface contaminants into groundwater. The data sources for these layers include the U.S. Geological Survey, National Resources Conservation Service, Arizona Department of Water Resources, and the Arizona Meteorological Network.

Potable water service providers, as well as private users, rely nearly entirely upon groundwater resources for drinking water within the upper Santa Cruz and San Pedro river basins. Each basin receives about 12 inches of rainfall per year, and this rainfall serves as significant recharge to the shallow alluvium overlying an important groundwater extraction zone. Another important contributor to recharge of the shallow alluvium within the upper Santa Cruz river basin is the Nogales International Wastewater Treatment Plant (NIWTP), located approximately 15 kilometers north of the border at Nogales. This treatment plant handles wastewater from Nogales, Arizona and Nogales, Sonora, the latter of which is home to many industrial production facilities, where the regulation of contaminant waste is uncertain. The possibility for industrial contaminants to be produced under varying degrees of regulation and enforcement (depending from which side of the border they originate) adds a complicated aspect to wastewater treatment at the NIWTP. A thorough understanding of the potential for harmful substances that exit the treatment plant to enter groundwater resources downstream is important, as both public and private supply wells are located within the shallow alluvium downstream of the NIWTP.

The goal of the groundwater vulnerability assessment is to analyze groundwater resources within both the upper Santa Cruz and San Pedro river basins, north of the international border. Due to historical mining, agricultural, and industrial practices, as well as the effects of continued urban and rural residential growth in both river basins, a variety of contaminants have been documented throughout the Santa Cruz and San Pedro basins. This DRASTIC assessment, coupled with current land use practices and knowledge of their contribution to groundwater contamination, can be used to guide city planning, zoning, and groundwater monitoring efforts throughout the Santa Cruz and San Pedro basins.

The data layers that will be compiled for database inclusion are: aquifer media, soil media, net recharge: precipitation / evaporation / runoff / infiltration, topography, aquifer hydraulic conductivity, depth to groundwater, and aquifer contaminants. These layers will first be analyzed and rated for their individual contribution to the vulnerability of each aquifer, then added with the other factors to create an overall vulnerability rating for each aquifer. Data have been obtained to complete four of the layers. Information gathering and processing are continuing in order to complete the other layers.

E. Water quality assessments including anthropogenic impairments

Activity description (2010-11 work plan): 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.

Summary of Activities Completed:

- Callegary, James *et al.* 2011. Linking hydrology, geology, chemistry, and biology in the Upper Santa Cruz River Basin. *Santa Cruz River Researcher's Day* presentation. March 29, 2011. Tucson, Arizona.

- McAndrew, Rose M., James B. Callegary, and Mark L. Brusseau. 2011. Groundwater Contaminant Transport Modeling in the Upper Santa Cruz Basin. *Santa Cruz River Researchers' Day* Poster Presentation. March 29, 2011. Tucson, Arizona. and University of

Arizona, Department of Hydrology and Water Resources' El Dia del Agua, March 30, 2011. Tucson, Arizona.

- McAndrew, Rose M. 2010. Developing a Groundwater Contaminant Transport Model along the Effluent-Dominated Reach of the Santa Cruz River. *USGS Border Environmental Health Initiative (BEHI) Interdisciplinary Showcase* Presentation. October 12, 2010. Tucson, Arizona.

- McAndrew, Rose; M.S. Thesis- in progress; Hydrology and Water Resources Department, University of Arizona; Dr. Mark Brusseau, advisor.

Graduate Research Assistant Rose McAndrew is developing a database of groundwater contamination within the upper Santa Cruz River basin within Arizona, based on records compiled by Arizona Department of Water Resources, US Bureau of Reclamation, and the US Geological Survey, as well as other sources. The database is in the final phase of review. The data compiled for the database are being used to assess the primary groundwater contaminants of concern for the study area. They are also being used to support a contaminant transport modeling effort described below.

The Upper Santa Cruz Basin has experienced population growth and industrial development that has resulted in increasing water demand and greater risk of groundwater contamination. This demand and subsequent pumping that began in the late 1800s have led to ephemeral flow in portions of the river, while effluent discharge from the Nogales International Wastewater Treatment Plant (NIWTP) now sustains perennial flow in the downstream reach (Logan, 2002 and Nelson, 2001). In combination, these factors have altered the natural groundwater flow patterns in the basin (Nelson, 2001). The objective of this study is to examine the potential for contaminant transport in the subsurface as well as associated human-health risks, by using a groundwater flow model previously developed for the portion of the aquifer down-gradient of the NIWTP. Water-quality data from numerous sources (federal, state, consultant, and academic- see Table 1 below) have been collected and compiled into a database of sampling events for the area and were then aggregated to identify major contaminants and their distribution. Using a numerical model (MT3D), simulations have been conducted for specific contaminants, including nutrients and trace metals, to evaluate their movement in the aquifer (Zheng and Wang, 1999). The results of this study will be used to evaluate the potential for groundwater contamination and transport to drinking water wells.

	Number of Locations	**Number of Results***	**Sample Type**
ADEQ Water Quality Database (up to 4-2005)	840	16,243	Groundwater
	69	31,230	Surface Water
ADEQ Santa Cruz Water Quality Report 1997	24	881	Groundwater
	3	108	Surface Water
IBWC	15	2,249	Groundwater
FOSCR	9	3,481	Surface Water
ADWR GWSI	229	1,037	Groundwater
NURE	55	2,671	Groundwater
	2	93	Surface Water
USGS NWIS	79	5,666	Groundwater
	10	8,875	Surface Water
Treese Thesis, 2008	17	290	Surface Water
	15	342	Groundwater

Table 1. Data Summary by Source

* number of parameters sampled with results from all visits made to the sites

TAAP-A/S resources have provided financial support for laboratory fees associated with volunteer water-quality monitoring activities along the Santa Cruz River. The non-profit organization, Friends of the Santa Cruz River (FOSCR) has been sampling water from various locations along the upper Santa Cruz River in Arizona for over 10 years. FOSCR adheres to a sample plan approved by the Arizona Department of Environmental Quality (ADEQ), which includes requirements for quality assurance and quality control. ADEQ used FOSCR data to report on the state of the Santa Cruz River to Congress as a requirement of the federal Clean Water Act.

FOSCR samples quarterly at four locations along the river (see map below), depending on the presence of surface flows. Monitoring sites located downstream from the Nogales International Wastewater Treatment Plant (NIWTP) tend to demonstrate year-round surface flows, due to the treatment facility releasing approximately 14 million gallons per day of treated effluent, which, depending on seasonal conditions (i.e. riparian vegetation demand/evapotranspiration) may flow for up to twenty miles downstream.

Figure 5. Water Quality Sampling Locations (FOSCR)

The FOSCR sampling record provides a crucial data source for surface water conditions, especially for monitoring contaminants originating from the Ambos Nogales urban area, and passing through the NIWTP to the river. Water quality parameters monitored by FOSCR include nutrients, metals (see Figure 6), and microbiological indicators such as *e.coli*. Laboratory analyses were previously supported by ADEQ, yet budgetary restrictions forced ADEQ to withdraw monetary support during the summer of 2010, at which time TAAP-A/S assumed responsibility for paying for lab analyses of FOSCR-collected samples.

Metals- Total by EPA 200.8 / Change from Previous Sampling
Metals- Dissolved by EPA 200.8 / Change from Previous Sampling
Metals- Total by EPA 200.7 / Change from Previous Sampling
Metals- Dissolved by EPA 200.7 / Change from Previous Sampling
Nitrogen, Ammonia by EPA 350.1 / Change from Previous Sampling
Nitrogen, Kjeldahl- Total by EPA 351.2 / Change from Previous Sampling
Nitrate- Nitrite as N by EPA 353.2 / Change from Previous Sampling
Suspended Sediment by ASTM 3977C / Change from Previous Sampling
Phosphorus-Total by EPA 365.4 / Change from Previous Sampling

Figure 6. Indicators analyzed for Santa Cruz River samples collected by FOSCR

During the last fiscal year, sampling supported by TAAP-A/S identified impairments to the water quality of the Santa Cruz River related to Arizona standards for the protection of aquatic wildlife in effluent dominated waters. Impairments were sourced to upstream industrial users that were discharging contaminants passing through the NIWTP to the river. Respective details were shared during public meetings of the U.S. Environmental Protection Agency's Border 2012 Program. Subsequent regulatory and voluntary actions by upstream stakeholders resulted in significant improvements in the quality of influent impacting the NIWTP and the river. Additional details can be requested from FOSCR.

F. Assessment of institutional asymmetries and bi-national cooperation frameworks

Activity description (2010-11 work plan): Due to differing groundwater management strategies between the US and Mexico, it is imperative to understand how cross-border cooperation can best function. The bi-national International Boundary and Water Commission does not regulate shared groundwater, thus federal-level management in Mexico is mismatched with state-level management in the US, posing challenges for binational cooperation.

Summary of Activities Completed:

- Megdal, S., R. Sención, C.A. Scott, F. Díaz, L. Oroz, J. Callegary, R.G. Varady. 2010. Institutional Assessment of the Transboundary Santa Cruz and San Pedro Aquifers on the United States – Mexico Border. UNESCO-IAH-UNEP Conference, Paris 6-8 December 2010.
- Megdal, S., R. Sención, C.A. Scott, F. Díaz, L. Oroz, J. Callegary, R.G. Varady. 2010. Evaluación Institucional de los Acuíferos Transfronterizos Santa Cruz y San Pedro en la Frontera México – Estados Unidos. UNESCO-IAH-UNEP Conference, Paris 6-8 December 2010.
- Varady, R.G., C.A. Scott, S. Megdal. 2010. Transboundary aquifer institutions, policies and governance: A preliminary inquiry. UNESCO-IAH-UNEP Conference, Paris 6-8 December 2010.

- Scott, C.A. 2010. Energy Efficiency and Water Systems/ Eficiencia de Energía y Sistemas de Agua (session moderator) and speaker "La escasez de energía y agua: impactos sobre la infraestructura, el crecimiento y el desarrollo económico en Arizona y Sonora (Energy and water scarcity: impacts on infrastructure, growth and economic development in Arizona and Sonora)" Border Energy Forum XVII. Chihuahua, Chih., Mexico, Sept. 29 – Oct. 1, 2010.

- Milman, A., C.A. Scott. 2010. Beneath the surface: intranational institutions and management of the United States – Mexico transboundary Santa Cruz aquifer. *Environment and Planning C: Government and Policy* 28: 528-551.

- Wilder, M., C.A. Scott, N. Pineda Pablos, R.G. Varady, G.M. Garfin, J. McEvoy. 2010. Adapting across boundaries: climate change, social learning, and resilience in the U.S.-Mexico border region. *Annals of the Association of American Geographers* 100(4): 917-928.

- Scott, C.A., S. Dall'erba, R. Díaz-Caravantes. 2010. Groundwater rights in Mexican agriculture: spatial distribution and demographic determinants. *Professional Geographer* 62(1): 1-15.

Activity Advancement: This topic has been addressed in a variety of presentations and research topics addressed by TAAP-A/S team members. The effects of institutional asymmetries reverberate around discussions related to binational objectives dealing with shared groundwater between Sonora and Arizona. Each state, and nation, has a unique approach to managing and assessing groundwater resources, as well as the environment in general.

Local, State, and Federal agencies and organizations rarely match up, in terms of responsibility and/or authority when working on a shared issue or topic across the Arizona / Sonora border, thus, an inherent disconnect between agencies/organizations is common when working on topics that span the border and involve representatives from both nations and different states. A variety of organizational and agency stakeholders must often be engaged in an effort to comprehensively address a particular issue under discussion.

Dr. Sharon Megdal has analyzed the issue of institutional asymmetries in the case of stakeholder agencies engaged with the TAAP-A/S project. She has presented such work at the Scientific Segment of the 19th Session of the Intergovernmental Council of the UNESCO International Hydrological Programme (IHP), with the presentation, "Institutional Mechanisms for the Assessment and Management of Transboundary Aquifers: The Importance of Partnerships" given on July 7, 2010 in Paris, France.

Similarly, Dr. Megdal participated and presented at World Water Week in Stockholm on August 20, 2009, giving the talk titled, "The U.S.-Mexico Transboundary Aquifer Assessment Program: The Arizona-Sonora Portion as a Case Study". World Water Week in Stockholm is an internationally-recognized annual event that brings together regional leaders in water resource assessment and management.

Dr. Megdal has also developed the issue of institutional asymmetries further, during a subsequent presentation, co-authored by fellow TAAP-A/S collaborators from Arizona and Sonora, "Institutional Assessment of the Transboundary Santa Cruz and San Pedro Aquifers of the United States-Mexico Border". This presentation was given at the UNESCO / ISARM- sponsored conference on Transboundary Aquifers held in Paris, France, December 6-8, 2010.

G. Improved linkages with international best practices (via ISARM)

Activity description (2010-11 work plan): 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 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 General Assembly in 2011.

Summary of Activities Completed:

- Megdal, Sharon B. "The U.S.-Mexico Transboundary Aquifer Assessment Program: The Arizona-Sonora Portion as a Case Study." Presentation given at World Water Week. August 20, 2009. Stockholm, Sweden.

- Megdal, Sharon B. "Institutional Mechanisms for the Assessment and Management of Transboundary Aquifers: The Importance of Partnerships." Presentation given at the Scientific Segment of the 19th Session of the International Hydrological Programme Intergovernmental Council. July 7, 2010. Paris, France.

- Organization and Coordination of the International Workshop, "Developing a Work plan for the Santa Cruz and San Pedro Aquifers". November 3-4, 2009. Tucson, Arizona.

Dr. Sharon Megdal has engaged stakeholders and representatives of the Internationally Shared Aquifer Resource Management (ISARM) Programme of UNESCO, based in Paris, France. ISARM also maintains regional focus areas, in particular ISARM-Americas (centered in Montevideo, Uruguay), of which TAAP-A/S is recognized as a case study. Dr. Megdal has made presentations at a variety of ISARM-related meetings and conferences detailing the particular issues related to the binational Santa Cruz and San Pedro aquifers as well as the role of TAAP-A/S in respect to bi-national cooperation related to hydrological assessment of the shared aquifer resources.

ISARM consultant Raya Stephan attended the November 3-4, 2009 TAAP-A/S workshop, and presented on global shared aquifer initiatives including draft articles from the UN regarding shared aquifer management.

TAAP-A/S team members Dr. Megdal and Dr. Christopher Scott attended and participated in the December 2010 UNESCO / ISARM- sponsored conference on Transboundary Aquifers held in Paris, France. The presentation, "Institutional Assessment of the Transboundary Santa Cruz and San Pedro Aquifers of the United States-Mexico Border" was co-authored by TAAP-A/S counterparts in Arizona and Sonora, Mexico.

A variety of details make TAAP-A/S a unique initiative on the global level, namely the importance of groundwater as supply for potable water, growth rates of urban areas as well as the evolving roles of agriculture and mining/industry in the shared aquifer regions, and also the different governance strategies employed within the US and Mexico in respect to water resources. A main focus of Dr. Megdal's ISARM-related work has been to better understand the organizational asymmetries between water resource assessment and management agencies in the United States and Mexico. The degree of centralization as well as regulation and oversight is unique between the two nations, as well as the existence of the binationally coordinated International Boundary and Water Commission, which has a long history of coordinating resolutions related to the international border and shared waters of the U.S. and Mexico.

TAAP-A/S team members have supported further engagement between representatives of the US Geological Survey and the Mexican National Water Commission, as both agencies provide national representatives to the ISARM-Americas section of the global ISARM Programme. The communication medium of ISARM-Americas provides an excellent opportunity to share and learn from regional counterparts regarding common experiences. In the case of the US and Mexico, the shared border region contains many issues that would benefit from a binational perspective, in which ISARM-Americas may provide a medium in which to develop such a discussion.

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Megdal, Sharon B. "The U.S.-Mexico Transboundary Aquifer Assessment Program: The Arizona-Sonora Portion as a Case Study." Presentation given at World Water Week. August 20, 2009. Stockholm, Sweden.

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Use of Fish as Integrative Samplers of Uranium and Lead Isotopes in the Colorado River

Basic Information

Title:	Use of Fish as Integrative Samplers of Uranium and Lead Isotopes in the Colorado River
Project Number:	2010AZ320B
Start Date:	7/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	AZ-07
Research Category:	Water Quality
Focus Category:	Toxic Substances, Water Quality, Radioactive Substances
Descriptors:	Uranium, integrative fish sampling, Lead, Colorado River
Principal Investigators:	Charles Sanchez, John Theodore Chesley, Peter N. Reinthal

Publications

There are no publications.

Problem and Research Objectives:

Renewed emphasis on alternative energy sources has revived interest in uranium mining on the Colorado Plateau. The Colorado River, which transects and drains the plateau, is used both as a source of drinking water and a source of irrigation water for food crops. Therefore the potential for mine waste and runoff into the Colorado River requires an understanding of current U concentrations, sinks and sources. From this project, we will gain additional information on possible sources of U, Pb, and other metals to aquatic biota in the Colorado Basin. These data will augment existing data sets we have on water, river sediments, agricultural soils, and irrigated food crops in the region and lead to a better understanding of contaminant sources and sinks within the Colorado River Basin.

The objectives of these studies are to evaluate fish tissue as an integrative sample of U, Pb, and other metal contaminants in the Colorado River region. We propose to utilize high-precision analyses of radiogenic isotopes (Pb, U, and Sr) to identify probable sources of these elements and by proxy, other potential contaminants. These data, as well as other we have collected on water, sediments, soil, and plants are critical in identification of the sources and pathways of these potential toxins in the food web. This information is a prerequisite for any possible effort to reduce human exposure to these and other toxic elements. These measurements will also provide a baseline should future exploration and mining activity enhance contamination or accidental release occurs.

Methodology:

Fish were collected at specific sites along the river. These locations are selected to correspond to sites where we have already collected background water information. All fish collecting activities were coordinated with Arizona Game and Fish Department. No Federal permits were necessary as we did not collect threatened or endangered species. In fact in some instances a PI went electro fishing with the Arizona Game and Fish Department.

For all species, fish livers were removed; freeze dried, ground, and digested using peroxide and nitric acid. As of the writing of this report we have not completed all analytical work. Dr. Chesley has left the University of Arizona and this work occurs on infrequent visits he makes to Tucson. Pb isotopic ratios are separated using standard techniques and measured on a Multi Collector Inductively Coupled Mass Spectrometer (MC-ICPMS) at the department of Geosciences at University of Arizona (Morfin et al., 2003; Buttigieg et al., 2003; Bau et al., 2004). Sr was measured on a thermal ionization mass spectrometry (TIMS). Uranium-series isotope analyses will be done at the Radiogenic Isotope Laboratory at the University of New Mexico under the direction of Yemane Asmerom. Because of the low levels of metals being found and the large sample required for detection we will have to use separate fish specimens for Pb and U analysis.

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Perflouronated Compounds in Arizona Groundwater: Sources of Contamination

Basic Information

Title:	Perflouronated Compounds in Arizona Groundwater: Sources of Contamination
Project Number:	2010AZ380B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	seventh
Research Category:	Water Quality
Focus Category:	Groundwater, Toxic Substances, Water Quality
Descriptors:	None
Principal Investigators:	David Matson Quanrud, Leif Abrell, Robert Arnold, Eduardo Saez

Publication

1. Quanrud, D. and Propper, K., 2010, “Wastewater Effluent: Biological Impacts of Exposure and Treatment Processes to Reduce Risk—A Literature Review, The Nature Conservancy.

PROBLEM AND RESEARCH OBJECTIVES

This project was motivated by recent (2009) recognition that the trace organic contaminant perfluorooctane sulfonate (PFOS) is present in potable Arizona groundwater sources. PFOS was detected by the Tucson Water Department in their Microconstituent Sentinel Program in 2009 in all four groundwater production wells tested, at concentrations ranging from 3.9 to 65 ng/L. PFOS was also reported at a concentration of 0.21 ng/L in the “finished” water produced by the Clearwater Recharge and Recovery Facility (CRRF). The CRRF recharges Central Arizona Project (CAP) water, which is a mixture of water from the Colorado and Agua Fria Rivers, via infiltration basins at the Central Avra Valley Storage and Recovery Project (CAVSARP). Recharged water is subsequently extracted and served to the public. There is an Environmental Protection Agency (EPA) health-based advisory guideline of 200 ng/L for PFOS. PFOS was added to the Safe Drinking Water Act Contaminant Candidate List 3 (CCL3) in 2009. The CCL3 represents a chemical “watch list” consisting of chemicals that have been marked for potential regulation via promulgation of maximum contaminant limits.

PFOS is a perfluorinated anthropogenic chemical that is a very persistent, suspected human carcinogen with half lives in the human body of 4-10 years. PFOS is a fully fluorinated anion (Figure 1) within the family of perfluoroalkyl sulfonate substances. The majority of these compounds are high molecular weight polymers so that PFOS is only a fraction of the polymer and a final degradation product. Paul (2009) estimated an annual global release of 450 – 2700 tons of PFOS into wastewater streams, primarily through losses from stain repellent treated carpets, waterproof clothing, and aqueous fire fighting foams. PFOS is highly resistant to natural breakdown processes (e.g. hydrolysis, photolysis, biodegradation) due to the strength of the fluorine-carbon bond, one of the strongest in nature. PFOS is a commercial surfactant in fire retardant foam. It is widely used in dirt repellent products (e.g. Scotchgard) for textiles and carpets. In 2000, 3M, the main manufacturer of PFOS, agreed to cease production (USEPA, 2000), and the USEPA imposed a ban on PFOS, with exemptions for special uses in the aviation, photography, and microelectronics industries.

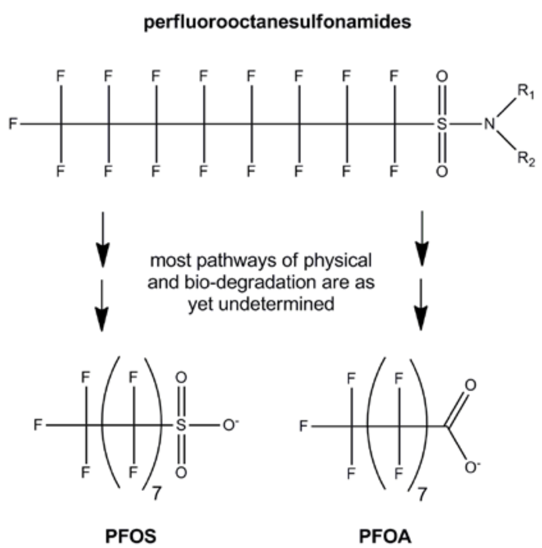

Figure 1. Degradation of a generalized perfluoronated surfactant precursor into products PFOS and PFOA.

Unlike persistent chemicals that accumulate in fat, fluorinated chemicals bind to proteins in the blood and can accumulate and damage organs such as the liver. There is also evidence that PFOS has negative effects on hormone systems. PFOS has been measured and detected in human blood samples of the general population with mean levels of 30-53 μg/L (ppb) reported for sera from blood banks. In individual serum samples obtained from adults and children in various regions of the U.S., the mean level of PFOS was approximately 43 ppb. There is a statistically significant association between PFOS exposure and bladder cancer and there appears to be an increased risk of episodes for neoplasms of the male reproductive system, the overall category of cancers and benign growths, and neoplasms of the gastrointestinal tract (OECD, 2002).

PFOS levels in the general public have also been measured in Europe; samples of sera were taken from blood banks in Belgium, the Netherlands and Germany. Of these sample groups, the highest PFOS levels were observed in sera from the Netherlands (a mean value of 53 ppb) and the lowest in serum from Belgium (a mean value of 17 ppb) (OECD, 2002). In a study undertaken by the World Wildlife Fund, PFOS and six other perfluorinated chemicals were found in the blood samples of forty three people from various EU Member States (including the new EU countries) (WWF, 2004).

Recent reports provide evidence of PFOS production during wastewater treatment (Boulanger et al., 2005; Schultz et al., 2006; Sinclair and Kannan, 2006) and there is some speculation that PFOS may possibly be created during percolation in soil via the breakdown of precursor compounds (Murakami et al., 2008a; Murakami et al., 2009). PFOS contamination in ground water near the Tokyo metropolitan area has been attributed to infiltration of wastewater effluent and stormwater runoff, with effluent being the more important source (Murakami et al., 2009). That study also showed that PFOS concentrations in groundwater were similar to or higher than levels detected in municipal wastewater effluent. PFOS was detected in drinking water sources in the United Kingdom (McLaughlin et al., 2009), in Japan (Murakami et al., 2008b; Takagi et al., 2008), in China (Ling Mak et al., 2009), and in the Great Lakes region (Boulanger et al., 2004).

The European Union has regulation of PFOS. In June 2005, Sweden proposed a global ban on PFOS and related substances under the Stockholm Convention on Persistent Organic Pollutants. Previously, both Sweden and Britain filed for national bans on PFOS to the European Commission (EC), and urged the EC to pursue an EU-wide ban. In December 2005, the EC issued a proposal for a Directive to restrict the use of PFOS in carpets, textiles, clothing and other items.

PFOS is indefinitely persistent in the environment. Food, drinking water, outdoor air, indoor air, dust, and food packaging are all implicated as sources of PFOS to people (Renner, 2007) and contaminated food and drinking water are suspected to be the largest contributors (Trudel et al., 2008). When water is a source, blood levels have been found to be approximately 100 times higher than drinking water levels (Johnson, 2009; Post et al., 2009).

The origin of PFOS contamination in Tucson Basin ground water is unknown although it was strongly suspected that municipal wastewater effluent that recharges the local aquifer via the Santa Cruz River is a critical source. Our primary objective was to investigate the presence/fate of PFOS and to identify the source(s) of PFOS contamination to the Tucson Basin. The project yielded PFOS data at critical locations in the City of Tucson service area to establish the most probable source(s) of PFOS contamination (infiltration of municipal wastewater effluent, stormwater runoff, or infiltration of CAP water) among area ground waters. We established the fate of PFOS under highly controlled conditions--through recharge/recovery at the CAVSARP facility (CAP water) and at the Sweetwater Recharge Facilities (secondary effluent). This portion of the project provided preliminary data regarding the fate of PFOS during infiltration/percolation. The City of Tucson provided in-kind support for this project, including access to facilities and assistance with water sample collection.

METHODOLOGY

Sampling Plan. The sampling plan was structured to support hypothesis testing as follows.

> *Hypothesis #1: Municipal wastewater effluent and stormwater runoff are sources of PFOS in ground water in the Tucson Basin*

To understand the contribution of effluent to groundwater concentrations of PFOS, grab and 24-hr composite samples of secondary effluent from the Roger Road Wastewater Treatment Plant (#1, #2 in Table 1) and secondary effluent from the Ina Road Water Pollution Control Facility (#3, #4 in Table 1) were measured for PFOS.

To understand the importance of stormwater runoff as a contributor of PFOS to ground water, stormwater runoff was collected at nine locations (#5 - #13 in Table 1) within the City of Tucson during a summer 2010 monsoon storm event. Sampling was performed during and shortly after a storm that delivered 0.57 inches of rain (city of Tucson Airport, AZMET data) over a 1-hr period mid-day on September 22, 2010.

Four groundwater production wells (City of Tucson service area) located near the Santa Cruz River at distances of 0, 2.6, 3.3, and 13.3 miles downriver (below) from the effluent outfall of the Ina Road Water Pollution Control Facility (Figure 2) were sampled (#14 - #17 in Table 1).

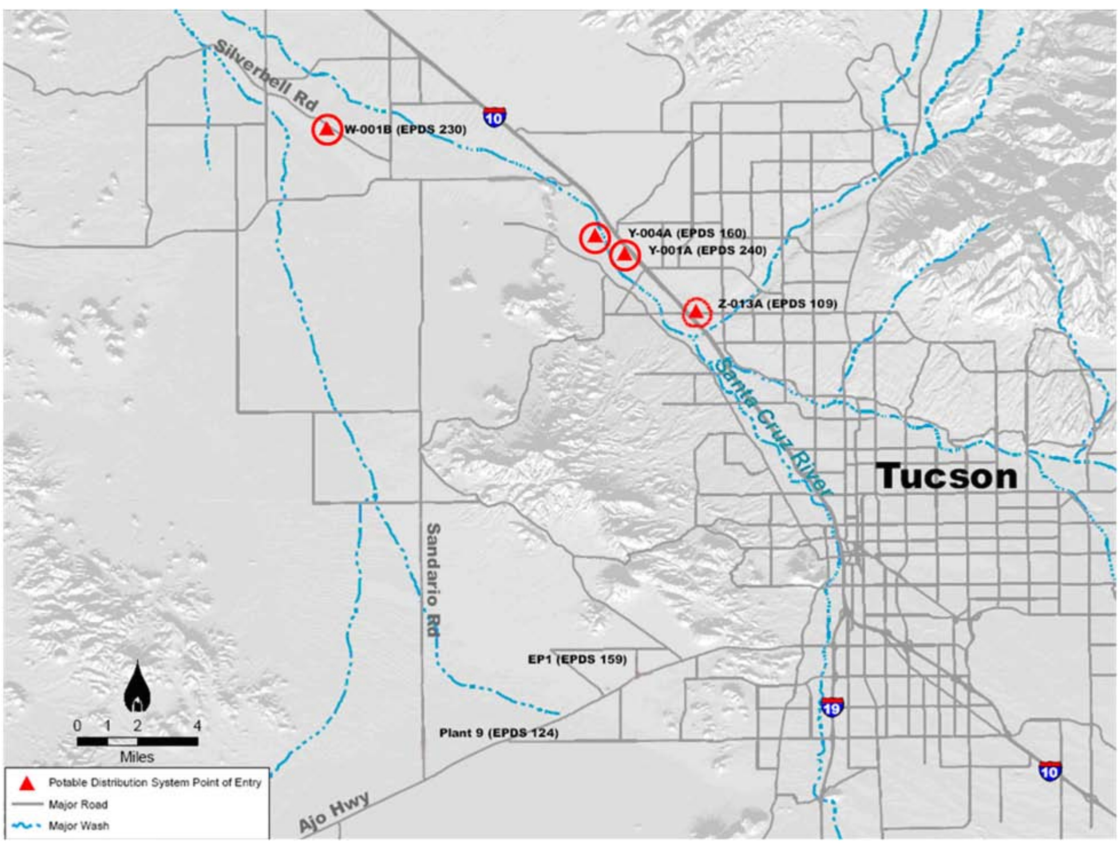

Figure 2. Map showing groundwater well sampling locations (circled triangles) along the Santa Cruz River northwest of the City of Tucson, Arizona.

Hypothesis #2: PFOS is not attenuated during percolation of municipal wastewater effluent/CAP water in unsaturated basin fill sediments.

Raw CAP water (#18 in Table 1) and monitoring wells at depths of 400 and 1000 feet below land surface (#19, #20 in Table 1) were sampled at the CAVSARP facility to test Hypothesis #2 related to attenuation of PFOS during percolation of CAP water. Finished production drinking water produced by the Hayden-Udall Water Treatment Plant (#21 in Table 1) was also sampled.

Secondary effluent (#22 in Table 1) collected at Recharge Basin No. 1 and monitoring wells at depths of 15 and 130 ft below land surface (#23, #24 in Table 1) were sampled at the Sweetwater Recharge Facilities to assess if PFOS is attenuated during percolation of municipal wastewater effluent in unsaturated sediments. Duplicate 1-L samples were collected and the sampling was staggered over a two-week period according to known hydrology of the basin to follow the same "packet" of water during percolation.

In total, there were 24 sampling locations for PFOS determination (Table 1). Laboratory and field blanks were used, and samples were analyzed in triplicate. Extraction/analysis of samples was performed at the Arizona Laboratory for Emerging Contaminants (ALEC) using methods described below.

Table 1. Sampling locations for PFOS determinations.

Sample	Location description (details)	Abbrev.	Type	Hypoth.
1	Roger Road secondary effluent (grab)	RR-grab	WWTP	1
2	Roger Road secondary effluent (composite)	RR-comp.	WWTP	1
3	Ina Road secondary effluent (grab)	IR-grab	WWTP	1
4	Ina Road secondary effluent (composite)	IR-comp.	WWTP	1
5	Storm runoff (CE bldg. roof)	St-CE roof	StW	1
6	Storm runoff (2nd and Mountain, 12:00)	St.-2nd 12:00	StW	1
7	Storm runoff (2nd and Mountain, 12:20)	St.-2nd 12:20	StW	1
8	Storm runoff (2nd and Mountain, 12:40)	St.-2nd 12:40	StW	1
9	Storm runoff (4th and Park)	St.-4th Park	StW	1
10	Storm runoff (parking lot, 6th and Campbell)	St.-6th Camp.	StW	1
11	Storm runoff (parking lot, 6th and Highland)	St.-6th High.	StW	1
12	Storm runoff (6th and Stone)	St-6th Stone	StW	1
13	Storm runoff (Santa Cruz R. at St. Mary's bridge)	St.-SCR	StW	1
14	production well (Z013)	Well-Z013	GW	1
15	production well (Y001A, 2.6 mi below Ina WWTP)	Well-Y001A	GW	1
16	production well (Y004A, 3.3 mi below Ina WWTP)	Well-Y004A	GW	1
17	production well (W001B, 13.3 mi below Ina WWTP)	Well-W001B	GW	1
18	CAP water (before infiltration)	CAP-raw	SW	2
19	CAVSARP monitoring well (400′ bls)	CAP-400′	GW	2
20	CAVSARP monitoring well (1000′bls)	CAP-1000′	GW	2

21	Hayden Udall polished water (production water)	H-U DW	DW	2
22	Sweetwater Recharge Facility (SRF pond)	SRF pond	WWTP	2
23	Sweetwater Recharge Facility (SRF 15′ bls)	SRF 15bls	GW	2
24	Sweetwater Recharge Facility (SRF 130′ bls)	SRF 130bls	GW	2

WWTP = wastewater treatment plant, DW = drinking water,
GW = groundwater, SW = surface water, StW = stormwater runoff

Analytical Methods

1. Collection

Stormwater Runoff**.** Single stormwater samples were collected discretely shortly after a rain event on September 22, 2010. Runoff flowing along street edges was collected in 1-L amber glass bottles. $^{13}C_6$-PFOS isotopologue was added to the 1-mL extracts as an internal standard prior to UPLC-MSMS analysis.

Sweetwater Recharge Basin. Samples were collected from Sweetwater Recharge Facility Basin RB-1 from three different depths. Collection took place during two weeks in February 2011. Duplicate 1-L samples were collected discretely. Samples were collected from piezometers at increasing depths following recharge. During collection no additional water was added to the basin, and sampling events were staggered according to known hydrology of the basin in an attempt to follow the same “packet” of water. $^{13}C_6$-PFOS internal standard was added after SPE extraction and prior to UPLC-MSMS analysis.

Groundwater Production Wells, CAP, and WWTP Samples**.** Water samples were collected in duplicate from CAVSARP and from wells in Tucson, AZ on Dec 6, 2010 and from the two major wastewater treatment plants (Ina Rd. and Roger Rd., managed by the Pima County Regional Wastewater Reclamation Department) on Jan 4 and 11, 2011, respectively. WWTP samples were collected as both 24 hour composite and discrete (grab). Samples were delivered on ice to the laboratory the same day. No internal standard was used for PFOS quantification in these samples.

2. Filtration. Water samples were collected in muffled (550^{o} C) 1-L amber glass bottles and held at 4° C. All samples were filtered immediately upon return to the laboratory. Vacuum filtration was performed using 0.7um glass fiber filters (PALL, VWR, cat. # 28149-456). Filters were muffled at 200°C for 3 hrs prior to use and a minimal amount of filters per sample was used. Sample volumes were recorded.

3. Extraction. Filtered samples were extracted within 24 hours of collection by solid phase extraction (SPE). An automated solid phase extraction instrument (Caliper Life Sciences Autotrace) (Figure 3) was used with a hydrophilic-lipophilic balance sorbent (Oasis HLB, 6 mL, 150 mg Waters Corp, cat. # 186003365) to concentrate the target analyte and remove unwanted sample components (concentration factor = 1000x). Sorbent was conditioned with 5 mL of MeOH, 5 ml of MTBE and 5 ml of ultrapure water prior to use. EDTA (0.5g) was added to each 1-L water sample and allowed to dissolve completely prior to loading onto the SPE sorbent at a rate of 10 mL/min. Sorbent was then dried with N_2 for 40 min, followed by an elution sequence using 3 mL of MeOH, 3 mL of 0.5% NH_4OH in MeOH, 3 mL of acetonitrile, and 3 mL of

MTBE. Eluates were evaporated to 50 µL and resuspended to 1.0 ml in 0.5 mL 50% aqueous methanol for UPLC-MSMS injection. An isotopologue ($^{13}C_6$-PFOS) was added to the 1 mL extracts as an internal standard prior to UPLC-MSMS analysis.

Figure 3. Autotrace solid phase extraction workstation (left) and liquid chromatography tandem mass spectrometer (right). Instruments are located at the UA's Arizona Laboratory for Emerging Contaminants.

<u>4. Liquid Chromatography - Tandem Mass Spectrometry</u>**.** Liquid chromatography was performed using 5-µL sample injections on a Waters Acquity UPLC system (Figure 3) with an Acquity UPLC BEH C18 column (1.7 µm, 2.1 x 50 mm) and a gradient mobile phase of water and acetonitrile for 15 min (with ammonium acetate buffer) at 0.4 mL min^{-1}. PFOS detection was accomplished by negative mode electrospray ionization tandem mass spectrometry. Electrospray ionization and mass spectrometer multiple reaction monitoring detection parameters were optimized as follows: StWR and SRF samples - cone voltage 68 V, capillary voltage 2.95 kV, drying gas 654 L/hr, collision energy 50 V, and collision gas pressure 0.00982 mbar; Well, CAP, and WWTP Samples - cone voltage 49 V, capillary voltage 2.90 kV, drying gas 650 L/hr, collision energy 42 V, and collision gas pressure 0.010 mbar. A multiple reaction monitoring method was used for detection of PFOS at the following transitions: 499.10 > 79.97 for Well, CAP, and WWTP samples, and 498.87 > 80.32 for StWR and SRF samples. $^{13}C_6$-PFOS detection was accomplished using a 502.87 > 80.32 transition. Examples of typical PFOS and $^{13}C_6$-PFOS chromatograms are provided in Figure 4.

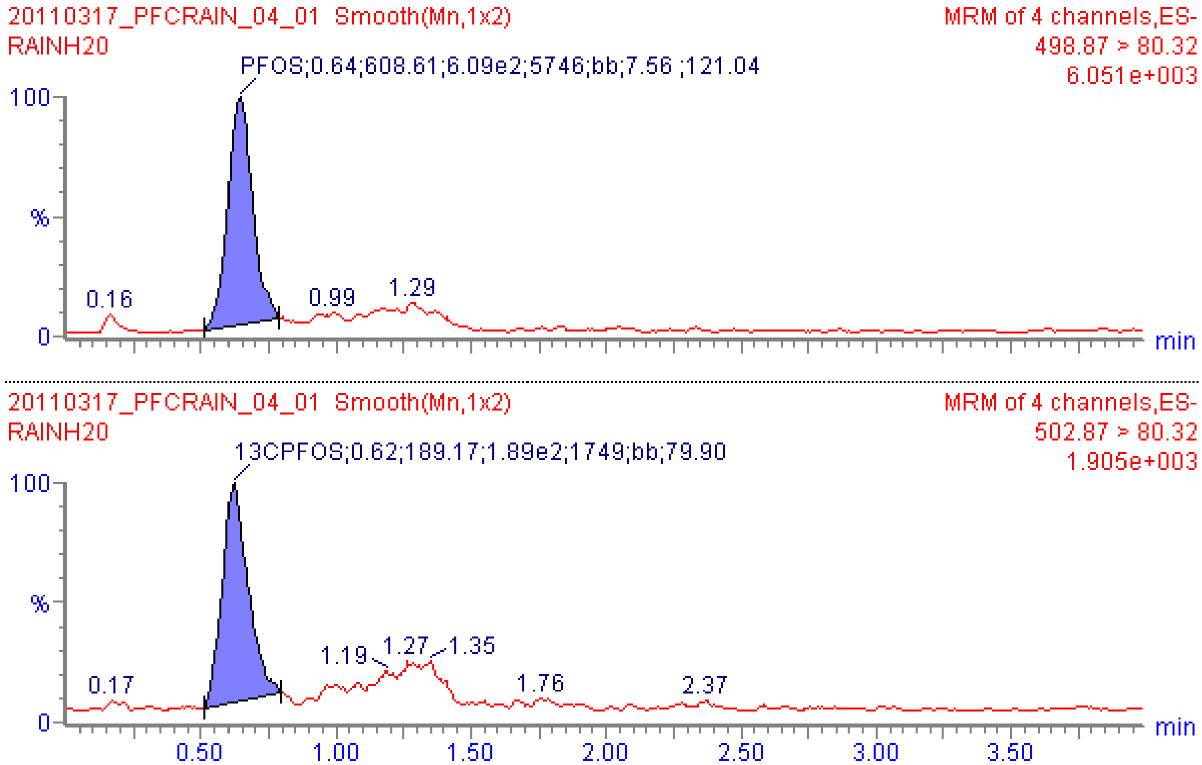

Figure 4. PFOS chromatograms obtained by UPLC-MSMS. Upper chromatogram shows the integrated PFOS peak in a stormwater sample extract. Lower chromatogram shows the integrated peak for $^{13}C_6$ labeled-PFOS (internal standard) added to each sample and used to correct PFOS quantification for matrix suppression in UPLC-MSMS.

<u>Quality Control</u>. A calibration curve consisting of at least 7 points was developed for PFOS. All water sample extracts were injected in triplicate. In the case of StWR and SRF samples, the PFOS analyte response was calculated with respect to the corresponding internal standard isotopologue. In the case of Well, CAP, and WWTP samples, duplicate sample collections were made and analyzed. For StWR and SRF samples the method limit of quantitation (MLOQ) was 0.5 ng/L, and the MLOD was 0.1 ng/L. For Well, CAP, and WWTP samples the method limit of quantitation (MLOQ) and the MLOD were both 0.48 ng/L based on sufficient signal-to-noise (9:1 and 3:1, respectively) observed for the peak detected at the lowest concentration calibration standard used. Field blank samples collected during well sampling ranged in concentration from 6.6 to 13.8 ng/L (ppt) PFOS.

The project benefited from synergy with an ongoing Water Research Foundation grant (4269) to the University of Arizona led by Environmental Chemistry Prof. Jonathon Chorover, Co-director of the Arizona Laboratory for Emerging Contaminants (ALEC). Water Research Foundation project 4269, titled “Detection and quantification of EDC/PPCPs in source waters containing dissolved and colloidal organic matter” includes an assessment of EDC/PPCP levels and persistence in potable water sources and treated wastewaters in Tucson and three other U.S. metropolitan locations. Representative EDC/PPCPs, including PFOS, measured in the project are based on a number of criteria that included their widespread presence in waters impacted by the disposal of treated wastewater and reported detection limits (relative to expected levels in municipal wastewater).

The City of Tucson provided in kind support to the project, including assistance with sample collection at City-owned facilities. Gratitude is expressed to Danial Quintanar and John Kmiec (Tucson Water) for their valuable assistance to this project. In addition, the City of Tucson has an ongoing contract with a private analytical laboratory that provides for testing of perfluoronated compounds as part of their microconstituent testing program.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Assessment of Secondary effluent and Stormwater Runoff as Contributors of PFOS in the Tucson Aquifer. PFOS was detected in all secondary effluent samples analyzed (Figure 5); concentrations in secondary effluent from the Roger Road WWTP (trickling filter process) were about 70 ng/L, approximately 7x greater than in effluent produced by the Ina Road WWTP (activated sludge process). At both WWTPs, there was little difference in results from grab versus 24-hr composite samples, suggesting that temporal composite sampling is not necessary to obtain representative PFOS measurements in secondary effluent. Assessment of the fate of PFOS during wastewater treatment was beyond the scope of this project but previous work has indicated PFOS is not attenuated during wastewater treatment and some have even suggested the possibility of PFOS production via breakdown of precursor perfluorinated compounds (Boulanger et al., 2005; Schultz et al., 2006; Sinclair and Kannan, 2006). Thus, we suspect that there is a much greater PFOS loading in the wastewater delivered to the Roger Road plant, perhaps due to an unknown point source.

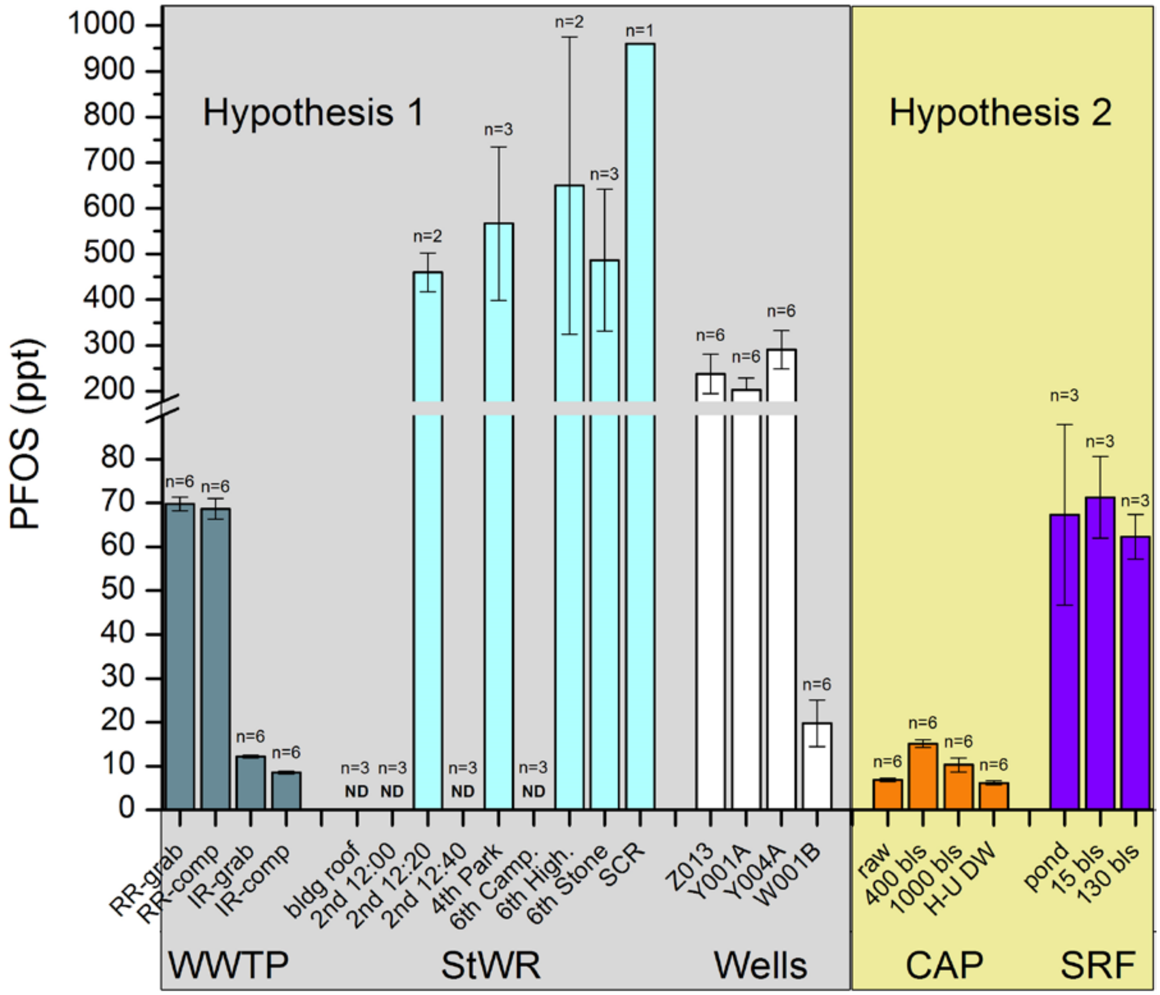

Figure 5. Mean PFOS concentrations, ng/L (ppt), in water samples obtained during this project. WWTP = wastewater treatment plant, StWR = stormwater, Wells = Tucson production wells, CAP = Central Avra Valley Storage and Replenishment Project infiltration site, SRF = Sweetwater Recharge Facility infiltration site. The number of measurements is indicated above each bar. Error bars represent ± one standard deviation. ND = nondetected.

PFOS was detected in the majority of stormwater runoff samples, albeit at widely ranging concentrations. A series of three runoff samples collected over a 40-minute period from the same location on 2nd Street at the UA campus showed PFOS levels ranging from nondetect (ND) to 460 ng/L. Runoff obtained along 6th street from campus going westward towards the Santa Cruz River ranged from ND to 960 ng/L PFOS in the Santa Cruz River at St. Mary's Road (highest value obtained during the project). It is not possible to assess temporal and spatial distribution of PFOS loading in stormwater runoff based on this preliminary work. Future efforts should be conducted with consideration of runoff hydrographs at specific sampling sites. The presence of PFOS in secondary effluent and in the majority of stormwater runoff samples, including from the Santa Cruz River, confirm Hypothesis #1 that both sources contribute PFOS to the region of the Tucson aquifer impacted by recharge from the Santa Cruz River.

All four of the City of Tucson production wells sampled during the project showed presence of PFOS. PFOS levels in three of the wells (≥ 200ng/L) were higher than observed in the secondary effluent samples. Given that these production wells extract a combination of native ground water along with a fraction of water originating from recharge along the Santa Cruz River, it was anticipated that PFOS concentrations in the wells would be lower than in effluent. In this study, PFOS concentrations in ground water (three wells downstream from the WWTPs, along the Santa Cruz River) were higher than in contemporaneous effluent. Similar findings were reported in Tokyo, Japan by Murakami et al. (2009). Possible explanations for this result could include: 1) PFOS concentrations in recharged effluent were higher in the past than at the present time 2) production of PFOS in the vadose zone/aquifer by biodegradation of perfluoronated precursor compounds, and/or 3) PFOS contamination of well water due to PFOS-containing materials in the well and/or pump that came in contact with the recovered water. PFOS was also detected in all three field blank samples collected during the well sampling, ranging in concentration from 6.6 to 13.8 ng/L. Possible sources of field blank contamination may have included lab instrument, water facility plumbing or some other source.

Fate of PFOS during percolation of CAP Water and Secondary Effluent:
PFOS was detected in all CAP and SRF samples collected during the project. Results from both infiltration sites indicate PFOS was not attenuated during percolation through unconsolidated sediment, supporting Hypothesis #2. Mean PFOS concentrations in ponded CAP water, 400 ft BLS, and 1000 ft BLS were 7, 14, and 10 ng/L, respectively (Figure 5). Similarly, PFOS concentrations were little changed during percolation of secondary effluent through 130 feet of unconsolidated sediment at the Sweetwater Recharge Facilities. Mean PFOS concentrations in the pond, perched water (15 ft BLS), and in ground water (130 ft BLS) at the SRF were 67, 71, and 62 ng/L, respectively (Figure 5).

Summary of Findings:
This project investigated the presence of PFOS in secondary effluent and in stormwater runoff that are discharged to the Santa Cruz River in the City of Tucson. The study also examined the fate of PFOS during soil percolation. PFOS was measured using ultra-performance liquid chromatography with tandem mass spectroscopy at the Arizona Laboratory for Emerging Contaminants located on the University of Arizona Campus. Secondary effluent and stormwater runoff both contained PFOS, with concentrations ranging from 10 to almost 1,000 parts per trillion. Thus, both sources are contributors to the PFOS levels found in ground water in the region of the Tucson aquifer impacted by recharge along the Santa Cruz River. It should be noted that there remains the possibility of other sources of PFOS to the Tucson aquifer. Landfills, feedlots and dairies, agricultural fields, septic systems, etc. that are located near the Santa Cruz River could be contributing sources. It was beyond the scope of this study to examine these other possible PFOS sources.

This study also found that PFOS is not attenuated during percolation through soil; PFOS levels were essentially unchanged during percolation of secondary effluent through 130 ft of unconsolidated sediment. The project was designed as an initial step to identify major source(s) of PFOS in ground water in the Tucson Basin and confirmed that secondary effluent and stormwater runoff play a role; future work is needed to determine the relative importance of these sources and of perhaps other as yet unknown contributors of PFOS to the Tucson aquifer.

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Biochar soil amendments to increase the water holding capacity of sandy, arid soils

Basic Information

Title:	Biochar soil amendments to increase the water holding capacity of sandy, arid soils
Project Number:	2010AZ389B
Start Date:	4/1/2010
End Date:	3/31/2011
Funding Source:	104B
Congressional District:	8
Research Category:	Climate and Hydrologic Processes
Focus Category:	Agriculture, Conservation, Water Use
Descriptors:	None
Principal Investigators:	Janick Artiola

Publications

There are no publications.

PROBLEM AND RESEARCH OBJECTIVES

Agriculture in Arizona accounts for about 70% of the total State's water use. In addition, flood and furrow irrigation, known to have poor (<50%) irrigation efficiencies, are the primary methods of water delivery to Arizona crops. Sandy soils, such as those present in Red Rock and the Yuma valley do not retain water efficiently and require more irrigations than loamy Arizona soils, to maintain adequate water supplies to crops during the growth season.

Agricultural soils in AZ usually contain less than 1% total organic carbon (TOC), but are usually rich in carbonate minerals. A study by Artiola and Pepper (1992) measured the TOC of an agricultural field that had received ten consecutive yearly applications of eight dry mT ofbiosolids.ha_{-1}. They found no significant change in the TOC content in the top 1.5 m of the soil. This is because the carbon mineralization rates are very high (>70% annually), precluding significant organic carbon accumulations in soils even from repeated biosolids applications.

Biochar, also known as charcoal or black carbon, is produced by pyrolysis (oxygen-limited combustion) of biofuels such as agricultural residues. Research has demonstrated that the highly porous nature of biochar materials allows then to act as sponges and modify the soil texture, thereby increasing soil water holding capacities. These effects (that need to be quantified and studied further) are likely to be maximized in light-textured sandy soils. The beneficial effects of biochar-amended soils may extend many years due to the refractory (chemically and biologically stable) nature of this carbon form with estimated half-lives in the soil environment ranging from 100-1000s of years. Therefore, these and other benefits (CO_2 emissions reductions, carbon storage, and energy production) may make these materials ideal soil amendments.

We determined how the addition of biochar, derived from various Arizona biochar (derived from AZ forest pine wood residues) affects some physical properties of a loamy sand, semi-arid alkaline soil. The ability of soils to retain water is linked to their texture and organic matter content. We looked at changes in soil water holding capacities with varying biochar loading rates of biochar, using laboratory and greenhouse studies. We also measured the effects of biochar additions to a light-textured, alkaline soil with changes in the biomass production of two plants and plant survival rates under induced water stress.

METHODOLOGY

Arizona pine forest waste woodchips, obtained from the Forest Service via Arizona Power Service (APS), were used to produce biochar using a 50,000BTU wood gas stove. Biochar was produced using slow pyrolysis (batch mode) with a biochar internal temperature of 450-500 ^{o}C and a yield of about 20% by mass. Two greenhouse (GH) studies were undertaken to test the viability of biochar as a soil amendment in AZ soils that are typically alkaline, moderate to high pH, and well-drained. A well-characterized loamy sand soil from the Red Rock (RR), AZ, Agricultural Experiment Station was selected. The GH experiments were conducted using 3-gallon pots with 8 replications and a randomized block design using drip irrigation. Two plants were selected, romaine lettuce, a C3 (cool season) vegetable, and Bermuda grass a C4 (warm season) grass. Given the low particle bulk density of PFW biochar, measured at 0.22 g per cubic cm, two application rates were selected: 2% and 4% by weight biochar to RR soil – being equivalent to 40 and 80 tons of biochar per hectare (to a 15cm depth), respectively.

Lettuce results: No significant differences in germination rates were observed in any of the treatments or control, all exhibiting a 95% success. However, during the first month of growth biochar treated lettuce pots displayed significant stunted growth, particularly in the 4% treatment pots (compared to controls), but plant in the biochar treatments began to recover during the

second month. All plants where harvested after 2.5 months of growth and fresh weight plant matter yields were measured. An ANOVA analysis (n=8) of the data ranked (at the 95%CI) the 2% biochar higher than the control and significantly higher than the 4% biochar treated soil. At the 99%CI the 2% biochar treatment was only marginally higher than the control.
Bermuda grass results: Germination proceeded normally in all pots. Clippings were collected from pots, as soon growth exceeded 2.5-3", once a week for two months. Statistical analysis of dry biomass again placed the 2% biochar treatment above the other two treatments at the 95%CI, but not at the 99%CI. Pots were water –stressed for one month and grass clippings were collected every week for 4 weeks. Biomass dry weight yields increased as a function of biochar treatment, these being significantly higher above the control at the 99%CI at the 4% and 2% biochar application rates. During this period the grass in the control pots died or went dormant after 14-16 days. Seven days later most of the grass in 2% biochar pots had similar symptoms. And about 6 days later most of the 4% biochar pots looked gray and showed no growth. Irrigation was restarted but after two weeks none of the control pots showed signs of life, about 50% for 2% pots had marginal/spotty growth (in the form of runners) and all of the 4% biochar pots showed growth considered normal, having recovered from the water stress period with no apparent ill effects.

PRINCIPLE FINDINGS AND SIGNIFICANCE

This study demonstrated that biochar can be produced from forest and woodland pine forest waste, produced in large quantities (more than 4 million tons per year in AZ) from normal silvicultural practices and drought-related changes AZ forests. Pine forest waste biochar is relatively low in alkalinity (~1-5%), a desired trait for AZ soils, and has an extreme porosity (measured at ~86%). Pine forest waste biochar can sorb twice its weight in water under field conditions. A water stress test on Bermuda grass suggests that biochar-amended soils may prevent severe damage to turf grass, extending its survivability for up to two weeks. Greenhouse growth experiments have also shown benefits in the form of increased biomass production may be had when Bermuda grass is planted in a light sandy soil amended with 2% biochar.
Romaine lettuce, which is sensitive to soil salinity changes, benefited from biochar applications at the 2% rate compared to the control. But we observed stunted plant growth at the 4% biochar rate. Although eluent salinity did not change significantly across treatments, there was a measurable increase in the eluent pH of pots with biochar amendments (up to 0.3 units), perhaps affecting plant growth at the early stages, despite normal germination rates. Preliminary observations on an ongoing greenhouse study using the same pots reseeded with lettuce, suggest that poor plant growth responses, observed in the first study, may be temporary. As the biochar "ages" in the soil, the equilibration of alkaline species with carbon dioxide lowers its solution pH (after several wet/dry/leaching cycles). In this second trial we observed again, no changes in germination rates (~95% across all treatments), and very similar plant growth rates in all the pots, including those amended with 4% biochar. After harvest a statistical analysis of the plant biomass ranked the 4% and 2% biochar treatment significantly higher (@99% C.I.) than the control.
We can cautiously conclude that the addition of PFW biochar to sandy, alkaline soils may require a period of "aging" before pH-salinity sensitive vegetables like lettuce can benefit. Conversely, warm season grasses, and possibly other species tolerant to extreme pH-salinity soil conditions, may adapt quickly to a soil amended with PFW biochar, becoming more drought-resistant.

Bioremediation of Uranium Plumes with Nano-Scale Zero Valent Iron

Basic Information

Title:	Bioremediation of Uranium Plumes with Nano-Scale Zero Valent Iron
Project Number:	2010AZ395B
Start Date:	3/1/2010
End Date:	2/28/2011
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Congressional District:	07
Research Category:	Engineering
Focus Category:	Toxic Substances, Groundwater, Treatment
Descriptors:	Uranium, Groundwater, Bioremediation, Microbial Reduction, Nano Zero-Valent Iron
Principal Investigators:	James Field, Reyes Sierra

Publication

1. Aida Tapia-Rodriguez, 2011, Anaerobic Bioremediation of Hexavalent Uranium in Groundwater, Department of Chemical and Environmental Engineering, The University of Arizona, PhD dissertation.

PROBLEM AND RESEARCH OBJECTIVES

Uranium is an important environmental contaminant impacting groundwater supplies in Arizona. The main sources are from uranium mine tailings, former uranium processing plants, and high natural background levels in areas of granite bedrock [1]. In the environment, uranium generally occurs as hexavalent uranium (U(VI)) or tetravalent uranium (U(IV), often present as the mineral uraninite, UO_2). While U(VI) is soluble and mobile, U(IV) is highly insoluble and immobile [2]. Therefore, reductive precipitation is an attractive approach to remove soluble uranium and remediate contaminated groundwater [3]. Reduction of soluble U(VI) can be catalyzed by chemical and by microbial processes involving anaerobic bacteria [4-6]. Typically organic substrates (e.g. ethanol, lactate, acetate) are utilized as the electron donors to drive biological uranium reduction [7].

$$\underset{\textbf{Soluble}}{\mathbf{U^{(VI)}O_2^{2+}}} \xrightarrow{\textbf{Microbial Reduction}} \underset{\textbf{Insoluble}}{\mathbf{U^{IV}O_2}\downarrow}$$

Several studies have proven that zero-valent iron (ZVI, Fe^0) is an effective reactive material for the immobilization of U(VI) [8]. ZVI is most commonly applied in permeable reactive barriers [9]. The removal of U(VI) by these methods has been found to be mainly due to reductive precipitation [10-11], although co-precipitation with iron corrosion products has been also found to be an important mechanism in some of the studies [12]. However, the kinetic limitations of the chemical reductive precipitation are a constraint to these methods [13]. While ZVI is a well-known source for electron equivalents for many microorganisms in the environment [14-15], its use by uranium-reducing microorganisms has not been defined.

Preliminary work by our research group has led to the enrichment of a novel uranium-reducing bacterial culture that is capable of utilizing ZVI as an electron donor [16]. The microbial culture greatly accelerates uranium reduction rates with ZVI by more than 20-fold in a sustained fashion. ZVI has some important advantages over alternative bioremediation strategies relying on organic electron donors. The ZVI could provide a long-term reservoir of slow-release electron equivalents as well as buffer against uranium re-oxidation.

OBJECTIVES

The objective of this study is to investigate the use of nano-sized ZVI (nZVI) as an electron donor for uranium-reducing microorganisms. Stabilized dispersions of nZVI can be transported through porous media to facilitate in situ bioremediation of uranium-contaminated groundwater. This project is expected to lead to the development of a low-cost and low-maintenance method for the in situ bioremediation of groundwater contaminated by uranium, which generates insoluble uranium minerals that are stable against re-oxidation over prolonged time periods. Application of this technique could be expanded to the treatment of other toxic contaminants amenable to microbial reductive processes (e.g., perchlorate, arsenate, oxidized radionuclides).

METHODOLOGY

Source of inoculum. Inoculum for the experiments were obtained from enrichment cultures developed from the effluent of a continuous ZVI/sand packed column that reduced U(VI) with ZVI as electron donor [16]. A 16S-rRNA bacterial clone library performed prior on this enrichment culture proved that it was composed of two major bacterial genera (*Dechloromonas* and *Stenotrophomonas*, publication in progress); due to this reason, the inoculum is referred to as a bacterial co-culture.

Basal media. The mineral media used in the batch experiments was adapted from previous works [16]. The composition of the media was the following (in mg L^{-1}): NH_4HCO_3 (5.0), K_2HPO_4 (2.0), $Ca(OH)_2$ (1.0), yeast extract (1.67) and $MgCl_2 \cdot 7H_2O$ (41.0). The concentration of the trace element solution was (in mg L^{-1}): H_3BO_3 (0.01), $FeSO_4 \cdot 7H_2O$ (0.56), $Na_2WO_4 \cdot H_2O$ (0.10), $ZnSO_4 \cdot 7H_2O$ (0.02), $MnSO_4 \cdot 7H_2O$ (0.08), EDTA (0.20), $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ (0.04), $AlK(SO_4)_2 \cdot 12H_2O$ (0.04), $NiSO_4 \cdot 6H_2O$ (0.02), $CoSO_4 \cdot 7H_2O$ (0.47), $Na_2SeO_3 \cdot 5H_2O$ (0.02), $CuSO_4 \cdot 5H_2O$ (0.03), and resazurin (0.04). After adjusting to a pH value of 7.5, the media was sterilized in an autoclave (Yamato Scientific America Inc., Santa Clara, CA) at 120°C for 20 min. After cooling down, it was amended with a filter-sterilized $NaHCO_3$ solution to a final concentration of 1.0 g L^{-1}.

Batch experiments. All batch microcosms were performed in 160-mL sterilized serum bottles (Wheaton, Millville, NJ), consisting in 100 mL of basal media and 60 mL of headspace. These consisted in treatments with 1 mM of ZVI (either micron-sized or nano-sized ZVI, depending on the conditions tested) and aliquots from a 10 mM stock solution to get final concentration of 30.0 μM U(VI). Anaerobic conditioning of the headspace was carried out by flushing a N_2/CO_2 gas mixture as described previously [6]. For biological treatments or controls, aliquots corresponding to 5% v/v of planktonic inoculum from an active treatment were added to each bottle inside an anaerobic glove box (COY Laboratory Products Inc., Grass Lake, MI) after the anaerobic flushing. Finally, the headspace was re-conditioned with N_2/CO_2 gas mixture at the end of the inoculum addition to replenish anoxic conditions. Controls consisting in non-inoculated, ZVI-only, as well as inoculum only (endogenous control) were set-up for each transfer. All treatments and controls were carried out in duplicated replicates, and incubated statically in the dark at 30°C. Soluble U was measured over time during the whole experiment. For biological experiments with polyethylenimine (PEI) as dispersant for nZVI, aliquots from a 400 mg L^{-1} PEI stock solution were added to the media prior to sterilization for a final concentration of 11.2 mg L^{-1} (ratio nZVI/PEI of 5:1).

Soluble U(VI) analysis. Liquid samples were taken into Eppendorf ™ centrifuge tubes, being then centrifuged at 10,000 rpm (RCF of 10,621 x g) for 10 min. After transferring the supernatant to a 3% HNO_3 solution, soluble U was measured by using an Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES) system model Optima 2100 DV from Perkin-Elmer™ (Shelton, CT, USA) at a wavelength of 385.958 nm. This technique is based on the electromagnetic radiation emission or absorption by an ion in solution. Since U(VI) is being consumed through redox transformation to an insoluble specie U(IV), the reduction process was monitored by measuring the intensity of the remaining soluble uranium. The detection limit for U was 10 μg L^{-1}.

Dispersions preparation. For the particle size distribution (PSD) determinations, nanoparticle dispersions of nZVI were prepared both in MilliQ water and in the biological media used in the bioassays. Polyethylenimine (PEI) and polyacrylic acid

(PAA) were tested as dispersants for the nanoparticles. The following dispersions were prepared: nZVI with MilliQ water, nZVI with water and PEI, nZVI with water and PAA, nZVI with medium, nZVI with medium and PEI, and nZVI with medium and PAA. For this purpose, a 1000 mg L^{-1} nZVI stock solution was prepared at pH 7.2, and then the solution was sonicated for 5 min at 70% of amplitude in an ultrasonic processor. Also, 400 mg L^{-1} PEI and PAA stock solution was used. The final concentrations of nanoparticles and dispersant were 100 and 20 mg L^{-1}, respectively.

PSD determination. The particle size distribution of the nanoparticle dispersions was measured by dynamic light scattering (DLS) using Zeta Sizer Nano ZS instrument (Malvern, Inc., Sirouthborough, MA). PSD measurements were performed using the same instrument. DLS analyzes the velocity distribution of particle movement by measuring dynamic fluctuations of light scattering intensity caused by the Brownian motion of the particle. The technique yields a hydrodynamic diameter that is calculated via the Stokes-Einstein equation from the aforementioned measurements. The unit employs a 4mW He-Ne laser with a wavelength of 633 nm, and a measurement angle of 173°.

pH. Measurements were performed in a VWR SympHony SB20 electrode as indicated by Standard Methods [17].

Chemicals. Uranium (VI) was purchased in form of uranyl chloride trihydrate ($UO_2Cl_2 \cdot 3H_2O$) from International Bio-Analytical Industries Inc. (Boca Raton, FL). Nano-sized ZVI (Fe^0, 40-60 nm, 99.9% purity) was purchased from SkySpring Inc (Houston, TX, USA). Polyethylenimine (PEI, branched, $H(NHCH_2CH_2)_nNH_2$) and ZVI powder (Fe^0, <10 μm, 99.9+% purity) were purchased from Sigma Aldrich Co. (St. Louis, MO). Poly(acrylic) acid powder (MW ~1800) was purchased from Sigma Aldrich (St Louis, MO). Ammonium bicarbonate (NH_4HCO_3, 21.30-21.73% as NH_4^+), sodium hydroxide (NaOH), methylene blue ($C_{16}H_{18}ClN_3S \cdot 3H_2O$) and nitric acid ($HNO_3$, 70%) were supplied by Fisher Chemical (Fair Lawn, NJ). Magnesium sulfate ($MgSO_4 \cdot 7H_2O$), calcium hydroxide ($Ca(OH)_2$), potassium phosphate dibasic (K_2HPO_4, >99.0%) and potassium nitrate (KNO_3, 99.0%), were purchased from J.T. Baker (Phillipsburg, NJ). Yeast extract was supplied from BD (Sparks, MD). Sodium bicarbonate was obtained from Pfaltz & Bauer (Waterbury, CT).

PRINCIPLE FINDINGS AND SIGNIFICANCE

1. Evidence of biological enhancement of U(VI) reduction with ZVI

Preliminary experiments were carried out to evaluate the capacity of the microbial co-culture to accelerate the reduction of U(VI) with ZVI. Figure 1 shows an example of an assay carried out with micron-sized ZVI and U(VI). As can be observed from this plot, uranium is more rapidly reduced in the presence of the enrichment co-culture, compared to the abiotic incubation with ZVI. Neither biological controls without electron donor (endogenous) or abiotic controls without ZVI could remove any significant U(VI) during the experimental period. These experiments revealed that there is an enhanced rate of reduction by the incorporation of the enrichment culture over the abiotic rate of uranium reduction.

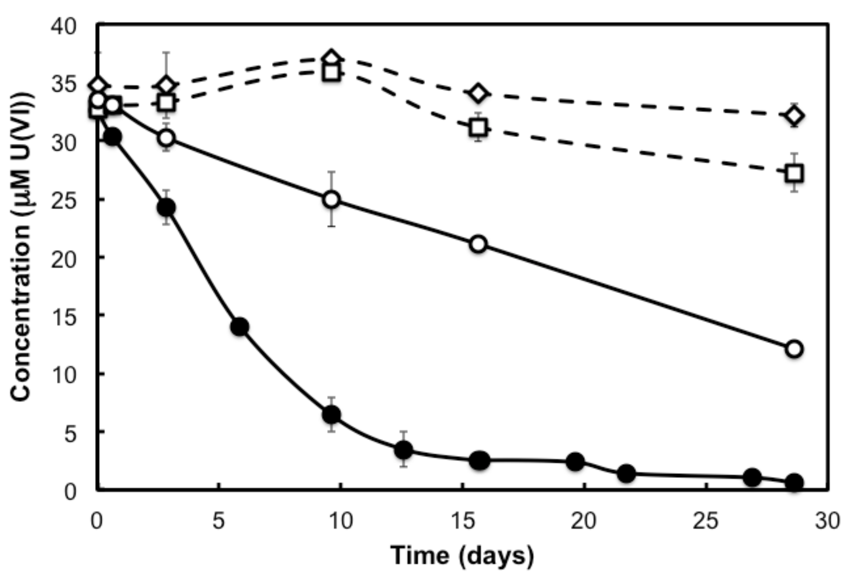

Fig. 1. Removal of soluble U(VI) by the microbial co-culture with ZVI.
Legends: ---◊---, Abiotic, no Fe^0; ---□---, Biological, no Fe^0; —○—, Abiotic with Fe^0; —●—, Biological with Fe^0.

2. Biological enhancement of U(VI) reduction with nano-ZVI

2.1. Comparison of different sources of ZVI

Two experiments were done comparing the effectiveness of micron-sized ZVI in reducing U(VI) versus that of nano-sized ZVI. In the first experiment, thin septa were used to seal the bottles from the atmosphere. The results of this experiment can be found in Figure 2. The thin septa that were used were not sufficient to seal off leaks of gas, and oxygen was able to seep into the bottles. Initially, it can be seen that the U(VI) was reduced in the bottles containing either size of ZVI and in those containing the iron with the enrichment co-culture. However, oxygen leaking into the bottles caused the U(IV) to reoxidize to U(VI), which accounts for the periodic increases in the U(VI) concentration.

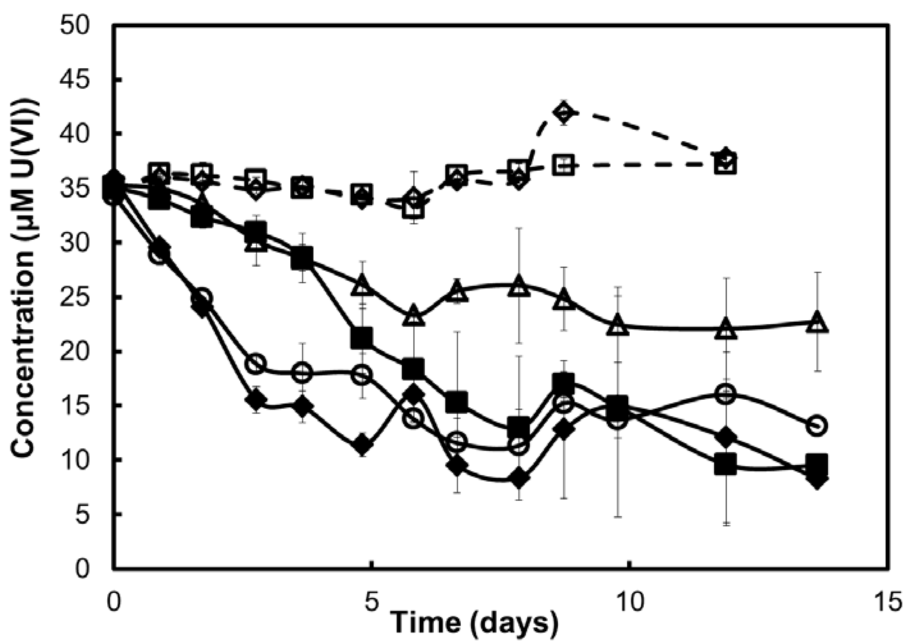

Fig. 2. Removal of soluble U(VI) by the microbial co-culture under uncontrolled atmospheric conditions with micron-ZVI versus nano-ZVI.
Legends: --◊--, Abiotic, no Fe^0; --□--, Biological, no Fe^0; —○—, Abiotic with nZVI; —Δ—, Abiotic + micron-Fe^0, —♦—, Biological + nZVI; —■—, Biological + micron-Fe^0.

In the second experiment, thicker septa were used in order to ensure that conditions within the bottles were kept anaerobic. The results of this experiment can be found in Figure 3. As can be seen in this plot, the removal of U(VI) occurred faster in the bottles containing the enrichment culture and nZVI than in the abiotic bottles containing nZVI. The same effect can be seen when comparing the bottles containing the enrichment culture and micron-sized ZVI to the abiotic bottles containing micron-sized ZVI. This shows an enhancement in U(VI) reduction rate in the presence of co-culture with either type of ZVI. Additionally, there was faster reduction in the abiotic bottles containing nZVI than in the abiotic bottles containing micron-sized ZVI. Removal also occurred faster in those bottles containing the enrichment culture with the nZVI than in those containing the enrichment culture and micron-sized ZVI. However, this increase in uranium removal in the bottles with enrichment culture and nZVI is shown to happen only for the first seven days of the experiment before uranium levels in the bottles containing enrichment culture and micron-sized ZVI became the same as those observed with treatments with nZVI. After this, neither treatment appears to reduce faster than the other. Lastly, the lack of U(VI) removal in the endogenous controls and the abiotic controls without ZVI confirm the results of the inactivity controls as was found in the preliminary experiments.

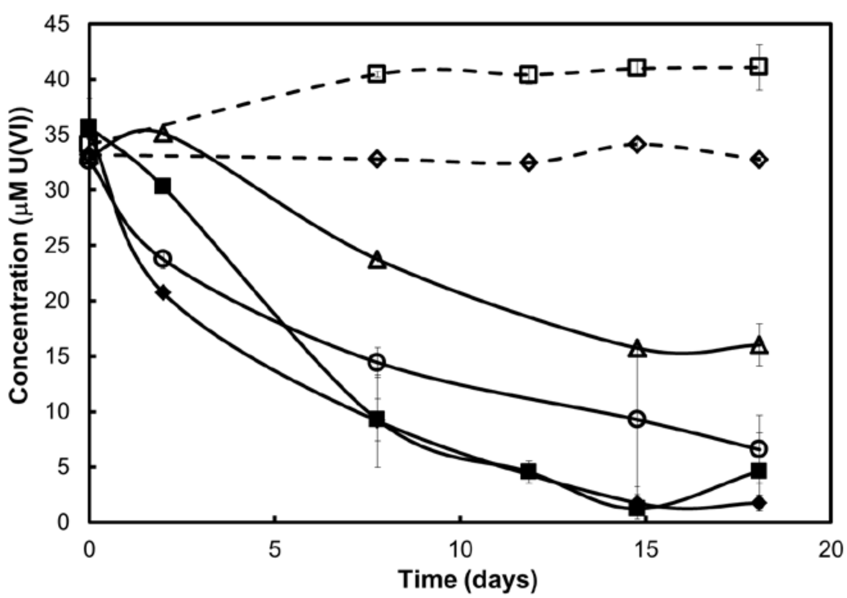

Fig. 3. Removal of soluble U(VI) by the microbial co-culture under anaerobic conditions with micron-ZVI versus n-ZVI.
Legends: ---◊---, Abiotic, no Fe^0; ---□---, Biological, no Fe^0; —○—, Abiotic with nZVI; —Δ—, Abiotic with micron-Fe^0; —♦—, Biological with nZVI; —■—, Biological with micron-Fe^0.

2.2. Characterization of nano-sized ZVI (PSD) and use of dispersants to enhance nZVI dispersion stability

A DLS test was carried out to determine the PSD of nZVI in MilliQ water and in the normal basal medium used in the bioassays. Table 1 summarizes the particle size values at the different conditions tested. The average PSD of nZVI provided by the manufacturer ranges from 40-60 nm. DLS measurements revealed that particles aggregate in water (pH 7.4) as well as in the medium (pH 8.7) used in bioassays. Polymeric surfactants may be used to modify the surfaces of the nanoparticules in order to counteract the aggregation tendency by the normal van der Waals forces.

In this way, two dispersants were used to improve the stability of nZVI: PEI (cationic) and PAA (anionic), either with water or the basal medium from bioassays. The plot displayed in Figure 4 shows the differences in PSD obtained in mineral medium, based on the mean intensity.

Table 1. Average particle size (hydrodynamic diameter) of nZVI in water and biological medium in the presence and absence of dispersant addition.

	Diameter (nm)	
Conditions tested	**Average**	**Std Dev**
Water	829	±130
Water-PEI	1295	±267
Water-PAA	1317	±267
Medium	1383	±144
Medium-PEI	1249	±302
Medium-PAA	2803	±1054

From results obtained in these tests with the basal medium, it could be observed that a marginally lower level of aggregation is possible with PEI. In this way, this cationic dispersant may increase the stability of the nZVI at the pH conditions of the biological assays for the treatment of U(VI).

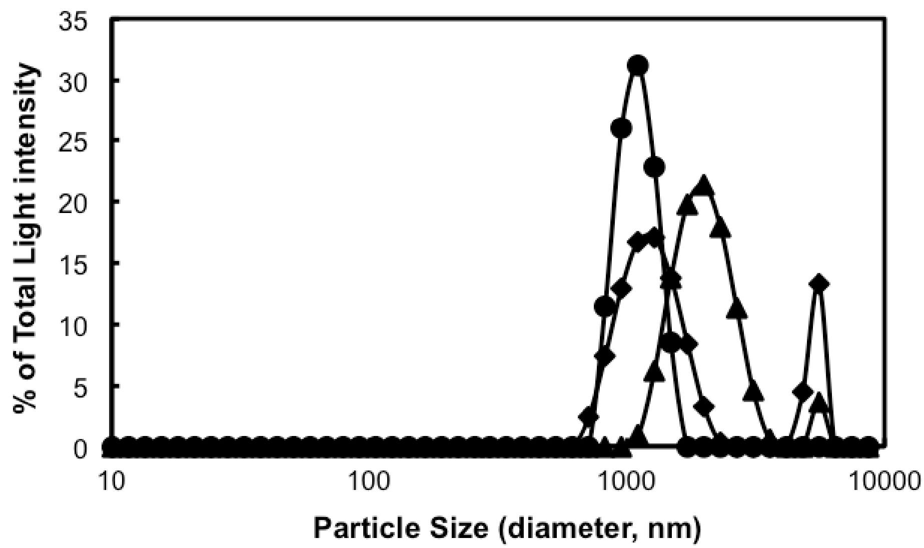

Fig. 4. Comparison of the PSD achieved with different dispersants in media (pH 8.7). Legends: —◆—, ZVI with media only; —●—, ZVI with PEI and media; —▲—, ZVI with PAA and media.

2.3. Use of PEI as dispersant for nZVI

An experiment was conducted to determine if the addition of PEI to the enrichment culture with nZVI enhances the removal capacity of this treatment. The results for those bottles that did not contain PEI can be found in Figure 5, while those for the bottles that did contain PEI are in Figure 6. For those bottles without PEI, there was no removal of U(VI) in the endogenous and abiotic bottles without nZVI. Also, there was an increase in removal in those bottles containing the co-culture and nZVI over those that were abiotic containing nZVI. In the bottles that did contain PEI, however, this increase did not occur. This shows that enhancement due to the presence of co-culture with the nZVI was eliminated by the presence of PEI and that may be due to inhibitory impact of PEI. Also, it can be seen that the initial concentration of U(VI) in the bottles containing the PEI was lower than in those without PEI. This suggests that the PEI interacted with the U(VI) in a way that removed it from solution.

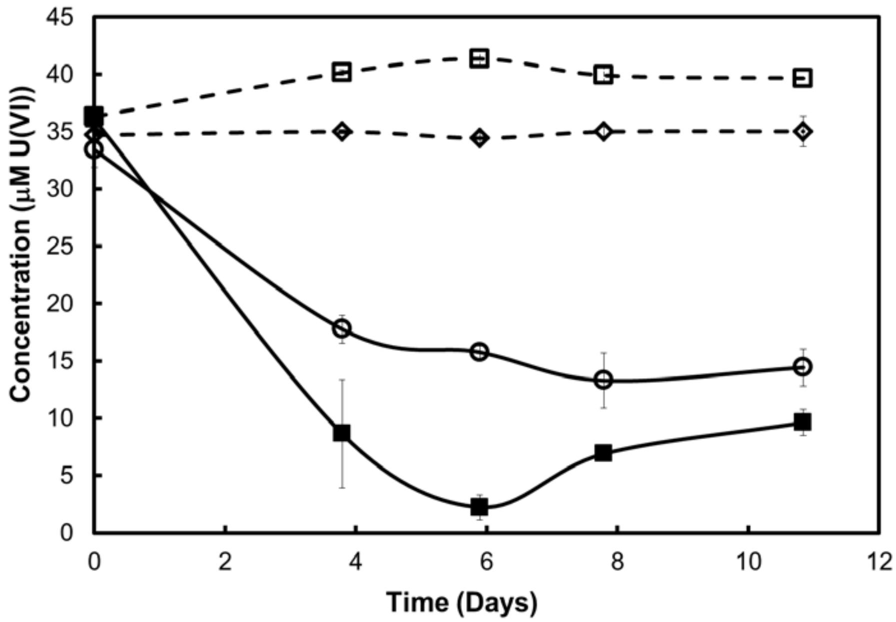

Fig. 5. Removal of soluble U(VI) by the microbial co-culture with nZVI without PEI. Legends: ---◊---, Abiotic, no Fe^0; ---□---, Biological, no Fe^0; —○—, Abiotic with nano-Fe^0; —■—, Biological with nano-Fe^0.

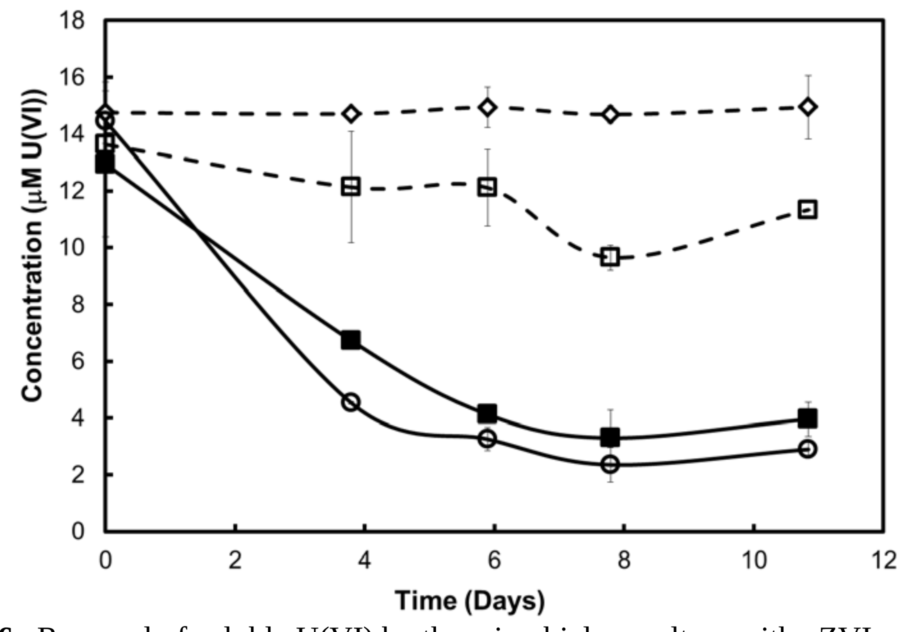

Fig. 6. Removal of soluble U(VI) by the microbial co-culture with nZVI with PEI. Legends: ---◊---, Abiotic with PEI, no Fe^0; ---□---, Biological with PEI, no Fe^0; —○—, Abiotic with nano-Fe^0 and PEI; —■—, Biological with nano-Fe^0 and PEI.

Conclusions

Results demonstrate that microbial co-culture enhanced the uranium reduction over the abiotic rate with ZVI as electron donor. This enhancement can occur whether the ZVI present is micron-sized or nano-sized. Furthermore, improvements in both the biological and abiotic rates of uranium removal rates were observed due to the use of nZVI compared to micron-sized ZVI. The rate improvement is most likely due to an improved surface area of the smaller particle size of nZVI. Polymeric surfactants, such as PEI, may improve the stability of nZVI nanoparticles in aqueous solutions. However, PEI interacts with the soluble uranium in an unknown way that results in the uranium being partially removed from solution. Future work should evaluate alternative dispersing agents which would work better in improving the stability of nZVI in aqueous solutions.

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Sources and transport of nitrogen from sky-island ecosystems to groundwater basins

Basic Information

Title:	Sources and transport of nitrogen from sky-island ecosystems to groundwater basins
Project Number:	2010AZ407B
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End Date:	2/28/2011
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Congressional District:	8
Research Category:	Water Quality
Focus Category:	Water Quality, Nutrients, Hydrogeochemistry
Descriptors:	
Principal Investigators:	Jennifer McIntosh, Kathleen Ann Lohse, Armin Sorooshian

Publications

There are no publications.

Problem and Research Objectives.

Introduction to the Problem - Major uncertainty surrounds the importance and magnitude of nitrogen (N) input into local environments in Arizona. Wet and dry deposition of ammonia, amines, and oxidation products of nitrogen oxides represent major inputs of N onto land, where enhanced rates of nitrogen fixation have been observed as a result of anthropogenic activity, including fossil fuel combustion (e.g. Smil, 1990; Vitousek and Matson, 1993; Ayers et al., 1994; Galloway et al., 1995). Some of the highest levels of N deposition in the western United States (29 kg per ha per year) were reported for desert sites near Phoenix, Arizona (AZ); yet, nitrogen "deposition rates are unknown for most areas in the West" (Fenn et al., 2003), including Tucson, AZ. In addition, high altitude regions and ecosystems, which are common in Arizona, are especially vulnerable to the effects of N deposition. Recent measurements in the Rocky Mountain region indicate that N deposition fluxes have increased nearly 20-fold since pre-industrial times (Galloway et al., 1982, 1995; Hedin et al., 1995; Beem et al., 2009). Nitrogen deposition is intimately linked to regional water quality - an issue that is underappreciated in terms of attention and research in Arizona. In addition to N-species, major uncertainty also surrounds the nature and magnitude of organic carbon (OC) deposition to terrestrial surfaces (Goldstein and Galbally, 2007). While wet deposition of OC (in the form of dissolved organic carbon, DOC) has received attention with regard to quantifying its average global chemical signature and deposition rate (Willey et al., 2000), dry deposition of OC remains even less understood.

Nitrate is one of the most common contaminants degrading water quality world-wide (e.g. WHO, 2006). In Arizona, over 1,000 groundwater wells contain nitrate concentrations above the EPA drinking water standard (10 mg/L NO_3-N). Nitrate contamination is attributed to agricultural activities, feedlots and effluent discharge from wastewater treatment plants and septic systems (Rahman and Uhlman, 2009). Recent studies in the Tucson Basin, using multiple-isotope tracers (^{17}O, ^{18}O, ^{15}N of NO_3), show that atmospheric deposition of N may also be a significant contributor to nitrate contamination to surface and ground water (up to 50%) (Dejwakh, 2008). Extending this study, a new NSF-funded research project (PI Lohse) is currently investigating the importance of atmospheric nitrate deposition on the water quality of storm runoff in urban landscapes (Tucson and Phoenix). At the margins of such basins, the majority of groundwater is derived from recharge in high elevation mountain blocks, which may also receive atmospheric deposition of nitrogen, leading to the question:

What is the contribution of nitrogen and organic carbon from atmospheric deposition in mountain systems surrounding these urban environments that may impact groundwater quality?

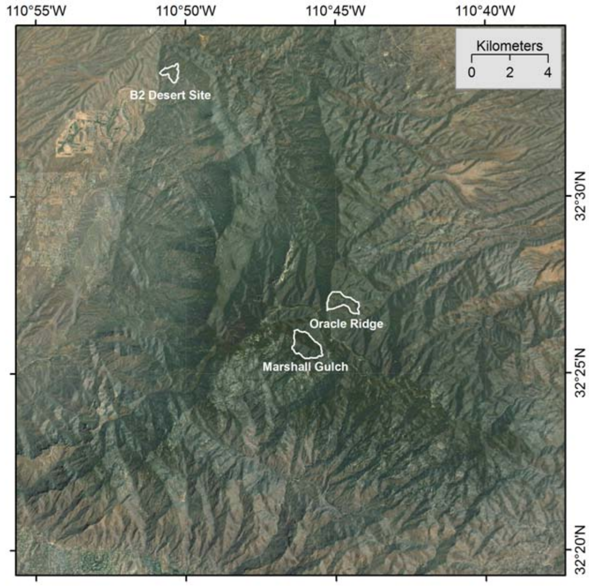


Figure 1: Satellite image of the Santa Catalina Mountains in southeastern Arizona, north of Tucson. This study focused two watersheds (outlined in white) – the Marshall Gulch high elevation site at the top of Mt. Lemmon, and the B2 Desert site near the base of the mountains.

Research Objectives – The primary objective of this project was to determine the amount, sources, and cycling of nitrogen and carbon deposition in the Santa Catalina Mountains in southeastern Arizona, north of Tucson. In addition, we aimed to evaluate how much of the N and C from atmospheric deposition are naturally reacted in soils and/or transported to surface water and groundwater. To meet this objective, we measured N-species composition (NO_3, NO_2, NH_4, amines, organic-N) and dissolved organic carbon (DOC) in atmospheric deposition, soil waters and surface waters at the B2 desert site at the base of the Santa Catalina Mountains, and at the Marshall Gulch and Mt. Bigelow sites at the top of the mountains (Fig. 1). Stable isotopes (^{15}N, ^{18}O, ^{17}O) of wet and dry deposition, soil pore waters, and surface waters are currently being analyzed. Nutrient data was coupled with hydrologic measurements (e.g. amount of precipitation, stream discharge) and catchment characteristics (e.g. soil depth, bedrock lithology) to investigate controls on nutrient dynamics. Specific questions addressed were:

(1) How does bedrock lithology control organic carbon and nitrogen cycling?
(2) How does landscape position effect organic carbon and nitrogen cycling?
(3) What are the amounts, sources, and seasonality of species in atmospheric deposition?
(4) How does variability in precipitation effect organic carbon and nitrogen cycling?

Methodology.

Study Site – The Santa Catalina Mountains are primarily composed of fractured granite with local occurrences of schist and other bedrock types. There is an extreme climate (precipitation and temperature) gradient from Sonoran Desert Scrub at the base (800 m) to Mixed Conifer Forest at the top (2600 m). Most of the precipitation is delivered in the winter as mixed snow and rain, and in the summer as rain from intense monsoon storm events. Infiltration of precipitation into the fractured bedrock migrates downgradient to the adjacent alluvial aquifers, providing an important source of recharge; the amount of N being transported from these mountain systems to groundwater basins is an important endmember that is still yet unknown.

During the timeframe of this project, there were two instrumented hydrologic and biogeochemical research sites established in the Santa Catalina Mountains at different elevations on schist and granite hillslopes: (1) a low elevation (1164 m) site near Biosphere 2; (2) a high elevation (2590 m) site near Summerhaven, AZ, including Marshall Gulch watershed and Mt. Bigelow (Fig. 1). The low and high elevation sites have hydrometeorology stations, stream gauges with autosamplers, automated tipping bucket rain gauges, soil moisture probes, and nested lysimeters to capture variations in soil water chemistry and transit times with hillslope position and depth.

During summer 2010, the B2 Desert site produced very little surface or soil water. The lysimeters were completely dry, and are currently being reinstalled in case the problem was poor installation. Thus, we have focused most of our analyses on data from the high elevation site – Marshall Gulch.

A third mid-elevation site (~2000 m; Oracle Ridge site) was recently (Spring 2011) established on the north side of the Santa Catalina Mountains; this site will have similar instrumentation as the other two sites. We plan to collect soil solution and surface water samples from Oracle Ridge, starting Summer 2011, to better constrain the influence of elevation gradients (e.g. change in temperature, precipitation, vegetation type) on nutrient dynamics.

Procedures and Methods - To distinguish the sources of N in the Santa Catalina Mountains, reaction in soils, and transport to adjacent alluvial basins, we collected and analyzed:

(1) Atmospheric deposition – Aerosol samples were collected at two sites representing the base and summit of the Santa Catalina Mountains. These included a B2 desert site, and the University of Arizona High-Altitude Laboratory (32.26° N, -110.46° W, 2791 m ASL) at the summit of Mt. Lemmon. The sampling systems (installed as part of this project) consisted of an inlet designed to remove contamination from precipitation and large debris. It was determined that precipitation events did not contaminate collected samples. Sampled air containing aerosol particles were passed through a filter sampler (URG), consisting of several sections. The sampled air first travels through a 2.5 μm impactor to remove particles with diameters exceeding 2.5 μm. The air stream is then passed through a series of three denuders to remove inorganic and organic vapors that could bias the aerosol measurements. Aerosol particles were then collected on 47 mm quartz filter fibers (PALL Life Sciences) that were all prebaked and sterilized to remove contaminants prior to sampling. The filter sampler was equipped with a critical orifice to maintain a constant volumetric air flow rate of approximately 16 LPM. A pump downstream of the critical orifice drew vacuum on the sampled air. A total of 8 samples were collected at the mountain-top site and 11 at mountain-base site, spaced between March 2010 and January 2011. Sampling typically lasted for a period of a week to collect sufficient material on the filters for a variety of different types of analyses. Filters were stored in a freezer after collection up until the point of chemical analyses.

The filter extraction procedure consisted of ultrasonication (15 min) of glass vials containing filter punches and 10 mL of 18.2 mega-ohm Milli-Q water. The filter extract liquid was then sent through a syringe filter (Acrodisc filters, 25 μm) to a separate vial. This procedure was repeated two more times to collect a total of 30 mL of extracted liquid for analysis. This liquid was then partitioned into fractions for separate types of analyses, including measurements of the total N associated with NH_4, total N, total organic carbon (TOC), N isotope analysis, and ion chromatography analysis (NO_2^-, NO_3^-, SO_4, Cl). Sections of each filter will remain archived for any future analyses that becomes of interest based on the initial set of results. Both water blanks and filter blanks were included in these analyses as well.

A complementary aerosol dataset was also obtained and analyzed to provide a longer statistical record to use along-side the measurements above that span one year in time. The other dataset includes measurements from a decade-long measurement campaign at the University of Arizona High-Altitude Laboratory on top of Mt. Lemmon between 1992 and 2002 (Matichuk et al., 2006). That studied relied on almost an identical sampling strategy using filters and water-extraction techniques to study the water-soluble composition of the aerosol.

(2) Surface water and soil water samples – Surface waters in Marshall Gulch were collected approximately every 7 days, starting in February 2009 through November 2010 at four locations: the granite hillslope outlet, the schist hillslope outlet, a seep on the schist hillslope, and a weir after the confluence of streams draining the granite and schist hillslopes (Fig. 2). Stream discharge at the weir was also measured using a pressure transducer. In addition, 11 soil lysimeters, installed on the schist and granite hillslopes, were sampled during the same time period as the surface waters, when water was available (Fig. 3). Seven water samples were collected from the B2 desert site from a seep on the schist hillslope, soil lysimeters in the schist and granite hillslopes, and surface water from the CDO wash. Due to the limited number of samples that were collected (dry conditions most of the study period), we did not include these samples in our analysis.

Surface water and soil water samples (730 total) were analyzed for pH, and filtered and analyzed for total dissolved inorganic carbon (TIC or DIC), total dissolved organic carbon (TOC or DOC), and total dissolved nitrogen (TN or TDN) on a Schimadzu carbon and nitrogen analyzer in Dr. Jon Chorover's laboratory in the Soil, Water, Environmental Sciences department at the University of Arizona. Anions, including NO_3, NO_2, Cl, SO_4, PO_4, F and Br were measured on an ion chromatograph in Dr. Chorover's lab.

A subset of water samples (30 total) were collected for triple isotope analyses (^{18}O, ^{17}O, ^{15}N) of nitrate: 14 from soil lysimeters and 7 from surface waters in Marshall Gulch; 4 from soil lysimeters and 3 from surface waters in the B2 Desert site; and 2 samples of Sabino Creek at the Sabino Dam. Samples were collected in May, June and August 2010. These samples have been shipped to Dr. Greg Michalski at Purdue University. Dr. Michalski had indicated that he could complete the isotope analyses in Fall 2010; however, the instrument was down until December 2010. He is currently analyzing the samples, and we expect results in the next ~3 months.

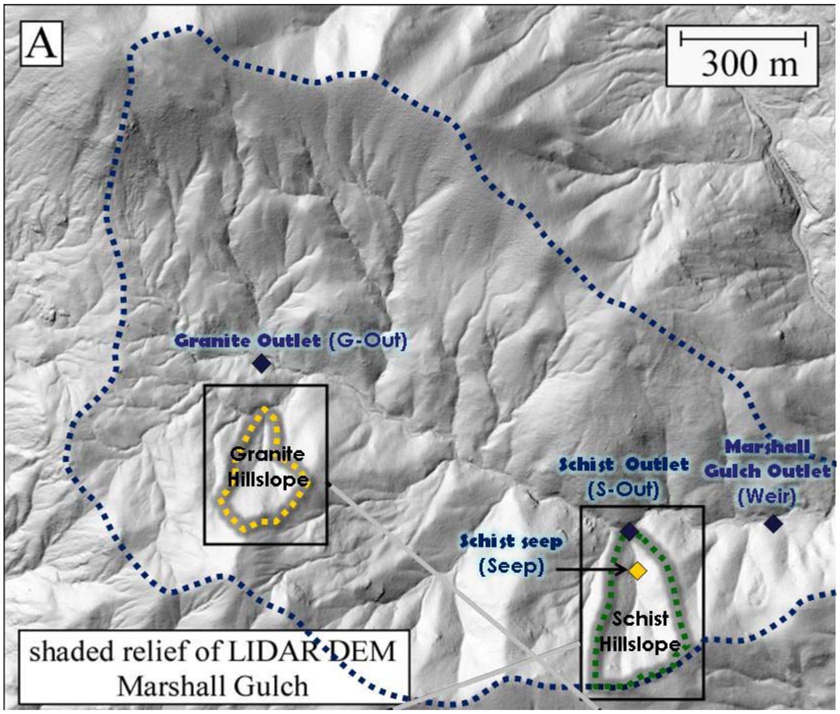


Figure 2: Land surface image of the Marshall Gulch watershed, showing the 2-paired hillslopes, and instrumentation installed as part of the NSF Jemez River Basin-Santa Catalina Mountains Critical Zone Observatory project. Figure courtesy of Angela Jardine and Matej Durcik.

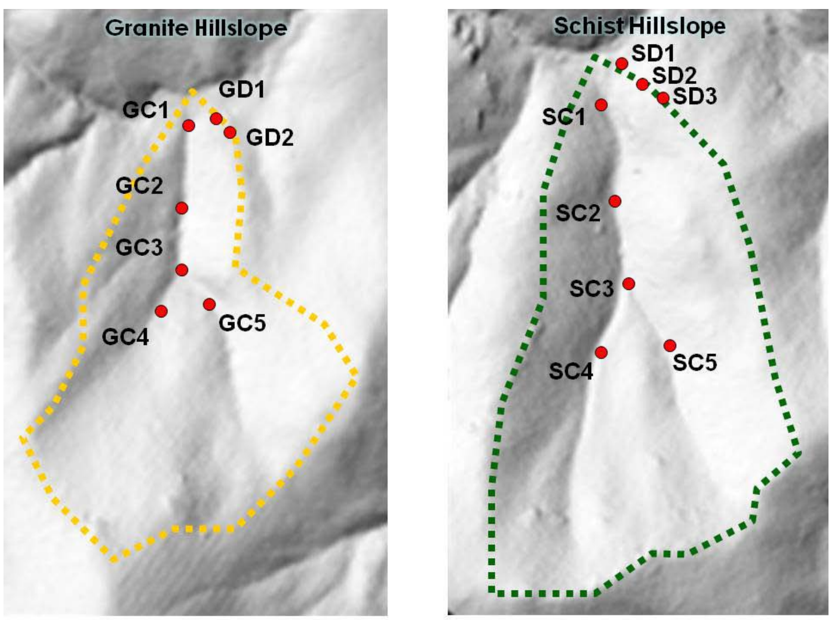


Figure 3: Zoomed-in view of the granite and schist hillslopes, showing the location of the soil solution samplers (soil lysimeters). Figure courtesy of Angela Jardine and Matej Durcik.

The triple isotope approach (δ^{15}N, δ^{18}O, and Δ^{17}O) will be used to distinguish sources of N (terrestrial vs. atmospheric), as well as to constrain biological reactions (denitrification and nitrification) taking place in soils and surface waters. There is often a lot of scatter in δ^{15}N and δ^{18}O relations of NO_3 due to variable sources of N. By adding Δ^{17}O, we can subtract the contribution from atmospheric N and better identify denitrification and nitrification reactions.

<u>Principle Findings and Significance.</u>

By coupling new measurements of organic carbon and N-species in atmospheric deposition, soil waters and stream waters, with precipitation and discharge data, we were able to determine the amount, sources and fate (e.g. transport and cycling) of C and N in the Santa Catalina Mountains, one of many sky island ecosystems in the southwestern United States that provide important water resources via mountain block recharge to adjacent alluvial basins and population centers. Major findings and significance are discussed below, organized by research question.

(1) How does bedrock lithology control organic carbon and nitrogen cycling?

We expected to observe differences in nutrient retention between the granite and schist hillslopes in Marshall Gulch due to differences in soil development. The schist hillslope has much thicker soils (80 to 120 m) than the granite hillslope (40 to 90 m), likely because schist bedrock is less resistant to weathering than granite. Total nitrogen (TN), NO_3-N and NO_2-N concentrations in stream waters draining the granite hillslope are slightly higher than the schist hillslope (Table 1; Fig. 4). Dissolved organic carbon (DOC) concentrations in the schist and granite hillslope outlets are similar, but the concentrations are more variable in the schist outlet. This suggests that N-species and organic carbon may be retained more in schist hillslopes possibly because of greater cation exchange capacity in more developed soils. DOC and N may be more easily flushed from granite hillslopes.

Table 1. Dissolved organic carbon (DOC), total nitrogen (TN), nitrate (NO_3-N), and nitrite (NO_2-N) concentrations at the Marshall Gulch outlet, Schist outlet and Granite outlet.

	DOC (ug/L)				TN (ug/L)		
	MG out	Sout	Gout		MG out	Sout	Gout
mean	7306	10633	10649	mean	594	733	622
median	6225	6234	9604	median	461	491	512
STD	3685	18346	7474	STD	530	821	462
Min	2429	476	4281	Min	0	0	0
Max	26414	63104	65495	Max	3578	4543	2364
	NO_3-N (ug/L)				NO_2-N (ug/L)		
	MG out	Sout	Gout		MG out	Sout	Gout
mean	528	521	628	mean	112	152	171
median	306	346	338	median	70	84	96
STD	694	568	752	STD	127	165	200
Min	1	1	18	Min	10	7	20
Max	3393	2976	3522	Max	516	530	995

Mean and median concentrations for DOC, TN, NO_3-N (median only) and NO_2-N decrease downgradient between the granite and schist hillslope outlets, and Marshall Gulch outlet (Table 1; Fig. 4). This may suggest in-stream processing of organic carbon and N, dilution, or absorption of DOC; future synoptic sampling of stream waters downgradient should be done to address these hypotheses.

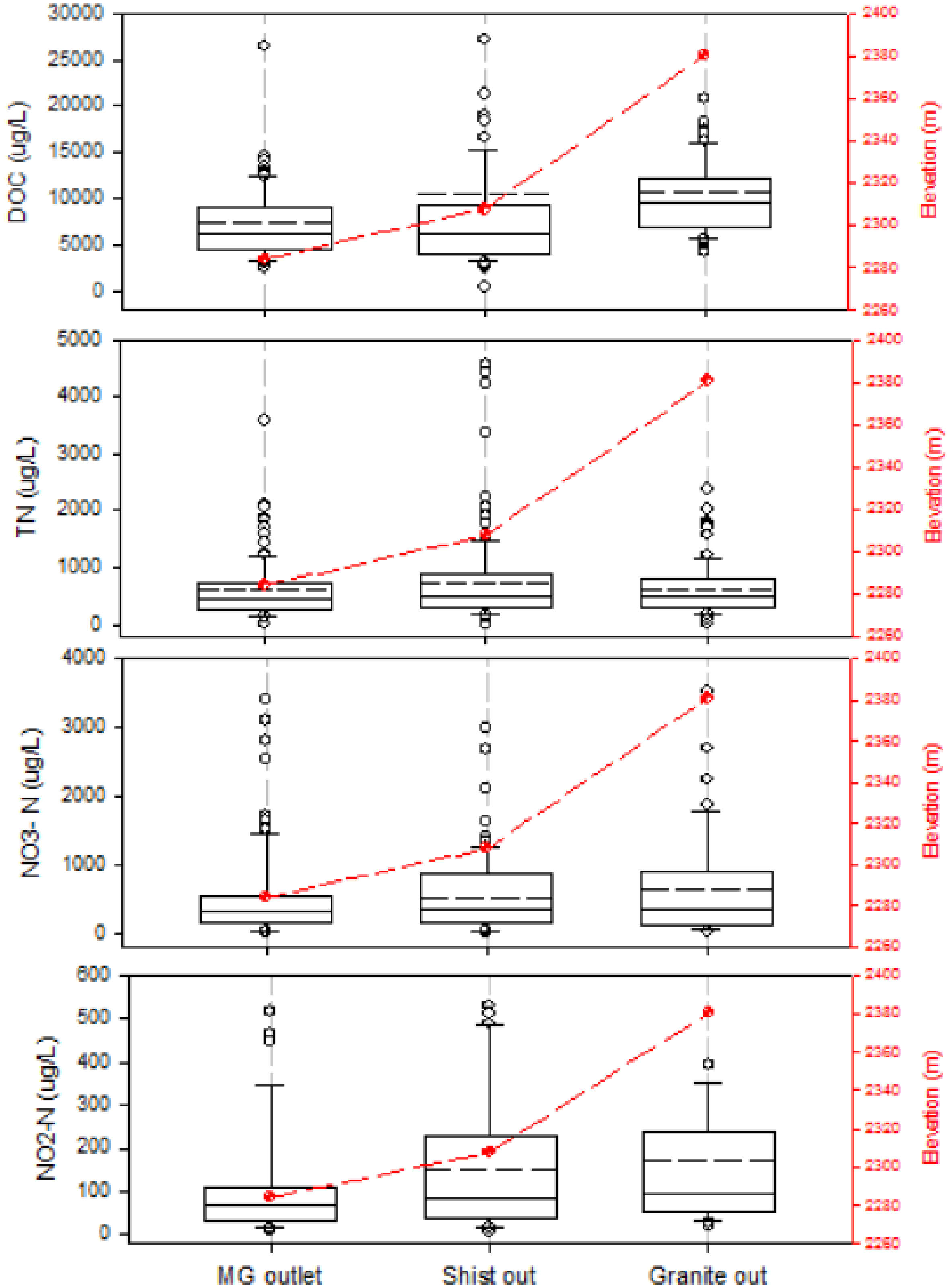


Figure 4: Dissolved organic carbon (DOC), total nitrogen (TN), nitrate (NO_3-N), and nitrite (NO_2-N) concentrations in stream waters, from the granite outlet to the Schist outlet, to the Marshall Gulch (MG) outlet (see Fig. 2 for sample locations).

(2) How does landscape position effect organic carbon and nitrogen cycling?

We expected to observe differences in nutrient concentrations in soils waters within each hillslope dependent on landscape position (i.e. up slope vs. riparian areas, and upstream vs. downstream riparian areas). Across the schist hillslope, DOC and TN concentrations are higher in the mid-elevation zone, and NO_3-N and NO_2-N values do not vary significantly along the elevation gradient (Table 2; Fig. 5). In the granite hillslope, DOC, TN, and NO_2-N concentrations are highest at the bottom of the elevation gradient, while NO_3-N concentrations do not vary along the hillslope (Table 3; Fig. 6). Differences in TN values may be a function of organic-N or NH_4, which were not measured in this study; future sampling campaigns will include these analyses. The highest DOC and TN values in the mid-elevation and bottom slope positions in the schist and granite hillslopes, respectively may indicate accumulation of solutes in downslope positions. Further investigation is needed to better understanding within catchment variability of nutrient concentrations.

Table 2. DOC, TN, NO_3-N and NO_2-N concentrations of soil water along the Schist hillslope.

	DOC (ug/L)							TN (ug/L)					
	Sout	SC1	SC2	SC3	SC4	SC5		Sout	SC1	SC2	SC3	SC4	SC5
mean	10633	26235	33682	27419	18722	17307	mean	733	1242	1843	1730	1696	1346
median	6234	15110	27487	15352	11326	14827	median	491	918	1642	1128	1354	1264
STD	18346	48044	20979	54458	20670	6766	STD	821	1108	824	1806	1201	405
Min	476	5470	16079	143	6233	10943	Min	0	296	962	627	425	438
Max	131983	334018	119829	358850	118848	32603	Max	4543	6729	3912	11594	5124	1996
	NO_3-N (ug/L)							NO_2-N (ug/L)					
	Sout	SC1	SC2	SC3	SC4	SC5		Sout	SC1	SC2	SC3	SC4	SC5
mean	521	1158	744	739	1190	744	mean	153	348	65	145	114	117
median	346	401	177	353	349	179	median	84	104	59	129	77	85
STD	568	1851	1248	954	1790	1145	STD	165	711	40	116	88	89
Min	1	36	16	38	32	31	Min	7	36	19	25	24	35
Max	2976	9628	5909	3556	6554	3969	Max	530	2828	164	579	417	373

Table 3. DOC, TN, NO_3-N and NO_2-N concentrations of soil water along the Granite hillslope.

		DOC (ug/L)					TN (ug/L)		
	Gout	GC1	GC2	GC3		Gout	GC1	GC2	GC3
mean	10649	18564	13958	15644	mean	622	1338	1336	1794
median	9604	13002	12778	16049	median	512	989	1153	1939
STD	7474	16179	4703	4046	STD	462	1110	774	767
Min	4281	9132	8624	9183	Min	0	428	370	675
Max	65495	82606	29766	22492	Max	2364	6599	3057	3194
		NO_3-N					NO_2-N		
	Gout	GC1	GC2	GC3		Gout	GC1	GC2	GC3
mean	628	516	638	496	mean	171	668	293	84
median	338	417	470	195	median	96	84	99	59
STD	752	662	691	672	STD	200	2263	772	104
Min	18	10	24	18	Min	20	26	26	31
Max	3522	3445	3184	2472	Max	995	9149	3711	376

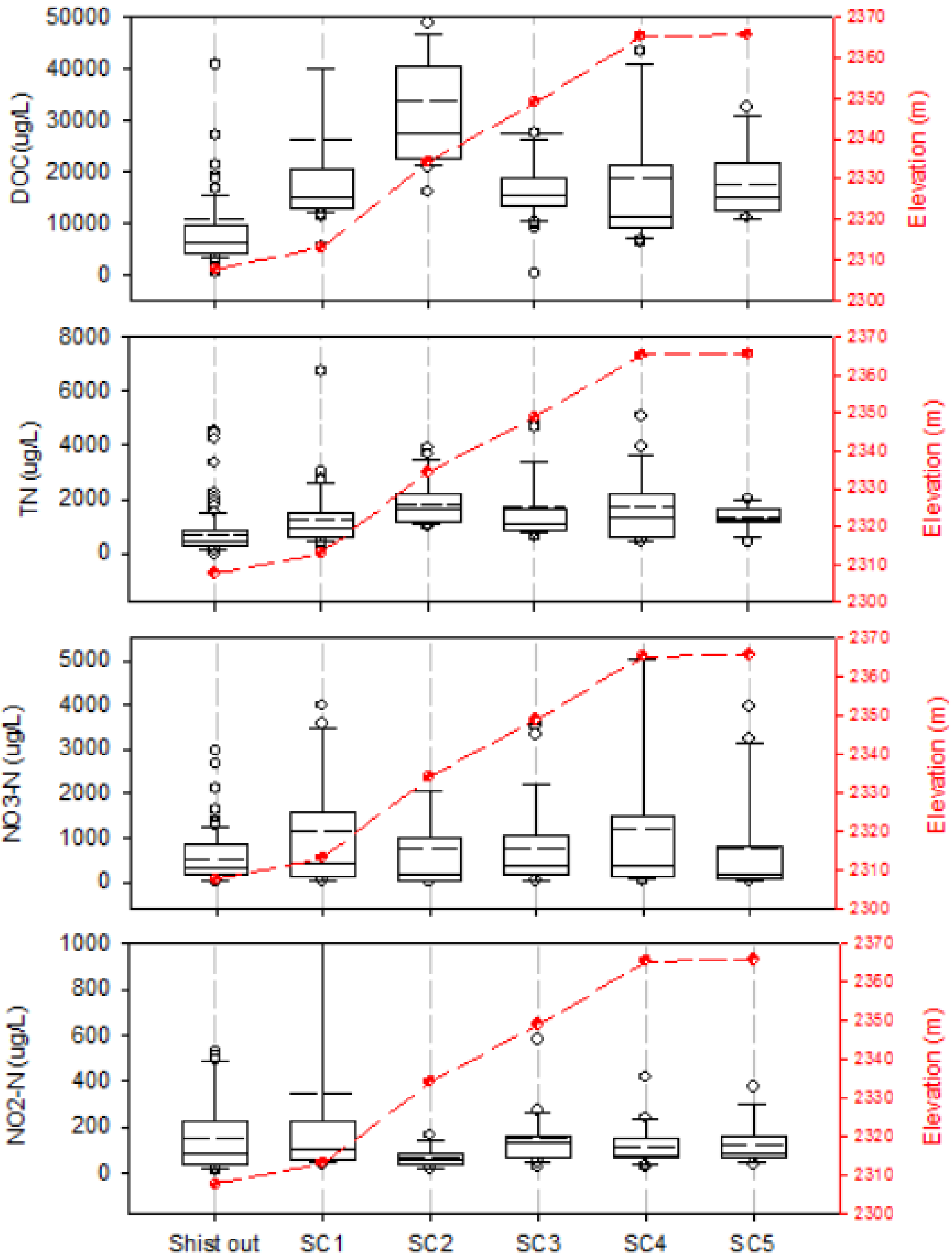


Figure 5: Dissolved organic carbon (DOC), total nitrogen (TN), nitrate (NO_3-N), and nitrite (NO_2-N) concentrations in soil waters along the schist hillslope (see Fig. 2 for sample locations).

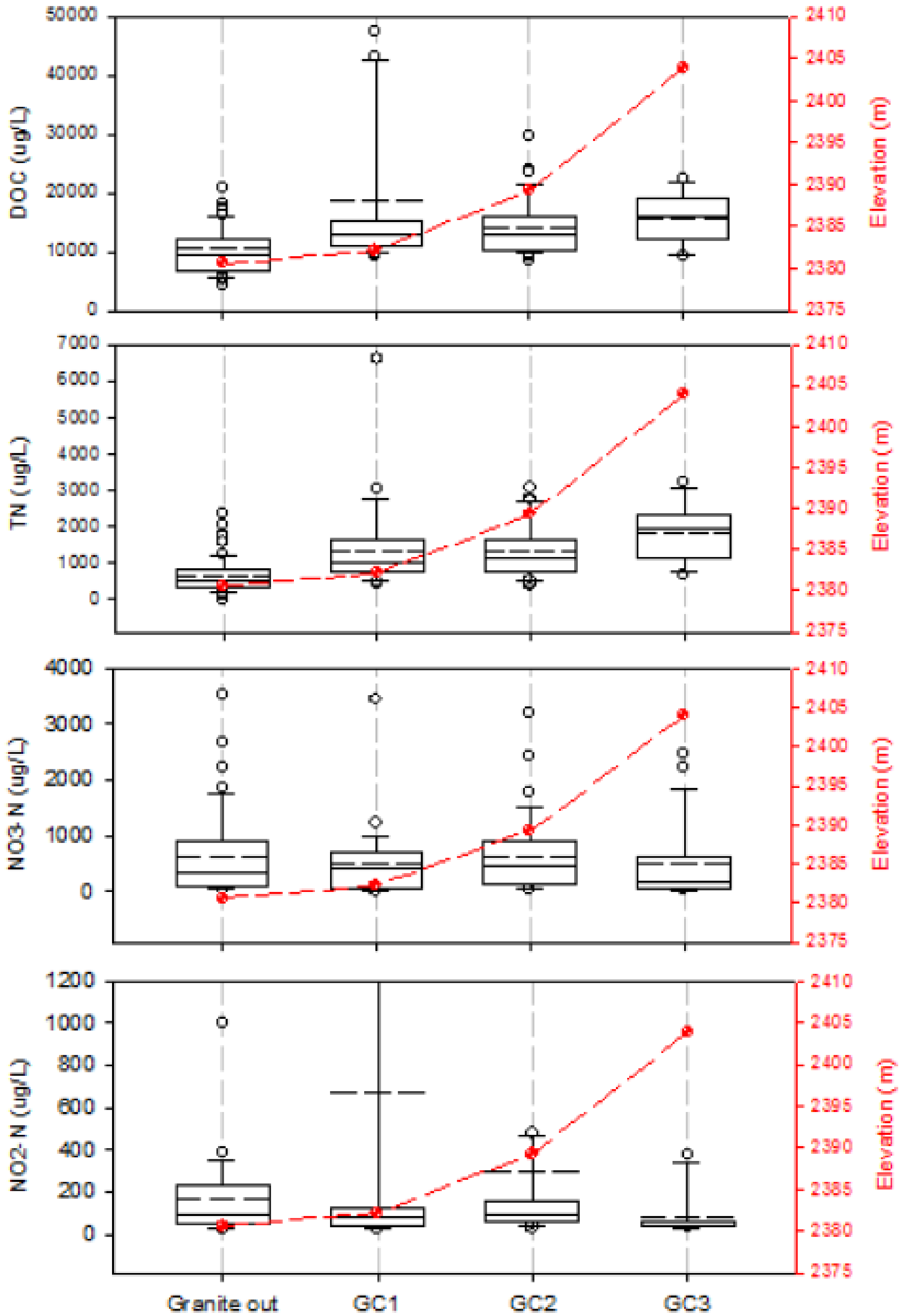


Figure 6: Dissolved organic carbon (DOC), total nitrogen (TN), nitrate (NO_3-N), and nitrite (NO_2-N) concentrations in soil waters along the granite hillslope (see Fig. 2 for sample locations).

(3) What are the amounts, sources, and seasonality of species in atmospheric deposition?
Aerosol measurements are used in this study to draw connections between particles that settle to the surface via dry deposition and the composition of soil water and surface waters downgradient of deposition areas. Temporal trends in aerosol concentrations and chemical composition of particles are dictated largely by meteorology, emissions sources, and air mass source origin. The summit of Mt. Lemmon is influenced by the Tucson urban plume during summer months when the mixing layer deepens as a result of higher ambient temperatures and more vigorous atmospheric convection. During the winter months, this high altitude site is exposed only to local sources (e.g. vehicular emissions by nearby town of Summerhaven and wood-burning) and free tropospheric aerosol, while the low-altitude B2 desert site is influenced by pollution sources in the metropolitan Tucson area. Aerosol particles are impacted by both natural and anthropogenic sources, where the predominant source of dry deposition at the summit of Mt. Lemmon is hypothesized to be dust, owing to its coarse size and prevalence at these high altitudes during spring and summer months.

Table 4: Concentrations of chloride, sulfate, nitrate, and nitrite in atmospheric deposition, measured as part of this study from the Mt. Lemmon and B2 sites.

			$\mu g\ m^{-3}$	$\mu g\ m^{-3}$	$\mu g\ m^{-3}$	$\mu g\ m^{-3}$
Collection Site	Start	End	**Cl**	**SO4**	**NO3**	**NO2**
Mt Lemmon	6/8/10	6/16/10	0.0497	0.5572	0.1891	0.0172
Mt Lemmon	7/14/10	7/22/10	0.0169	0.4649	0.1272	0.0127
Mt Lemmon	8/15/10	8/20/10	0.0337	0.5041	0.1278	0.0018
Mt Lemmon	9/4/10	9/10/10	0.0044	0.4393	0.1202	
Mt Lemmon	10/14/10	10/27/10	0.0074	0.4021	0.0179	0.0092
Mt Lemmon	10/27/10	11/5/10	0.0035	0.3396	0.0267	0.0082
Mt Lemmon	12/3/10	12/17/10	0.0043	0.2333	0.1008	0.0179
Mt Lemmon	1/25/11	1/30/11	0.0044	0.2933	0.0652	
B2	3/2/10	3/3/10	0.0489	0.3763	0.1647	
B2	5/21/10	5/22/10	0.1389	1.1164	0.1408	0.0194
B2	6/18/10	6/24/10	0.1247	1.3563	0.3555	0.0496
B2	7/27/10	8/2/10	0.0585	1.4236		0.0087
B2	8/27/10	9/5/10	0.0335	0.9320	0.1895	0.0127
B2	9/26/10	10/6/10	0.0172	0.7499	0.1190	0.0152
B2	10/26/10	11/15/10	0.0254	0.5116	0.1682	0.0096
B2	12/4/10	12/17/10	0.0701	0.4550	0.2081	0.0132

A number of species were investigated in this study, including nitrate, nitrite, sulfate, chloride, and organic carbon. Particulate nitrate (NO_3^-) mainly originates from oxides of nitrogen resulting from combustion processes. Submicrometer NO_3^- is typically present in the form of ammonium nitrate, produced via the reaction between gaseous ammonia (NH_3) and nitric acid (HNO_3), where sufficient NH_3 must be present to first fully neutralize SO_4^{2-} prior to formation of ammonium nitrate (NH_4NO_3). Nitrate in $PM_{2.5}$ can also be associated with the lower tail of a coarse mode due to reactions of HNO_3 (or precursors) with sea salt and dust (Lee et al., 2008; note that sea salt can be ruled out as a major aerosol component in southern Arizona). Nitrite (NO_2^-) similarly can partition into the aerosol phase as a result of uptake and reactions of nitrogen oxides on the surface of mineral particles such as dust (Grassian et al., 2001). While nitrate is a common constituent of atmospheric aerosol particles, there are sparse measurements of particulate nitrite as it usually is in low concentrations and is easily oxidized (e.g. Lammel and Cape, 1996). It is thought that nitrite is associated with local pollution and mineral particles (e.g. Acker et al., 2008). Sulfate originates mainly from anthropogenic pollution (i.e. SO_2 emissions) and is produced via photochemical reactions and therefore is most abundant during summer months as a result of vigorous solar radiation. Its production is also more rapid in the aqueous phase, and thus is produced most efficiently at high relative humidity and especially in clouds. The major sources for organic carbon (OC) include prescribed and natural wildfires, residential wood combustion, anthropogenic emissions, biogenic emissions, and suspended soil dust. Particulate organics can be formed via direct emission (e.g. primary biological aerosol particles such as pollen, fungi, and bacteria) and by secondary gas-to-particle conversion processes as a result of volatile organic compound (VOC) emissions. Similar to sulfate, secondary production of OC is expedited with high relative humidity and high solar radiation. Chloride originates from mineral aerosols (sea salt, dust), coal combustion (Ye et al., 2003), and biofuel combustion. This species is predicted to be most abundant at our two measurement sites in the spring and summer months.

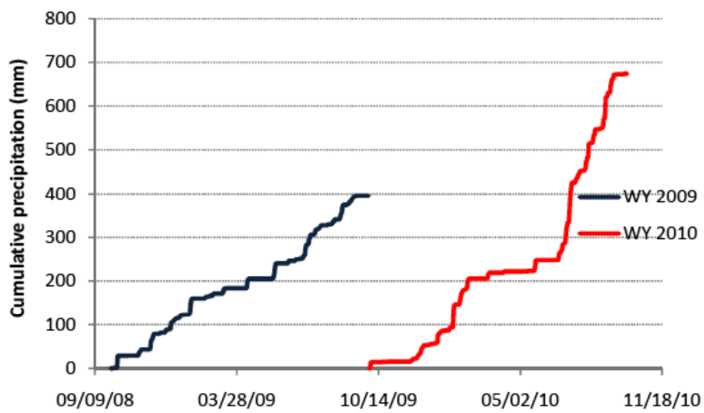
We hypothesized that the highest concentrations of all species studied in dry deposition aerosol samples should be observed during the spring and summer months owing to the largest influence of dust aerosol and the Tucson urban plume at both the low elevation (B2) and high elevation (Mt. Lemmon) sites. Dust emissions in Arizona are highest between April and July, and subsequently decrease as a result of monsoon precipitation suppressing the lofting of dust aerosol from surfaces. However, during the episodic monsoon storms, massive dust plumes are associated with gust fronts that also have the ability to impact both measurement sites. Satellite imagery confirms that massive dust storms extending from the surface to higher than 5 km in altitude frequently pass through southern Arizona and have a great potential to impact both measurement sites.

As predicted, the highest concentrations of Cl, SO_4, and NO_3 were measured in aerosol particles from the low elevation (B2) and high elevation (Mt. Lemmon) sites in the summer months (May-August 2010; Table 4) when dust deposition is the highest, and the Tucson urban plume (including NOx emissions) reaches the top of Mt. Lemmon. NO_2 values in dry deposition were highest in June-July and December at the Mt. Lemmon site, and May-June at the B2 site. A plausible explanation for the high concentration of NO_2 measured in dry deposition (up to 0.0496 ug/m^3) is that heterogeneous processes on dust surfaces allow this species to partition to the aerosol phase. Enhanced sulfate levels in atmospheric deposition during the summer time at the Mt. Lemmon site show that concentrations of dry deposited species at high-altitude sites can be governed to a large extent by variability in atmospheric mixing layer height, which is driven by solar radiation and convection.

(4) How does variability in precipitation effect organic carbon and nitrogen cycling?

Water year (WY Oct-Sept) 2010 was relatively wet compared to 2009, with significantly more precipitation (Fig. 7; 397 mm vs.675 mm, respectively). There was also a relatively large snowpack that developed on Mt. Lemmon during winter 2010 that led to higher spring snowmelt pulses in surface waters. Thus, we expected to see differences in the nutrient concentrations in stream waters between WY 2009 and 2010. In addition, we expected to see differences within years between the spring snowmelt, dry summer, and monsoon seasons.

A



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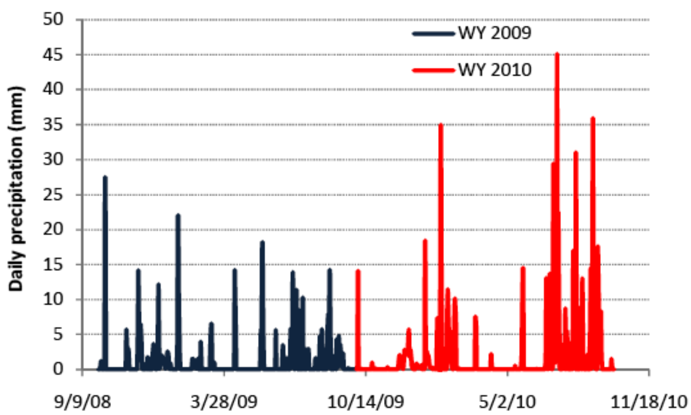

Figure 7: Comparison of precipitation amounts in the Santa Catalina Mountains between water years (WY; Oct 1-Sept 30). A) Cumulative precipitation, showing higher amounts in 2010. B) Daily precipitation values, showing higher precipitation during the winter and summer

Dissolved organic carbon (DOC; same as total organic carbon (TOC)) values in the Marshall Gulch outlet stream waters were highest during the spring and summer, likely due to flushing of shallow soils during snowmelt (Fig. 8). In addition, DOC concentrations were significantly greater in 2010 than 2009. We hypothesize that greater precipitation amounts in 2010 enhanced DOC production in soils, which was then transported to streams.

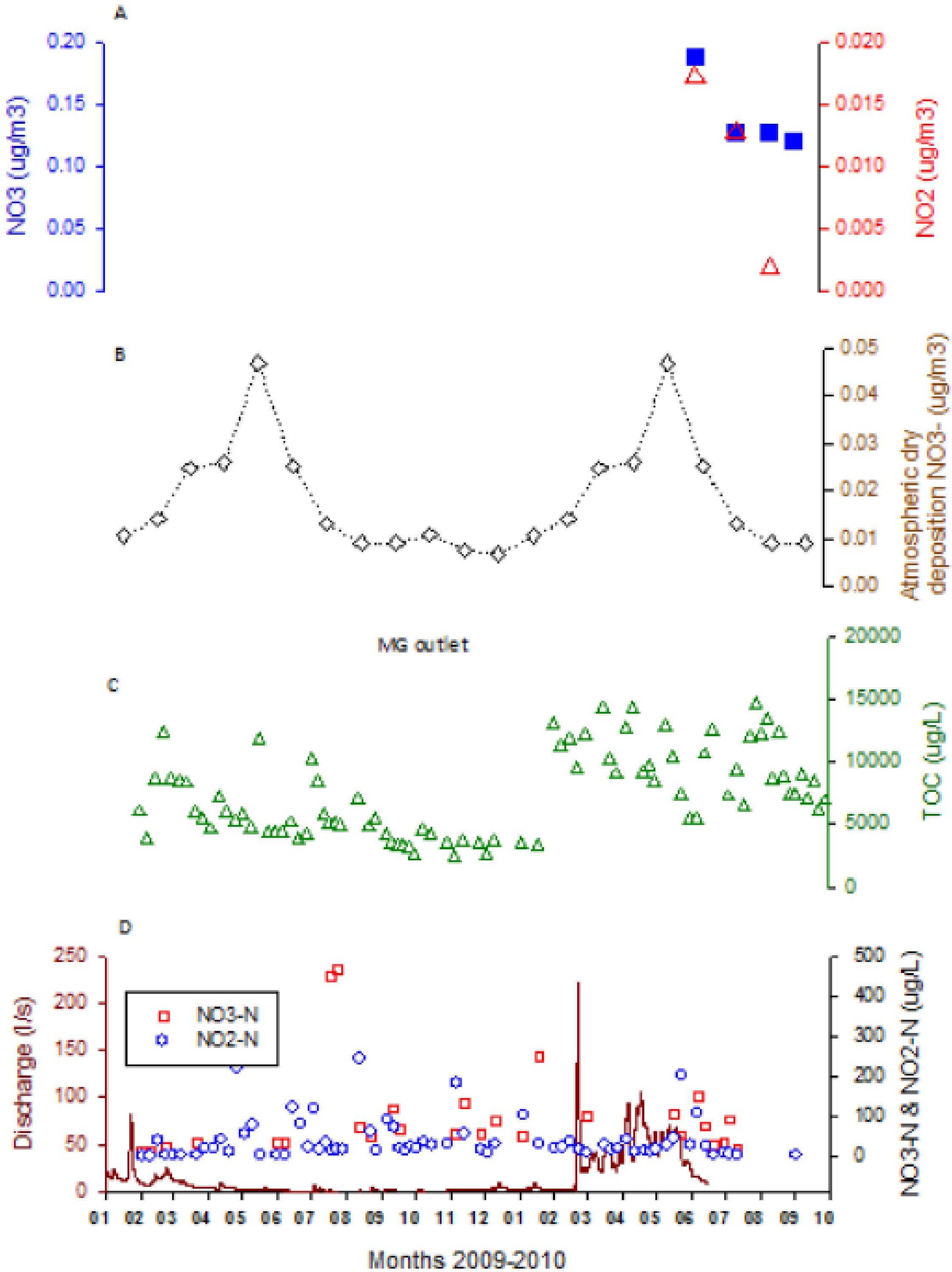

Figure 8. Comparison of atmospheric deposition to stream water quality of the Marshall Gulch outlet. A) Measured NO_3 and NO_2 concentrations in atmospheric deposition at Mt. Lemmon (this study). B) NO_3 levels atmospheric dry deposition (longer-term dataset courtesy Dr. Eric Betterton). C) Time series of total organic carbon (TOC) concentrations in stream waters from the Marshall Gulch (MG) outlet. D) Discharge data from Marshall Gulch outlet, and nitrate (NO_3-N) and nitrite (NO_2-N) concentrations of stream waters.

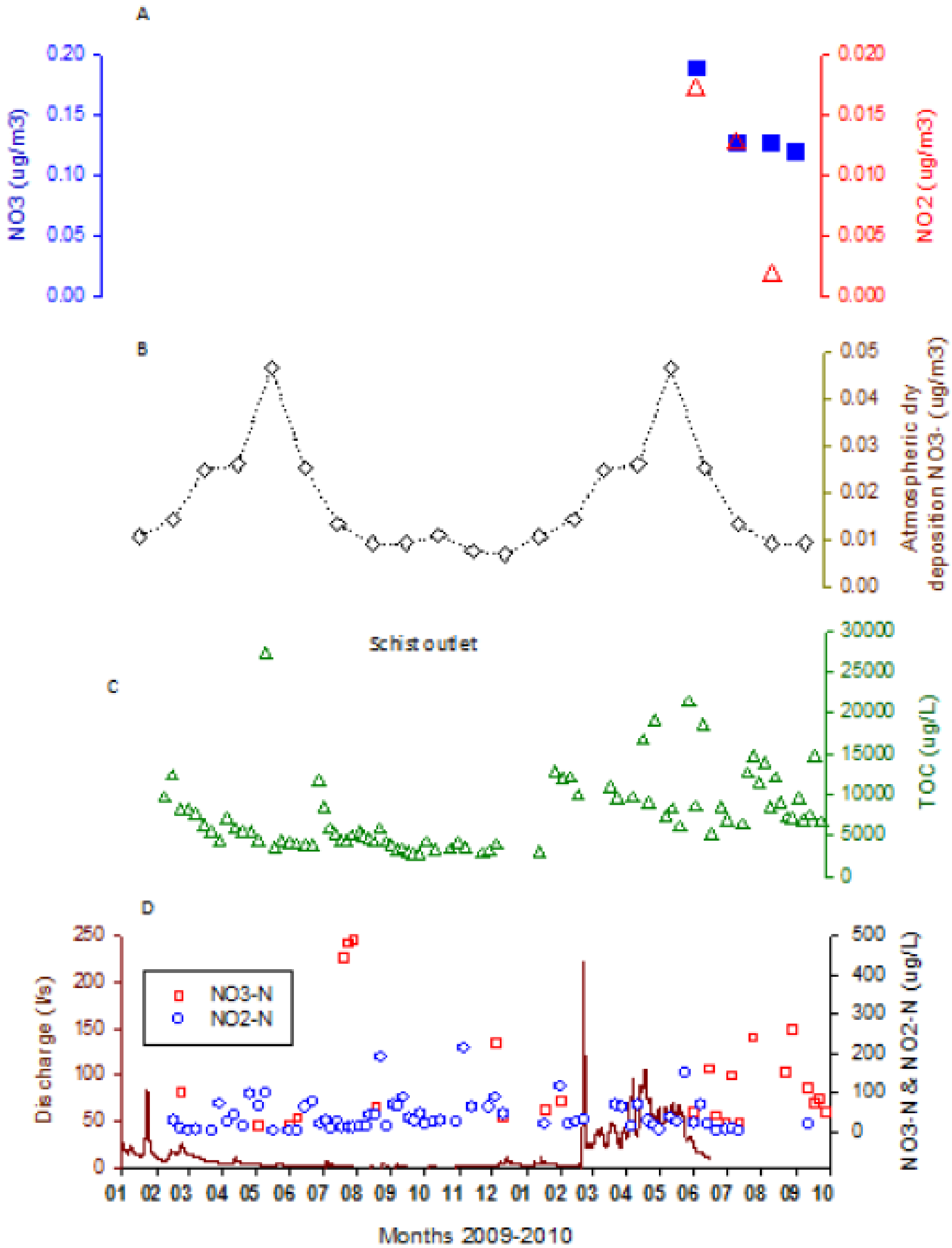

Figure 9. Comparison of atmospheric deposition to stream water quality of the Schist hillslope outlet. A) Measured NO_3 and NO_2 concentrations in atmospheric deposition at Mt. Lemmon (this study). B) NO_3 levels atmospheric dry deposition (longer-term dataset courtesy Dr. Eric Betterton). C) Time series of total organic carbon (TOC) concentrations in stream waters from the Schist hillslope outlet. D) Discharge data from Marshall Gulch outlet, and nitrate (NO_3-N) and nitrite (NO_2-N) concentrations of stream waters from the Schist hillslope outlet.

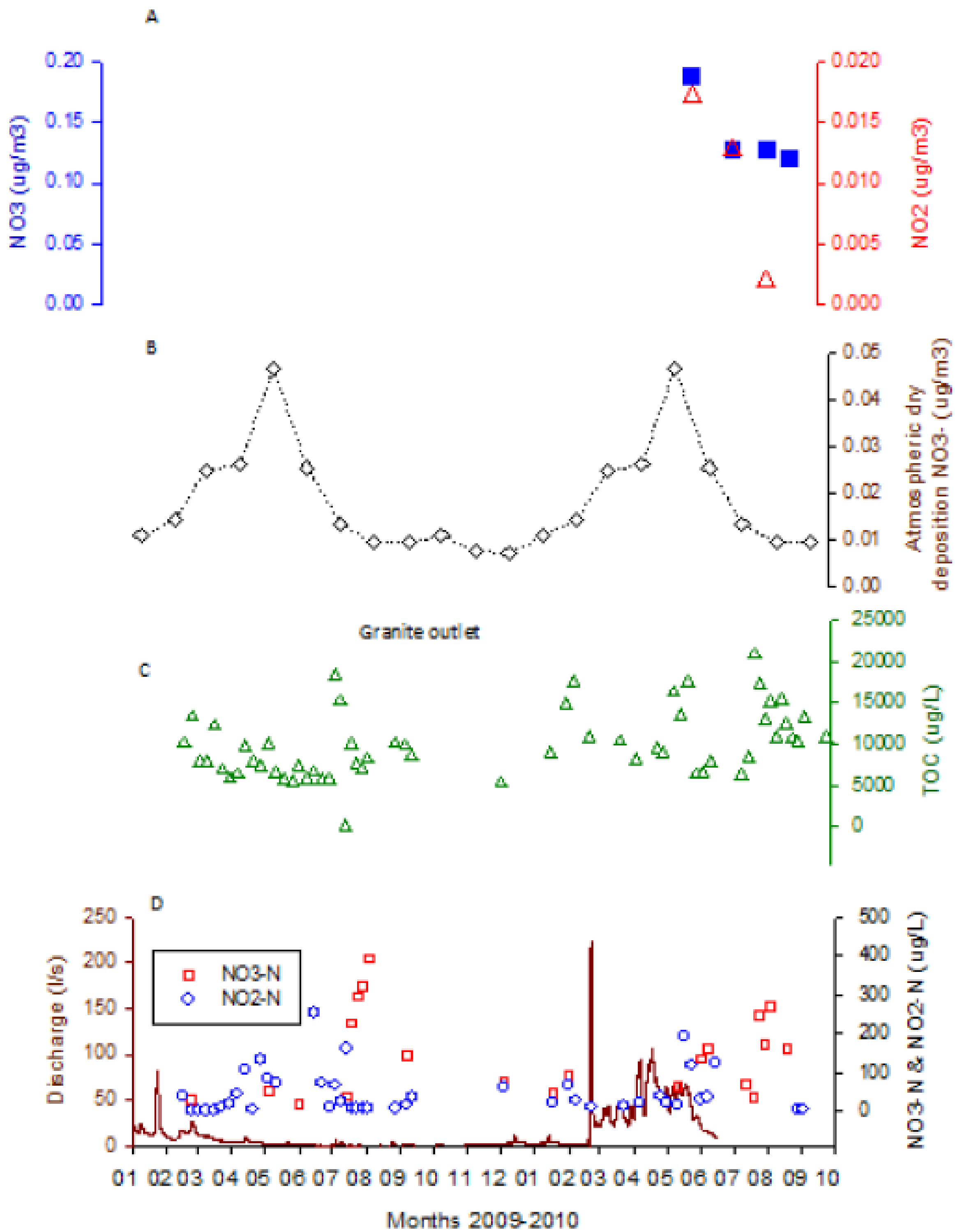

Figure 10: Comparison of atmospheric deposition to stream water quality of the granite hillslope outlet. A) Measured NO_3 and NO_2 concentrations in atmospheric deposition at Mt. Lemmon (this study). B) NO_3 levels atmospheric dry deposition (longer-term dataset courtesy Dr. Eric Betterton). C) Time series of total organic carbon (TOC) concentrations in stream waters from the granite hillslope outlet. D) Discharge data from Marshall Gulch outlet, and nitrate (NO_3-N) and nitrite (NO_2-N) concentrations of stream waters from the granite hillslope outlet.

Total dissolved nitrogen (TN) and NO_3-N concentrations in the Marshall Gulch outlet stream waters were highest during the summer dry period and summer monsoons (Fig. 8). The NO_3-N values of stream waters are well below the EPA maximum contaminant level (MCL) of 10 mg/L, with the highest values similar between the schist, granite, and Marshall Gulch outlet samples (3.0, 3.5, and 3.4 mg/L respectively). In contrast, NO_2-N concentrations were unusually high for most natural environments, with the highest values recorded during the summer monsoons. Typically, NO_2-N is thought to convert rapidly to NO_3-N in surface water and soil systems so that concentrations in surface and soil systems are often below detection limit. However, we observed surprisingly high NO_2-N concentrations in surface and soil solution waters (7-2828 ug/L, EPA drinking water standard is 1000 ug NO_2-N/L). These high pulses of N in stream waters in the summer appear to correspond to periods of intense atmospheric deposition of N (mentioned above), thus we hypothesize that high NO_3-N and NO_2-N values observed in stream waters during the summer dry period is derived from the atmosphere. Triple isotope analyses of NO_3 should enable us to distinguish atmospheric versus terrestrial sources of N. A similar study using triple isotope analysis of NO_3 is in progress in the Tucson metropolitan area, examining the impacts of urbanization on runoff nitrogen biogeochemistry. This study is also showing high NO_2-N concentrations in rainfall and runoff indicating that NO_2-N in solution is a longer-lived N form in these hot semi-arid ecosystems (Gallo et al. in revision, Gallo et al. in preparation). The mechanisms explaining higher concentrations of NO_2-N are unknown and merit further investigation. Aerosol data point to dust and aerosol deposition being the primary source of NO_2-N.

The lowest values of TN, NO_3-N, and NO_2-N in stream waters were measured after peak discharges (e.g. snowmelt and monsoons; Fig. 8), which may be due to N removal via uptake or denitrification, in which case the NO_3 should have an isotopic signature indicative of denitrification. Alternatively, lower values might be explained by different source waters and/or flushing of NO_2-N and NO_3-N from the soil catchment ecosystem during peak discharge.

There is no positive correlation between NO_3-N and NO_2-N as would be expected if both came from the same production pathway (i.e. biological production via two step process of nitrification). Thus, we hypothesize that NO_3-N and NO_2-N have different sources, NO_2-N via dry/particulate deposition and the NO_3-N as wetfall. These hypotheses would have to be further tested with triple isotopes in rainfall, throughfall, dry deposition samples.

Synthesis & Summary of Key Results.

⇒ Total dissolved nitrogen (TN), nitrate (NO_3-N), nitrite (NO_2-N), and dissolved organic carbon (DOC) concentrations were slightly higher in stream waters draining the granite versus schist hillslopes. We hypothesize that the thicker soils developed on the schist hillslope have higher cation exchange capacities to retain nutrients compared to thinner soils developed on the granite hillslope.

⇒ Mean and median concentrations of DOC, TN, NO_3-N and NO_2-N decrease downstream between the granite hillslope outlet, the schist hillslope outlet, and the Marshall Gulch outlet. This may suggest in-stream processing of organic carbon and N, dilution or adsorption of DOC.

⇒ DOC values in the Marshall Gulch outlet stream waters were highest during the spring

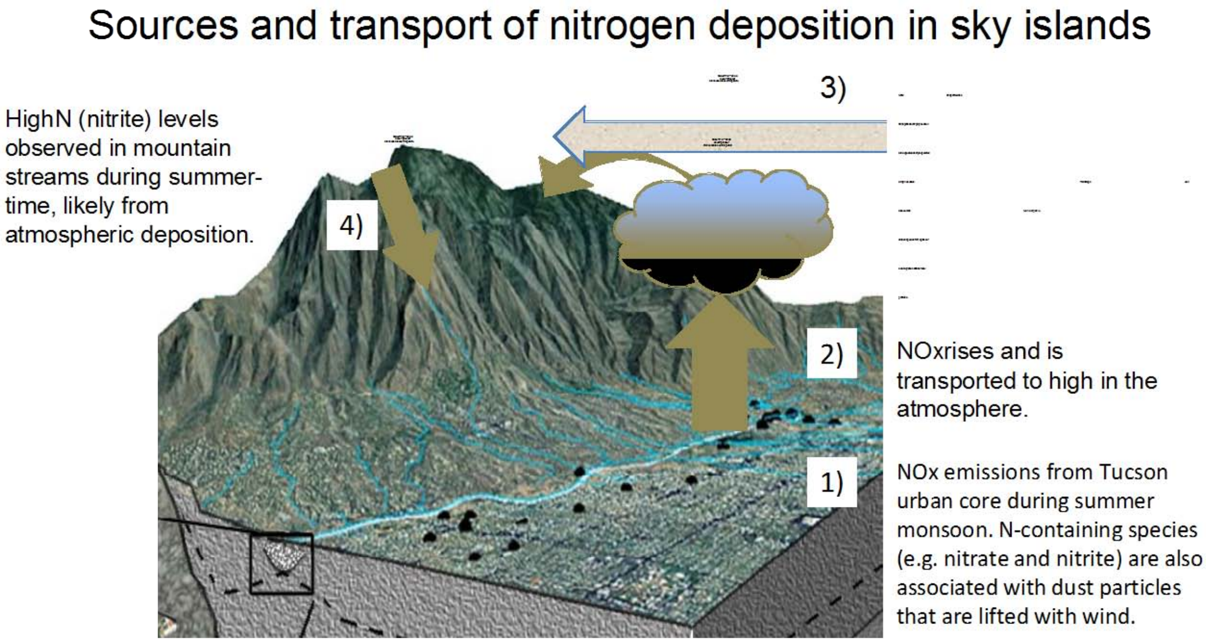

Figure 11: Schematic diagram showing sources of nitrogen deposition and transport in sky-island ecosystems.

and summer, likely due to flushing of shallow soils during snowmelt. In addition, DOC concentrations were significantly higher in 2010 compared to 2009. We hypothesize that greater precipitation amounts in 2010 enhanced DOC production in soils, which was then transported to streams.

⇒ Measurement of the composition of aerosol particles at the low and high elevation sites (B2 and Mt. Lemmon, respectively) show that dust aerosol is a major contributor of dry deposition at both sites, during the spring and summer. In addition, NO_3, NO_2, and chloride levels are high in aerosols during these dust-impacted months at both sites. High amounts of N deposition in the spring and summer may be related to NOx emissions from the Tucson urban core and dust, which are transported to the top of Mt. Lemmon (see Fig. 11).

⇒ TN, NO_3-N, and NO_2-N concentrations in Marshall Gulch outlet stream waters were highest during the summer dry period and summer monsoons, which corresponds to the period of greatest atmospheric deposition of N. Interestingly, measured concentrations of NO_2-N concentrations in stream and soil waters were exceptionally high (in some cases, above the EPA MCL; 1000 ug/L NO_2-N). Similarly high concentrations of NO_2-N have been measured in Tucson urban runoff (Gallo et al., in revision, in preparation), which suggests that nitrite may persist in hot, semi-arid environments.

⇒ There is no positive correlation between NO_2-N and NO_3-N, which suggests different sources for the N-species. We hypothesize that NO_2-N is sourced from dry/particulate atmospheric deposition, while NO_3-N is sourced from wet deposition (rainfall).

⇒ Ongoing triple isotope analysis of NO_3 will help to constrain atmospheric versus terrestrial sources of N and removal pathways, such as denitrification.

⇒ Results from this study enhance our understanding of the sources and amounts of nitrogen being deposited in sky-island ecosystems, and how nitrogen is retained and/or transported from mountain catchments to adjacent groundwater basins. These results are important for constraining water quality of surface water and groundwater, ecosystem function in semi-arid environments, and atmospheric pollution.

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Improving Hydrologic Investigations through Multi-Model Analysis and Discriminatory Data Collection

Basic Information

Title:	Improving Hydrologic Investigations through Multi-Model Analysis and Discriminatory Data Collection
Project Number:	2010AZ412G
Start Date:	9/1/2010
End Date:	8/31/2012
Funding Source:	104G
Congressional District:	AZ-7
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Models
Descriptors:	None
Principal Investigators:	Paul Andrew Ferre

Publications

There are no publications.

During the first year of the project, we have made significant progress on testing our MMA-DDC theory. Specifically, we have written a code to select measurements from a series of potential measurements given a suite of candidate models. We have completed a draft of our first publication on MMA-DDC, which is based on a virtual test for a simple, one-dimensional solute transport problem. We intend to submit a manuscript to Water Resources Research by the end of the summer. We have also been in communication with USGS scientists in Alaska and Arizona to make a final decision on our real-world implementation of MMA-DDC. Specifically, we are working with Arizona colleagues who are developing a new San Pedro flow model in an effort to integrate our efforts with theirs. In addition, the student on the project (Colin Kikuchi) is spending the summer in Alaska continuing to examine possible research sites that have appropriate model support.

Information Transfer Program Introduction

The WRRC maintains an information transfer program well-know across Arizona for the quality and usefulness of its publications, conferences, seminars and related activities. Despite budget cuts and retirements, the information transfer program continues to improve its delivery of relevant information on water management and policy and to expand its reach with new projects and collaborations. Details on the accomplishments of the past year follow.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2010AZ409B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	AZ-007
Research Category:	Not Applicable
Focus Category:	Law, Institutions, and Policy, Management and Planning, Economics
Descriptors:	water energy nexus, desalination, water reuse, decision support, stakeholder engagement, transboundary water issues
Principal Investigators:	Sharon Megdal, Susanna Eden

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WRRC STAFF INFORMATION TRANSFER RELATED ACTIVITIES

During the project year the WRRC professional staff members were actively engaged in the following programs and projects.

Sharon Megdal is the C.W. and Modene Neely Endowed Professor for Excellence in Agriculture and Life Sciences. Her selection as University of Arizona Outstanding Outreach Faculty Professor was announced in March 2010 and the honor was awarded publicly at UA's winter commencement ceremony, December 18, 2010. In addition to serving as WRRC Director, Prof. Megdal is the Water Sustainability Program Director and is a Professor/Specialist in the UA Departments of Agricultural and Resource Economics and Soil, Water and Environmental Science. Prof. Megdal holds courtesy appointments with the UA School of Government and Public Policy; 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 in 2010. She has been a member of the National Institutes for Water Resources since 2004, and the UNESCO-GEF Transboundary Waters Assessment Programme, Groundwater Expert Group, since 2009.

During the reporting period, Dr. Megdal gave numerous presentations on the topic of water management and planning, around the state and has published articles, reports and commentary based on her water policy research. She led a study on water conservation for environmental enhancement that has resulted in a prototype "Conserve to Enhance" program being demonstrated by Tucson Water and has generated considerable interest from conservation planners, municipalities and other water providers. As part of a larger research program on securing water for the environment, she led a study of environmental water needs in Arizona and co-authored a paper on Arizona water law and the environment. She was a leader on the Regional Water Assessment Task Force that held four ThinkTank workshops designed to elicit public input from a broad range of interests. The results will be used to assist regional efforts to identify and address water resource issues. 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, Arizona Water Resource.

At the national level, Dr. Megdal presented the CAST study report she led, which examined Water Availability for Agriculture in the United States using the impacts, regulations, challenges, and policies of specific U.S. states as examples. Three seminars were held in Washington, D.C. when the report was released, at the U.S. Department of Agriculture and on Capitol Hill. In addition, she presented study results at the ASA, CSSA and SSSA 2010 International Meetings, Long Beach, California; a USDA Agricultural Research Service Workshop, Chicago, Illinois; and "Toward Sustainable Groundwater in Agriculture" International Conference, San Francisco, as well as a Watershed Planning Subcommittee Meeting, Pima Association of Governments in Tucson.

Prof. Megdal has encouraged the growth of international collaborations. She has followed up hosting an international symposium and workshop on Arizona, Israeli and Palestinian water management in 2009, co-editing a book based on workshop presentations to be published by UNESCO Press and reinforcing ties with Israeli and Palestinian colleagues through invited presentations and meetings. She also led collaborative efforts resulting in a program of research for the U.S. Mexico Transboundary Aquifer Assessment Program (TAAP) in Arizona, presenting an invited paper for the 19th Session of the UNESCO- IHP

Intergovernmental Council, Scientific Segment, at UNESCO Headquarters in Paris, July 7, 2010, on that program and another at the ISARM 2010 International Conference on Transboundary Aquifers: Challenges and New Directions, UNESCO, Paris, France, December 7, 2010.

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 state, county, city public/private entities, and received NASA funding through a project with the Arizona-Sonora Desert Museum this past year. She has developed partnerships/ sponsorships with the Abbott Fund and The Nature Conservancy that focus on Pinal County programming and programming in Yavapai County and the Phoenix Valley, respectively. In addition, she meets weekly with an APW staff team of eight and quarterly with an advisory council to guide the APW program. The School Water Audit Program is actively saving water at area middle schools and teaching students through real-world scientific investigation. Students have presented data-driven results and recommendations to five different adult decision making groups. Ms. Schwartz was co-Recipient (with other ACE colleagues) of the 2010 Innovative Programs Gold Award in recognition of the School Water Audit Program, an innovative natural resources extension program which addresses critical community issues and needs by the Association of Natural Resource Extension Professionals (ANREP). She also was presented the Individual Program Leadership Gold Award in recognition of exemplary leadership of an individual natural resources program by the national ANREP.

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 Laurel Clark 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 Student Fellowship Program, Recruitment and Research Initiative, Education & Outreach Program, Competitive Grants Program (recently suspended due to budget cuts) and to the five water centers that serve as the management core. Ms. Moxley co-authored the paper, "Determinants of Environmental Noncompliance by Public Water Systems," *Contemporary Economic Policy* (April 2010) with T. Rahman, S. Megdal, S. Aradhyula, and M. Kohli. She organized the WSP-hosted workshop: Emerging Pathogens Workshop - March 9, 2010; the WSP Event Day November 22, 2010, a day of meetings and activities; and the WSP/WRRC Brad Udall Lecture, April 15, 2010, including videotaping, posting the video to the WSP UA YouTube site. She was responsible for projects, budgets, and communications for the WSP Education & Outreach Committee and supervised WSP and E&O staff on campus and in the Maricopa County Extension office. She directed the work of WSP-E&O staff located at SAHRA. She also assembled and presented WSP displays at multiple events, including the Arizona Hydrological Society, 2009 Annual Symposium: "Managing Hydrologic Extremes," Scottsdale, Arizona, August 30 - September 2, 2009; UA Meet Yourself event, March 4, 2010; UA Campus Earth Day, WSP-WRRC display on the Mall, April 22, 2010; and President's Club Reception, Student Union Ballroom, WRRC-WSP display, May 3, 2010. She was a member of the ICOSSE'11 Water Reuse Workshop Planning Committee, water reuse workshop, in January 2011, and she consulted on planning for the Campus Sustainability web site and Water Theme on UA Institute of the Environment Portal.

Kristine Uhlman, RG, Area Assistant Agent, Cooperative Extension, is the Program Coordinator for Arizona NEMO (Nonpoint Education for Municipal Officials). As an Area Assistant Agent with Cooperative Extension, Kristine Uhlman is working with several Arizona counties on projects addressing water resources. As the Arizona NEMO Program Director she manages students and staff that contribute to 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 predictive models of watershed response for implementation of restoration activities; isotope analysis of numerous water supply wells to determine groundwater age; and, a series of county-based workshops for the domestic well owner. 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. Ms. Uhlman also served as Chair and Moderator for the Session #3445, Source Water Protection, at the National Ground Water Association (NGWA) 2010 Ground Water Summit and Ground Water Protection Council Spring Meeting, in Denver, April 12, 2010, http://ngwa.confex.com/ngwa/2010gws/webprogram/Session3445.html. She continues her appointment to the Pima Association of Governments Watershed Subcommittee Chair position, the Arizona Water Protection Fund, State of Arizona Board of Technical Registration Enforcement Advisory Committee, the Editorial Board the *Ground Water*, and the Editorial Board of the *Journal of Extension*. In addition, she was recently elected to the Board of Directors, Scientists and Engineers Division, National Ground Water Association.

Susanna Eden, Coordinator, Applied Research, is responsible for managing the WRRA Section 104(b) research grant program and oversight of the 104(g) nationally competitive grant program for the Arizona 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. She supervised the student intern's research and writing for the *Arroyo* newsletter on the subject of the water-energy nexus and co-wrote the final article. Building on the Arroyo research, she was lead author on a chapter, "Energy-Water Interdependencies and the Central Arizona Project" in *The Water-Energy Nexus in the American West*, Doug Kenney and Robert Wilkinson, Eds., to be published by Edward Elgar Publishing. Dr. Eden also implemented a writing contest for undergraduate students at the three Arizona universities and carried it into its second year. The winning articles were published in the Spring 2010 edition of *AWR*, the WRRC's quarterly newsletter. Prizes for the winning entrants in the second (2010-2011) year were awarded in January 2011 and the winning articles are to be published in the Spring 2011 issue. She is co-editing a book to be published by UNESCO Press based on the presentations at the Arizona-Israeli-Palestinian Water Management and Policy Workshop. The paper she co-authored and presented at that workshop will appear in the book. She also was a member of the planning committee for both the 2010 and 2011 annual conferences and contributed to organization of the conferences. A report of her research on decision support was published on-line in *Environmental Science and Policy* in October 2010 and appeared in the January 2011 issue of that journal. In late 2010, she has assumed oversight of *AWR*, with the assistance of Graduate Assistant – Outreach, **Stephan Pryzbylowicz**, who wrote the feature article for the Winter 2011 issue.

Joanna B. Nadeau is a Research Analyst on two outreach/research projects working to quantify and address environmental water needs. Over the past year, Joanna worked on outreach and partner development towards implementation and evaluation of pilot programs of Conserve to Enhance "C2E", an innovative strategy to connect water conservation with environmental enhancement projects, funded by the U.S. Bureau of Reclamation. The outreach component of this work involved making presentations to regional audiences and facilitating meetings with stakeholders. She established working relationships with non-profits and local municipal water professionals in several Western communities to lay the foundation for Conserve to Enhance pilot programs in Tucson, Arizona; Las Cruces, New Mexico; and one or more communities in Colorado. Working with a team, she secured funding the City of Tucson's Together Green program and the City's cooperation on the pilot now underway in Tucson. She provided additional outreach for the Conserve to Enhance project by writing and distributing a progress report intended for use by interested communities. She was also co-author with Dr. Megdal on two papers related to this work: "The Environment as a Paying Water Customer: Connecting Water Conservation to Environmental Water Needs" in The Kachina News (Vol. 27, No.3) and "The Forgotten Sector: Arizona Water Law and the Environment" (with Tiffany Tom) to be published soon in the Journal of Environmental Law and Policy." In January 2010, she began work with Sharon Megdal on a one-year statewide assessment of Arizona's environmental water needs, funded by the Nina Mason Pulliam Charitable Trust. For this project she assembled information from ongoing and completed efforts to quantify the water requirements of Arizona's riparian areas and aquatic ecosystems. In addition, she oversees communication with the assessment's Advisory Committee, made up of environmental flows experts and key environmental stakeholders in the state.

In the project year **Candice Rupprecht** transitioned from the Watershed Steward Program to a position as Program Coordinator of Applied Programs and manages an Arizona Project WET partner program, funded by The Nature Conservancy, called the Water Investigations Program (WIP). In addition she works with Sharon Megdal and Joanna Nadeau on the residential water conservation program (Conserve to Enhance) that links water savings with envrionmental benefits. Both programs emphasize connecting urban water users with their natural environments and riparian areas. She is a board member for the Arizona Association for Environmental Education.

Renee Johns, NEMO Program Coordinator, wrote for a Miller/Coors Grant and responded to a NOAA RFP to support annual Wet/Dry activities. She aided in the preparation of a NSF Climate and Sustainability Grant proposal and an Advance Grant for research near Snowflake, Arizona, aimed at water age dating and water management. She organized a Wet/Dry Mapping 2010 event and transferred data into a GIS database. With **Carie Deatherage**, Ms. Johns aided in training the WRRC staff on how to use the IMS tool. Ms. Deatherage, Senior Research Associate, was responsible for ARC/GIS mapping and related product development. She assisted in the development of a research data base of historic photographs, as well as training sessions and presentations for Arizona NEMO.

Melissa Lamberton, Research Associate, made significant contributions to the Arroyo on the water-energy nexus in Arizona and was co-author on a chapter for a book on the same subject. She also assisted with the organization and implementation of the WRRC's 2010 Annual Conference.

Partially retired, **Joe Gelt** worked half time until midsummer 2010 when he retired fully. He completed writing and editing the two of the four annual issues of *Arizona Water Resource*, and making inputs to the *Arroyo,* an annual publication released in Spring 2010. He also had a role in conducting a summer writing internship and statewide contest for student writers. Mr. Gelt was honored upon his retirement by having the student writing contest renamed the Joe Gelt Student Writing Competition.

Terry Sprouse, Research Specialist Senior, also left the WRRC mid-year. He 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.

A list of presentations by WRRC professional staff is appended.

WRRC PUBLICATIONS

<u>Arizona Water Resource Newsletter</u>

The Arizona Water Resource is an 8 to 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 2,200 people on the mailing list and distributed to more than 2,700 addresses 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. The WRRC continues to receive commendations on the quality of its newsletter since the retirement of its long-time editor.

AWR Feature Articles 2010-2011:

- Decentralized Treatment Promises More Delivery and Use of Recycled Water Raising High-Rise Crops, Winter 2010
- Nanotechnology Promises Water Resource Gains But Raises Concerns, Winter 2010
- Mapping a Mythical River, Spring 2010
- Water and Environmental Leadership is Theme of WRRC's Annual Conference, Spring 2010
- Only seasoned, water-savvy leaders are honored as true Water Buffalos, Summer 2010
- "What is a Good Leader?" Was Lead Question at WRRC Conference, Summer 2010
- Sustainable Water for All: Lessons in Hydrophilanthropy, by Stephan E. Przybylowicz, WRRC Graduate Assistant Outreach, Winter 2011
- Blue Ribbon Panel Finishes Work, by special guest contributor, Chuck Graf, Senior Hydrologist, Water Quality Division, ADEQ, Winter 2011

WRRC Director's Public Policy Columns 2010-2011:

- "Now's the Time to Fit Together the Pieces of an Arizona Water Plan," Arizona Water Resource, Winter 2010
- "Applied Outreach Strategies, a Priority in Awarding UA Distinguished Outreach Professorship," Arizona Water Resource, Spring 2010
- A Summer Thought — Partnerships Are a Strategy For All Seasons, Summer 2010
- Uncertainty: Are We Running Out of Water? Winter 2011

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, WSP and NEMO have been prominent as supporters of the WRRC newsletters.

AWR Supplements 2009-2010

- Winter 2010, USGS, National Water-Quality Assessment Program, Dissolved Solids in Basin-Fill Aquifers and Streams in the Southwestern United States — Executive Summary
- Spring 2010, Arizona NEMO, Announcing: Arizona Water Map Poster and Educators' Curriculum Guide
- Summer 2010, WSP, New Water Leaders Spring from Arizona Desert
- Winter 2011, USGS/WRRC, A Snapshot of Programs at the WRRC

<u>Arroyo Newsletter</u>
The 2010 edition of the *Arroyo*, an annual newsletter focusing on a single topic of timely interest to Arizona, was published in April. Titled "The Water-Energy Nexus," the 2010 Arroyo addressed this subject after it was selected by the WRRC's External Advisory Committee as a timely topic in need of an accessible reference publication. Work on the 2010 *Arroyo* began with selection of the 2009 summer writing intern. 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. Published in early spring, the *Arroyo* dealt 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" provided 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. The Water-Energy Nexus *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 2011 *Arroyo* began with selection of the 2010 summer writing intern. Planned for publication in early spring, the *Arroyo* will deal with water supply salinity and desalination. The intern, **Tim W. Glass**, was a non-traditional student in Journalism, with a focus on photojournalism. In addition to doing background research and drafting major sections of the *Arroyo*, he took photographs reproduced in the publication and posted on the WRRC website. "Desalination in Arizona—a growing component of the state's future water supply portfolio" contains explanations of basic concepts, descriptions of existing and planned desalination facilities in Arizona, presentation of the legal context, discussion of emerging issues, both economic and technical, and a glimpse of cutting-edge research and technology.

WRRC PRODUCTS

<u>Arizona Water Map and Curriculum Guide</u>
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.

CONFERENCES, SEMINARS AND LECTURES

Annual Conference

The WRRC assembled 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 to develop plans for a highly interactive, diverse and multi-generational meeting on the subject of water and environmental leadership. The conference, “Creating New Leadership for Arizona’s Water and Environment in a Time of Change,” took place at the UA Student Union on June 9-10, 2010, with more than 250 registered participants. Strenuous efforts were made to attract a broad mix of young people and experienced professionals; community members and “insiders”; scientists and artists; activists and government officials. The program stimulated contact and conversation between people who ordinarily were not likely to meet. Students were provided opportunities to seek out potential mentors with shared interests. The conference’s four workshops each produced an output report to stimulate future actions.

Very shortly after conclusion of the successful 2010 conference, planning began on the 2011 conference. The topic, salinity and desalination, and what they mean for Arizona’s future water supply, was endorsed by the WRRC’s External Advisory Committee. It was consonant with the 2011 *Arroyo* topic, and plans were made to have the *Arroyo* published in time to distribute at the conference.

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 45 percent from the campus and 55 percent from the wider community. Seminars in the period March 2010 through February 2011 are listed below. Most of the presentations are posted on the WRRC’s website.

- March 12, 2010; Kristin Mayes, Chairman, Arizona Corporation Commission and Trevor Hill, President, Global Water Resources Inc.; “Private Water Company Water Policy”; “Mandating Conservation by Arizona's Private Water Companies”, “The Challenge of Conservation” and “A Brief History of Water”
- April 21, 2010; Melaney Seacat, Pima County Project Coordinator and Nicole Ewing-Gavin, Assistant to the City Manager at City of Tucson; “Tucson Pima Water Study”
- April 28, 2010; Ben Grumbles, Director, Arizona Department of Environmental Quality (ADEQ); “Hot Topics in Water & Climate Policy”
- May 11, 2010; Gaspar Mairal, Associate Professor, Social Anthropology, University of Zaragoza, Spain, Visiting Scholar, UA Bureau of Applied Research in Anthropology (BARA); “Water Crisis in Mediterranean Spain: Water Policy as a Gospel of Redemption”
- June 24, 2010; Dustin Garrick, University of Arizona & Ecosystem Economics; “Evaluating Emerging Markets for Environmental Flows: Lessons from Policy Reform and Implementation Experience in the Columbia Basin”
- September 16, 2010; Ardeth Barnhart, Co-Director, AzRISE (The Arizona Research Institute for Solar Energy) and George Frisvold, Professor of Agricultural and Resource Economics at the University of Arizona; “Solar Energy's Future in Arizona and the Impacts on Water Use”
- October 22, 2010; Paul Walker, President, Insight Consulting, LLC and Greg Sorensen, VP for Service Delivery for Liberty Water; “Liberty Water: A Framework for Implementing Water Conservation Plans”

- November 12, 2010; Stan Leake, Research Hydrologist/Groundwater Specialist, USGS; "Possible Effects of Groundwater Pumping and Artificial Recharge on the Verde River and Tributaries"
- November 17, 2010; Drew Beckwith, Water Policy Analyst, Western Resource Advocates; "Findings from the Arizona Water Meter"
- December 1, 2010; Holly Thomas-Hilburn, Program Coordinator, Arizona Project WET, and Candice Rupprecht, Statewide Coordinator, Arizona Master Watershed Steward Program; "Perception, Misconceptions & Community Connections: What does effective education look like?"
- January 19, 2011; Walter Piegorsch, Professor and Chair, Graduate Interdisciplinary Program (GIDP) in Statistics, University of Arizona; "Statistical Risk Benchmarking in Environmental Risk Assessment"
- January 26, 2011; Joe Abraham, Director of the UA Office of Sustainability; "UA Campus Sustainability Leadership, Resources, and Priorities – What's New, and How to Get Involved"
- February 2, 2011; Kurt Schnier, Georgia State University Department of Economics; "Economics in Action: Policy Relevant Research"
- February 23, 2011; Joanna Nadeau, Research Analyst, Water Resources Research Center, University of Arizona; "Securing Water for the Environment: An Update on Conserve to Enhance"
- February 24, 2011; Dr. Linda Fernandez, Associate/Full Professor, Agricultural and Resource Economics; "Economic Analyses of Policy Options for Solving Water Challenges"

Other Seminars, Workshops and Events

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.

Seminar and Book Signing
April 8, 2010; Jack August, Executive Director, Barry Goldwater Center for the Southwest presented excerpts from his new book *Arizona v. California and the Colorado River Basin*. A book signing followed the seminar.

Special Brown Bag Seminar and Joint Colloquium
On April 15, 2010, Brad Udall, Director, Western Water Assessment, NOAA Earth System Research Laboratory, University of Colorado at Boulder, presented *When Will the Reservoirs Run Dry: The Looming Water Crisis in the American Southwest.* The event was co-sponsored by the UA School of Earth & Environmental Sciences, Department of Geosciences, Water Resources Research Center, Water Sustainability Program and the Institute of the Environment.

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

WSP Student Fellowship Presentations and Reception

On February 3, 2011the WRRC hosted research presentations by the 2010-2011 Water Sustainability Program, Student Fellowship recipients. Both graduate student and undergraduate student fellowship recipients gave brief presentations on the results of their research over the academic year.

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. . 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. The site has continued to be reviewed and revised on a regular basis, but its functionality could be improved by using currently available advances in web design and programming. Therefore, the WRRC initiated efforts to migrate its current web content to a Drupal environment. This will give the Center greater connectivity with the College of Agriculture and Life Sciences web site and the web resources of Arizona Cooperative Extension. In addition, a student graphic designer will work with the web developers to update the look of the web site, and at the same time create an updated and coordinated look for the suite of WRRC publications.

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).

Social Media

With the need to more effectively communicate with students and businesses outside the usual channels, the WRRC began investigating social media. As a first step, the Center established a Facebook page to post notices about the 2011 Desalination conference. More use will be made of social media in the future as resources permit.

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 exceptional capacity 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 competitive grants program; student fellowship program; an education and outreach program; water center directed initiatives and activities support; and strategic recruitment and research initiatives. Investment in new faculty, state-of-the-art facilities and new research initiatives serves to enhance the competitiveness of UA to secure major grant funding; provide quality education; and attract top students. Ultimately, in a semi-arid state, ensuring sustainable, high quality water supplies is a fundamental basis for prosperity and enhanced quality of life for all of Arizona.

Funded through the state Technology and Research Initiative Fund (TRIF), WSP has approximately $2.4 million for the last year in a five-year funding cycle. A program evaluation process underway in 2010 helped to determine funding levels for the next five year period. WRRC continues to play a pivotal role in implementing, developing, and managing program components, under WSP and WRRC director, Sharon Megdal.

<u>WSP Activities</u>

Sponsored and Co-Sponsored Events
WSP was a co-sponsor with the College of Science of a UA Public Science Lecture "*Global Climate Change and the Southwest"* by Prof. Jonathan Overpeck, UA Institute of the Environment, an international climate change expert and a lead author on the 2007 Nobel Prize winning Intergovernmental Panel on Climate Change; Phoenix, February 15, 2010.

WSP organized and hosted a one-day workshop on Emerging Pathogens in water supplies - March 9, 2010. Speakers presented the latest research findings on emerging pathogens, detection and treatment issues, new real-time technologies, source tracking, and regulatory issues with a special session on *<u>Naegleria</u>* and *<u>Balamuthia</u>*. Workshop materials are posted at http://wsp.arizona.edu/education/workshops#04

WSP organized a Joint Colloquium, "*When Will the Reservoirs Run Dry: The Looming Water Crisis in the American Southwest"* by Brad Udall, Director, Western Water Assessment, NOAA Earth System Research Laboratory, University of Colorado at Boulder; co-sponsored by the UA School of Earth & Environmental Sciences, Department of Geosciences, Water Resources Research Center, Water Sustainability Program and the Institute of the Environment. April 15, 2010.

WSP was a collaborator for the WRRC Conference 2010, June 9-10, "*Creating New Leadership for Arizona's Water and Environment in a Time of Change.*" WSP-WRRC funding for conference planning assistance was provided.

WSP hosted a day of events for the WSP Water Forum 2010: Our Water Future, on Monday, November 22, 2010. Activities and demonstrations included: The Water Zone - Leaky Water House and inflatable Water Conservation House, Edible Aquifers, and "What's so important about Water?" a visual arts display on the missing species in the Rillito River watershed by Jessica Gerlach, MFA candidate. Student organized games and displays related to water, a poster session and a series of talks by UA water experts were also part of the forum.

WSP was a sponsor for the ICOSSE (International Congress on Sustainability Science and Engineering), Water Reuse Workshop, Tucson, January 13-14, 2011. Financial assistance was provided to bring in experts from around the world and logistical support was contributed.

WSP Displays:

- UA Meet Yourself event, UA, March 4, 2010.
- UA Campus Earth Day, on the UA Mall, April 22, 2010.
- President's Club Reception, UA Student Union Ballroom, May 3, 2010.
- WRRC Conference 2010, *Creating New Leadership for Arizona's Water and Environment in a Time of Change,* Tucson, June 9-10, 2010.
- Arizona Hydrological Society, 2010 Annual Symposium: *Dryland Hydrology: Global Challenges, Local Solutions*, Tucson, September 1-4, 2010.
- WSP Water Forum, UA Student Union Ballroom, November 22, 2010.
- ICOSSE'11 Water Reuse Workshop, Tucson, January 13-14, 2011

Other Activities

WSP presented awards to the top three high school students with water-related projects entered in the Southern Arizona Science & Engineering Fair (SARSEF) March 2010. These students were then invited to attend the WRRC leadership conference in June to present their science projects during the poster session.

Competitive Grants

One of the key components of the WSP has been the Competitive Grants Program. Due to budget shortfalls funding was cut back and no new competitive research grants were awarded in 2009/2010.
An open instrumentation call was circulated to the UA water community in late Fall 2009 and $250,000 was allocated to fund eight new pieces of state-of the-art equipment to six departments in three colleges. Funds were expended by June 30, 2010. PIs needed to demonstrate how the purchases would make them more competitive in submitting future proposals for external funding.

A special call for proposal s was released Fall 2010 for short-term project funding for seed grants for instrumentation and infrastructure investment; proof of concept/pilot projects; public education/outreach programs, on-line short courses and degree courses; and graduate student travel grants. A total of 18 seed grants were awarded covering a wide range of topics plus nine travel awards to students. WRRC staff members were investigators on four of the projects receiving funding:

- **Communicating Scientific Results and Conclusions at a Multiage UA Forum** $22,700; Kerry Schwartz, Agricultural Education/Water Resources Research Center, Holly Thomas-Hilburn, Water Resources Research Center
- **Sensitivity of Residential Water Demand to Recent Price Increases in Urban Phoenix** $19,233; Gary Thompson, Agricultural & Resource Economics, Sharon Megdal, Water Resources Research Center, Satheesh Aradhyula, Agricultural & Resource Economics
- **Water Budgeting for a Rural Arizona Community** $25,440; Kristine Uhlman, Water Resources Research Center, Chris Eastoe, Geosciences

- **Engaging Rural Domestic Well Users in Water Quality Analyses** $32,110; Mary Kay O'Rourke, Mel and Enid Zuckerman College of Public Health, Kristine Uhlman, Water Resources Research Center, Walt Klimecki, College of Pharmacy, Kristen Pogreba-Brown and Marlene Dermody, Mel and Enid Zuckerman College of Public Health

Abstracts of all projects funded through the program are available on the WSP site: http://wsp.arizona.edu/research/abstracts .

Education & Outreach Committee
WSP funded a variety of education and outreach projects through award of small grants that included: a demonstration of water harvesting; publication printing; scholarships for high school students to attend an environmental summer camp; and lab equipment purchases for a program for teachers. WSP staff in Maricopa County supported the School Water Audit Program, the Master Watershed Steward Program, a student internship program, and a water lecture series.

Student Fellowships
WSP awarded fellowships to five graduate students and two undergraduate students studying water resources issues relevant to Arizona. These are outstanding students making significant contributions to the body of knowledge across many disciplines. http://wsp.arizona.edu/education/student_fellowships

WSP Funded WRRC Directed Initiatives
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 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 for retention purposes. Funds were also provided to faculty in Family and Consumer Sciences for the start up of a new program called Consumers, Environment and Sustainability Initiative (CESI). Dr. Megdal has also been instrumental in building and supporting the Water Resources and Policy research emphasis in the School of Geography and Development.

WRRC-WSP also contributed funds for the U.S.-Mexico Transboundary Aquifer Assessment and to building the Conserve to Enhance Program. A rainwater harvesting was a component added into the program as part of the conservation measures, complementing other WSP funded activities relating to water harvesting and conservation.

WSP-WRRC funds were used to help to develop the new Water, Society and Policy Master's Degree in Science program based in the School of Natural Resources and the Environment. The degree program evolved from the Water Policy Certificate program also initiated by Dr. Megdal.

Arizona Project WET and Arizona NEMO have received WSP-WRRC funding for special projects. The NEMO project assessed drought vulnerabilities for rural Arizona Communities.
WRRC Applied Research Coordinator position (Susanna Eden) is funded through WSP-WRRC, and WSP funds also help to support WRRC publications, including the Arroyo and AWR, the WRRC newsletter.

ARIZONA PROJECT WET

Arizona Project WET Water Education Program for Teachers

Arizona Project WET is a comprehensive water education program with a long 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 and Common Core Standards. Professional development workshops incorporate focus and inquiry questions, pre and post lesson assessments through handheld responders and the use of science notebooks; all of which model 21st Century Learning. Program coordinators in Maricopa, Pima, Pinal and Yavapai Counties extend the presence of the Arizona Project WET team statewide. The Arizona Project WET program is guided by an advisory council, which meets quarterly. The Council members are water and education specialists 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, 733 teachers participated in at least one of 52 six to sixteen-hour water education workshops held in 18 cities across Arizona. These participating teachers reported reaching 30,134 students each year with water education.

Professional development training on the APW-FOSS Water Kit and EES Kit were conducted by APW and master teachers from districts. Americorps members, trained by APW, deliver in-class groundwater presentations and Sweetwater Wetlands Water Festivals. The third grade water unit is part of the curriculum for 5,673 students in Tucson, Sunnyside, Flowing Wells and Altar Valley district schools. The APW-FOSS training was attended by 133 third grade teachers, reaching 2,911 students annually with water curriculum. The rarely understood but important topic of ground water is taught in the classroom by trained individuals as part of the unit. APW-UA volunteers presented 144 in-classroom ground water flow model presentations to 3,239 students. The Sweetwater Wetland Water Festival, the culminating event for the water unit, was attended by 170 third grade classes, reaching 3,627 students and 778 adult chaperons.

In 2009 the Energy & Environmental Science sixth grade unit was finalized and adopted as one third of the sixth grade science curriculum. Sixteen APW lessons are part of the curriculum for 4,862 sixth grade students from Tucson, Sunnyside, and Flowing Wells district schools. To date, 42 sixth grade teachers have participated in the program and APW-UA volunteers delivered groundwater flow model presentations in 29 sixth grade teachers' classrooms instructing 1,591 students.

In response to a needs assessment for the Phoenix Valley, APW teamed with Arizona State University for the fifth year in a row to deliver a 2-day Advanced Water Educators' Workshop: Water and Agriculture. The workshop engaged 22 educators who report reaching 2,357 students each year. In addition, Northern Arizona University teacher training workshop engaged 36 pre-service teachers in learning to teach relevant water topics through interactive APW lessons. Locally, in the Tucson area, an invitation from the Biosphere 2 STEM Academy resulted in engagement of 46 K-3 teachers who will reach 1,864 students annually with locally relevant STEM education.

SWAP School Water Audit 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. The School

Water Audit Program (SWAP) develops and sustains mutual responsibility for efficient water use through school and community connections by:

- installing simple water efficient devices,
- generating credible water-use data that is compelling and motivating, and
- developing data-driven recommendations for water and cost savings.

The 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.

To date Arizona SWAP's have saved 7 million gallons of water per year. Students become leaders by communicating results to adult decision-makers, including:

- Yavapai County Water Advisory Committee (Cottonwood)
- Metropolitan Energy Council (Tucson)
- US Green Building Council, Arizona Chapter (Tucson)
- Tucson Unified School District School Board
- Mansfeld Site Council

Other student initiatives growing out of their SWAP experience include:

- a "how to" video to use at other schools
- a SWAP newsletter
- a Water Conservation Facebook page

City/County Water Education Programs

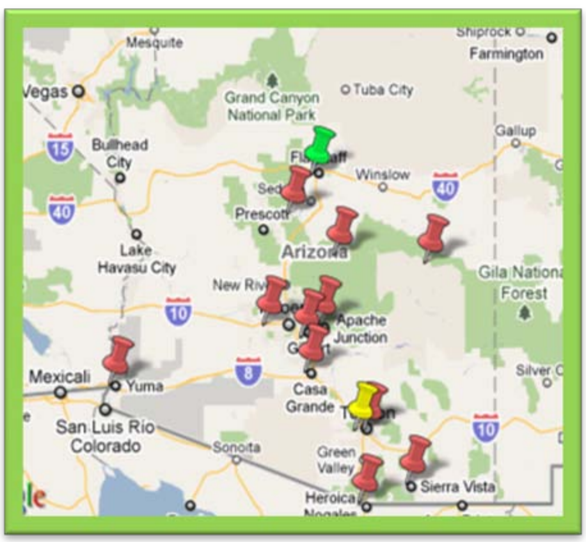
In Pinal County, the Abbott Fund and Laboratories contributed $200,000 over a 2-year period to implement APW programs. Abbott employees and other volunteers were trained to deliver water education lessons and facilitate school water audits. Four hundred water conservation kits, including efficient faucet aerators and toilet leak detection devices, were distributed to all Abbott Laboratories employees and are expected to save 288,125 gallons annually. Through a partnership with the Greater Casa Grande Chamber of Commerce, a monthly water savings tip is included in their monthly newsletter. Five Casa Grande restaurants participated in the water efficient Spray Valve Replacement Program. Through targeted education and water efficiency programs (community, K-12, residential and business) 2,372, 671 gallons of water is projected to be saved annually due to the installation of water conserving devices through the School Water Audit and Abbott Employee Spray Valve Replacement Programs.

In 2010, the third year that APW was invited to provide a professional development workshop in the Yuma area, 55 summer school teachers participated. These teachers report teaching 1,801 students annually with techniques modeled in the workshop and water content. The Yuma Water Festival included 21 fourth grade classes with 497 students and 34 parents.

In Yavapai County an Arizona Water Festival was held for 808 fourth grade students and got the positive attention of the Casa Grande School District. Six workshops were conducted for 77 participants who report reaching 979 students annually. In addition, 43 docents were trained to lead "Wild over Water" lessons in the classroom. A trained docent adopted a fourth grade class and delivered four lessons on four separate dates to their adopted class. Volunteers visited classrooms with grade level specific lessons to 54 classrooms reaching 1,430 students. A modified School Water Audit was conducted with 244 students. A 2-hour groundwater flow model presentation was delivered to 12 students at Tri-City Prep. All the APW trained area teachers attended the Water Festival professional development workshop and participated in the Verde Valley Water Festival with 476 students.

Arizona Makes a Splash with Project WET Water Festivals Program

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 engaged and instructed over 40,000 students in the previous ten years of the program's existence. This reporting period water festivals reached 5,811 students, and 175 teachers. Lessons were conducted by 561 trained volunteers, representing nearly 3,000 volunteer hours, or more than $60,000 of in-kind donation in the form of volunteer time. Over 94% of participating teachers agree that water festival participation increases student understanding of the standards based concepts covered. Students who participate in the Water Festival Program know more about water topics, are more interested in water conservation, and more interested in learning more about water after the festival than they were before. This project attracts about $65,000 annually in event funding from statewide partners and even more in-kind donations. Water Festivals are held all over the state, where volunteers have become loyal supporters and return year after year to continue their involvement. The map below shows all of the locations of water festivals for this year.



In addition to the fourth grade program Arizona Project WET also has supported small school based water festivals for smaller schools in Flagstaff and Tucson, incorporating older students into the program by training them to teach the younger students. With funding from the Arizona Department of Environmental Quality, APW also piloted a small Water Quality Festival program with middle schools students. Over two events with Tucson middle school students, 260 students participated in activities related to water quality led by APW staff and volunteers. The programs led the way to the Water Investigations Program, now in a full pilot for the 2010-11 fiscal year.

Laurel Clark Earth Camp

Laurel Clark Earth Camp is a collaboration between the Arizona-Sonora Desert Museum and the University of Arizona. Holly Thomas-Hilburn serves as the University of Arizona instructor in the middle and high school programs. Each program is a two- week field science and investigations program for students with an emphasis on environmental science and stewardship. The program reaches 20 middle school students and 20 high school students each year, and incorporates inquiry-based hands-on learning as well as the learning of outdoor skills and practical skills in conserving resources. Seventy percent of students expressed and increased interest in science-related careers after participating in the program, and 93% reported feeling closer to nature. Students explore their role in the Colorado River Watershed and the scientific evidence for climate change.

Water Investigations Program

The *Water Investigations Program (WIP) is* a new *project-based learning experience* that integrates *inquiry-driven, STEM education* into relevant instruction. The WIP will focus on middle school students and teachers throughout the Phoenix Valley, with special focus in the west Phoenix area. The WIP first engages students in a water audit of their school and homes that teaches good scientific practice and fundamental inquiry questioning, then focuses on building connections between urban water use and Arizona's riparian areas. The program culminates in a field trip to a Nature Conservancy riparian area where students are challenged to design and conduct their own investigations and then present their findings. Our goal is to engage 20 teachers in a year-long, paid professional development Cohort over the 2011-2012 school year. Teachers will be supported by APW staff based in Phoenix that will be available for in-classroom assistance for program implementation support.

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 (http://ArizonaNEMO.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. The NEMO team provides 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. NEMO sponsored and organized the Coordinated Resource Management 2010 Arizona meeting with Extension and NRCS in Phoenix, Arizona, November 5, 2010.

NEMO conducted workshops, training sessions and continuing education lectures include:

Workshops

- “WELL, What do we Know?” for Graham County Extension w/Janick Artiola (03/27/10) Solomon
- “WELL, What do we Know?” for Maricopa County Extension w/Janick Artiola (05/01/10) Chandler
- “WELL, What do we Know?” for Pima County Extension w/Janick Artiola (06/05/10) Arivaca

NEMO Program Training

- Oak Creek Watershed Improvement Council – “AGWA Modeling” Carie Deatherage (03/15/10) Tucson
- San Francisco Watershed Improvement Council, “GIS/GPS Mapping” w/Renee Johns, (04/22/10) Menges Ranch (Clifton)
- Wet/Dry Mapping of the Agua Fria, Trainings (05/08/10), (06/17/10) and mapping June 19, 2010 Renee Johns, Carie Deatherage, Steve Amesbury
- Oak Creek Watershed Improvement Council, “GIS/GPS mapping” w/Renee Johns, (05/29/10) Sedona

- San Francisco Watershed Improvement Council, “GIS/GPS mapping” w/Renee Johns, (06/07/10) Blue
- Oak Creek Watershed Improvement Council, “GIS/GPS mapping” w/Terry Sprouse and Renee Johns (06/12/10) Oak Creek Canyon
- Oak Creek Watershed Improvement Council, “NEMO Fuzzy Logic Decision Tools”, (07/07/10) Sedona
- Granite Creek WIC, Prescott (Deatherage) 1-12
- Gila Watershed Master Watershed Stewards field trip, Graham/Greenlee County (Uhlman) 1-22
- Coyote Creek (Little Colorado Watershed) meeting, Show Low (Uhlman) 1-26
- Agua Fria Watershed Partnership, Distribution of NEMO BMP Manual, Arconsanti , 2-1
- San Pedro WIC GPS/GIS Training, St. David (Uhlman, Johns, Craven, Underwood) 2-5
- La Paz County Extension + Colorado River Indian Tribe NEMO presentation and distribution of NEMO Plan, Parker (Uhlman) 2-22

Continuing Education Units (CEU) Lectures
- For Az Water Well Association (NGWA) – “Testing for Arsenic” (01/09/10) Gateway Community College, Phoenix
- For ADEQ Water System Certification Program – “Arizona Water Resources” (01/21/10) Cliff Castle
- For ADEQ Water System Certification Program – “Arizona Water Resources (02/10/10) BioSphere II
- For Az Rural Water Association, Water Systems Certification Program – “IMS/GIS Training” with Renee Johns, “Arizona Water Resources”, “Arsenic in Arizona Groundwater”, and “What’s IN the Water – Toxins and Pathogens” (08/10/10) Han Dah

MASTER WATERSHED STEWARDS PROGRAM

In the seventh year of funding from the Arizona Department of Environmental Quality (ADEQ), the Arizona Master Watershed Steward (MWS) Program continues to uphold its mission by educating and training citizens across the state of Arizona to serve as volunteers in the protection, restoration, monitoring, and conservation of their water and watersheds. The main focus of this year’s programming was to expand the focus of the MWS Program to enhance watershed education statewide, while better addressing local nonpoint source pollution issues and water quality in the watersheds targeted by ADEQ. The MWS Program is working primarily with Prescott Creeks Preservation Association (PCPA), Oak Creek Watershed Council (OCWC), Gila Watershed Partnership (GWP), Little Colorado RC&D/Coyote Creek WIC, Tonto Watershed Improvement Group (TWIG), San Pedro/Coronado RC&D to develop watershed-based training for these communities. One MWS Course was held in Phoenix, comprising 10-15 classes about watershed science and management. The MWS Program has now trained 450 participants statewide, contributing over 2,600 service hours and making 6,817 face-to-face contacts in the last year.

Evaluation results indicate that participants place a high value on the content and level of knowledge presented in the MWS classes. Participants feel that the classes do increase their awareness of local watershed issues, however the areas with the lowest scores relate to taking action and communicating watershed issues with others. This finding is not surprising because participants are not trained in how to communicate with the public and volunteer action opportunities for participants often are not available. Results suggest a continued need to pair MWS courses with on-the-ground projects, which is precisely the direction the MWS Program is moving. In addition, it illustrates a need for stakeholders receive more in training and education in how to communicate their messages with the community.

STUDENTS SUPPORTED

WRRC Information Transfer Program Supported Students
Stephan Elizander Pryzbylowicz, Information Science, MS

- Perla Garcia, Education, BA
- Corey Crosby, Computer Science, BS
- Patrick Hayes, English, BA
- Kevin Pieters, Marketing, MBA

WSP-WRRC Supported Students

- Jessica Gerlach, Fine Art, MFA
- Greta Anderson, Geography & Development, MA
- Tiffany Tom, Law, JD
- Valerie Herman, Soil, Water & Environmental Science, MA, 2011
- Marissa Isaak, Geography and Development, PhD
- Jorge Lara-Alvarez, Agricultural & Resource Economics, PhD
- Anubha Misha, Family & Consumer Studies, MS
- Kevin Pieters, Marketing, MBA
- James McGinnis (WSP Graduate Assistant Outreach) Landscape Architecture & Planning, MP
- Yancy Lucas, WSP (Graduate Assistant Outreach) Landscape Architecture & Planning, MP

APW Supported Students

- Brian Underwood, Environmental/Regional Planning, MS; Geograhic Information Science (GIS) graduate certificate
- Angela Athey Chemical Engineering, BS May 2011
- Rex de Roulhac History, BA

Arizona NEMO Supported Students

- Hui Chen, Natural Resources, PhD
- Steve Amesbury, Arid Land Studies, PhD
- James Summerset, Planning, MS
- Tim Craven, Planning, MS
- Jonathan Burnett, Soil, Water, Environmental Sciences, MS
- Anne Purkey, Hydrology, BS

PRESENTATIONS

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

1. Quanrud, D. 2010, “ECs: Concentration and Fate in Wastewater and Groundwater.” Presented at the forum Recharge of Treated Wastewater to Groundwater: What are the Risks, Verde Watershed Association, Prescott, Arizona, November 13, 2010.
2. Callegary, James et al. 2011, Linking hydrology, geology, chemistry, and biology in the Upper Santa Cruz River Basin. Santa Cruz River Researcher's Day presentation, March 29, 2011, Tucson, Arizona.

3. McAndrew, Rose M., James B. Callegary, and Mark L. Brusseau, 2011, Groundwater Contaminant Transport Modeling in the Upper Santa Cruz Basin, Santa Cruz River Researchers' Day Poster Presentation, March 29, 2011, Tucson, Arizona, and University of Arizona, Department of Hydrology and Water Resources' El Dia del Agua, March 30, 2011, Tucson, Arizona.
4. McAndrew, Rose M. 2010, Developing a Groundwater Contaminant Transport Model along the Effluent-Dominated Reach of the Santa Cruz River. USGS Border Environmental Health Initiative (BEHI) Interdisciplinary Showcase Presentation, October 12, 2010, Tucson, Arizona.
5. Megdal, Sharon, Roberto Sención, Christopher A. Scott, Florencio Díaz, Lucas Oroz, James Callegary, Robert G. Varady. 2010. Institutional Assessment of the Transboundary Santa Cruz and San Pedro Aquifers on the United States – Mexico Border. UNESCO-IAH-UNEP Conference, Paris 6-8 December 2010.
6. Megdal, Sharon B. "Institutional Mechanisms for the Assessment and Management of Transboundary Aquifers: The Importance of Partnerships." Presentation given at the Scientific Segment of the 19th Session of the International Hydrological Programme Intergovernmental Council. July 7, 2010. Paris, France.
7. Megdal, Sharon B. "The U.S.-Mexico Transboundary Aquifer Assessment Program: The Arizona-Sonora Portion as a Case Study." Presentation given at World Water Week. August 20, 2009. Prichard, Andrea, Christopher Scott, Sharon Megdal, Prescott Vandervoet. 2011. Stockholm, Sweden.
8. Uphill Both Ways: Natural Resource Impacts of Inter-Basin Transfers of Freshwater and Sewage at the US-Mexico Border City of Nogales, Sonora, Association of American Geographers annual meeting, April 16, 2011, Seattle, WA.
9. Prichard, Andrea, Christopher Scott, Prescott Vandervoet, Sharon Megdal, 2010, Drought and Urbanization: Water Supply Challenges of Nogales, Sonora, Arizona Hydrological Society Symposium, September 2, 2010, Tucson, AZ
10. Prichard, Andrea, 2010, L'eau et le Corridor de Croissance Urbaine dans le Désert de Sonora: Arizona Centrale jusqu'au Mexique du Nord, U. de Paris 6 Speaker Serie, May 11, 2010, Paris, France.
11. Prichard, Andrea and Christopher Scott, 2010, Stormwater Harvesting in the Santa Cruz Tributaries of Nogales, Sonora, Santa Cruz River Research Day, March 19, 2010, Tucson, AZ
12. Scott, C.A. 2011, The climate-groundwater-energy nexus in Mexico, Workshop on Water, Climate, and Society in Mexico, Guanajuato and San Miguel de Allende, Guanajuato, Mexico, May 11-12, 2011.
13. Scott, C.A. 2011, Groundwater as a strategic resource: managing overdraft or planned depletion? School of Geographical Sciences and Urban Planning Colloquium Series, Arizona State University, Tempe, Arizona, Feb. 9, 2011.
14. Scott, C.A. 2010, Energy Efficiency and Water Systems/ Eficiencia de Energía y Sistemas de Agua (session moderator) and speaker "La escasez de energía y agua: impactos sobre la infraestructura, el crecimiento y el desarrollo económico en Arizona y Sonora (Energy and water scarcity: impacts on infrastructure, growth and economic development in Arizona and Sonora)" Border Energy Forum XVII. Chihuahua, Chih., Mexico, Sept. 29 – Oct. 1, 2010.
15. Scott, C.A. and P. Vandervoet, 2010, Transboundary Aquifer Assessment, Management and Policy, Double session organized and moderated at the annual symposium of the Arizona Hydrological Society, September 3-4, 2010, Tucson, Arizona.
16. Vandervoet, Prescott L., Sharon B. Megdal, Christopher A. Scott. (In Review) Los acuíferos transfronterizos Santa Cruz y San Pedro entre Arizona y Sonora: Estado Actual y Creación de Base de Datos. Fortaleciendo el Dialogo Social: Desarrollo humano transfronterizo en la región Sonora-Arizona. Selected proceedings from the Bi-National coloquium hosted by the University of Sonora and Colegio de la Frontera. Nogales, Sonora May, 2010.
17. Varady, R.G., C.A. Scott, S. Megdal, 2010, Transboundary aquifer institutions, policies and governance: A preliminary inquiry, UNESCO-IAH-UNEP Conference, Paris December 6-8, 2010.

Presented by WRRC professional staff:

1. Thomas-Hilburn, H. and Rupprecht, C. "Perceptions, Misconceptions and Community Connections: What does effective education look like?" WRRC Brown Bag Presentation, December 1, 2010. *(Stakeholder Presentation)*
2. Megdal, Sharon, March 6, 2010, Opening Keynote Speaker "Expanding Your Horizons Women in Science and Engineering Program (WISE)", University of Arizona, Tucson, Arizona.
3. Megdal, Sharon, March 8, 2010, Speaker "Sustainable Tucson Forum on Tucson-Pima County Water Study", Tucson, Arizona.
4. Megdal, Sharon, March 15, 2010, Presentation "Arizona Water Management Issues", Israeli Water Authority, Tel Aviv, Israel.
5. Megdal, Sharon, March 28, 2010, Panelist "The Water Project, Water Policy Panel", Tucson, Arizona.
6. Megdal, Sharon, May 24, 2010, Presentation "Challenges to Sustainability Water Management and the Central Arizona Project", Workshop on Energy, Water and Global Climate Change as a Regional Agenda of the Americas, Pan American Advanced Studies Institute, San Diego State University, San Diego, California.
7. Megdal, Sharon, June 9-10, 2010, Conference Moderator-Water Resources Research Center 2010 Annual Conference, "Creating New Leadership for Arizona's Water and Environment in a Time of Change", University of Arizona, Tucson, Arizona.
8. Megdal, Sharon, June 15, 2010, Presentation "Water, People and the Future: Water Availability for Agriculture in the United States", Toward Sustainable Groundwater in Agriculture International Conference, San Francisco, California.
9. Megdal, Sharon, July 13, 2010, Presentation "Challenges to Sustainable Water Management", Annual Meeting of Western Agricultural College Deans, Tucson, Arizona.
10. Megdal, Sharon, July 15-16, 2010, Expert Panelist "Creating a Regional Water Strategy for Central Florida" Workshop, Orlando, Florida.
11. Megdal, Sharon and Joanna Nadeau, August 25, 2010, Presentation "Conserve to Enhance: Supporting Environmental Water Needs through Voluntary Conservation"
12. Colorado Water Congress Water Conservation Workshop, Vail, Colorado.
13. Megdal, Sharon, September 8, 2010, Presentation "Water, People, and the Future: Water Availability for Agriculture – and others – in the United States", USDA Agricultural Research Service Water Availability & Watershed Management Customer/Stakeholder
14. Workshop, Chicago, Illinois.
15. Megdal, S Megdal, Sharon, September 15, 2010, Presentation "Challenges to Sustainable Water Management in Arizona", Institute of the Environment Honors College Colloquium, University of Arizona, Tucson, Arizona.
16. Megdal, Sharon, September 21, 2010, Presentation "Water Management Collaboration and Challenges" International Visitors Sponsored by the U.S. Department of State, Water Resources Research Center, Tucson, Arizona.
17. Megdal, Sharon, September 28, 2010, Presentation "Water Management and Policy in Arizona and the Potential for Public-Private Partnerships", National Council for Public Private Partnerships Annual Conference, Phoenix, Arizona.
18. Megdal, Sharon, September 28, 2010, Panelist "Water Sustainability", Special 30 minute issue of Horizon, KAET PBS Television, Phoenix, Arizona.
19. Megdal, Sharon, September 30, 2010, Presentation "Challenges to Sustainable Water Management in Tucson, Arizona and the Southwest", Milagro Cohousing Seminar, Tucson, Arizona.

20. Megdal, Sharon, October 4, 2010, Guest Lecture "Barriers and Opportunities for the Use of Scientific Information: Making the Connection between Science and Decision Making" seminar, Geography 696j (Professor Connie Woodhouse), University of Arizona, Tucson, Arizona.
21. Megdal, Sharon, October 13, 2010, Panelist "The Talent Crisis: Who is Going to Replace You?", Annual Meeting of the National Association of Water Companies, Tucson, Arizona.
22. Megdal, Sharon, October 19, 2010, Presentation "The WRRC and our Water Management and Policy Focus", Presentation to guests from Tunisia, Tucson, Arizona.
23. Megdal, Sharon, November 2, 2010, Presentation "Water, People and the Future: Availability for Agriculture – and others – in the United States", Symposium-"The Blue-Green Revolution: Why Water Availability and Water Management Will Be Key to Success in Bio-Energy and Environmental Security", ASA/CSSA/SSSA, 2010 International Meetings, Long Beach, California.
24. Megdal, Sharon and Joanna Bate November 8, 2010, Presentation "Quantifying and Funding Water for the Environment: How Researchers Assist Practitioners", Drylands, Deserts and Desertification Third International Conference, sponsored by Ben Gurion University, Israel.
25. Megdal, Sharon, November 9, 2010, Plenary Presentation "Restoration Success Stories from Arizona", Drylands, Deserts and Desertification Third International Conference, sponsored by Ben Gurion University, Israel.
26. Megdal, Sharon, November 11, 2010, Presentation "Water Management Complexities of the Lower Colorado River Basin: The Case of the Imperial Irrigation District Water Transfer and the Salton Sea", Drylands, Deserts and Desertification Third International Conference, sponsored by Ben Gurion University, Israel.
27. Megdal, Sharon, November 22, 2010, Presenter and Moderator "Our Water Future, Forum" sponsored by the TRIF Water Sustainability Program, University of Arizona, Tucson, Arizona.
28. Megdal, Sharon, December 9-10, 2010, Expert Panelist "Integrated Transboundary Groundwater Management, Tools and Methods", UNESCO Second Pilot Course, UNESCO, Paris, France.
29. Megdal, Sharon, January 31, 2011, Presentation "The Central Arizona Groundwater Replenishment District's Role in Meeting the Renewable Water Supply Needs of Central Arizona", USDA Agricultural Research Service, Maricopa, Arizona.
30. Megdal, Sharon, January 13, 2011, Presentation "Water, People and the Future: Challenges Associated with Meeting Competing Water Demands, Global Implications for Domestic and Industrial Water Reuse Workshop", Starr Pass Resort, Tucson, Arizona.
31. Megdal, Sharon, February 2, 2011, Presentation "Water Sustainability Issues in Arizona", Rural Water Infrastructure Committee, Arizona Water Infrastructure Finance Authority, Tucson, Arizona.
32. Megdal, Sharon, Creating a Regional Water Strategy for Central Florida Workshop, Orlando, FL, July 15-16, 2010.
33. Nadeau, WRRC programs poster presentation, UA Outreach Meet Yourself Event, Mar. 4, 2010.
34. Nadeau, Lecturer, Arizona Water Policy (Prof. Sharon Megdal), Tucson, AZ, Mar. 26, 2010.
35. Nadeau, Conserve to Enhance Presentation to potential Las Cruces pilot partners (SW Environmental Center; LC Water Conservation Coordinator), Las Cruces, NM, April 28, 2010.
36. Nadeau, Environmental Programs Poster Presentation at UA President's Club Event, May 3, 2010.
37. Rupprecht, C. "Arizona's Master Watershed Steward Program." Oak Creek Watershed Council Meeting, August 13, 2010.
38. Rupprecht, C., J. Nadeau and S. Megdal, "Meeting the Challenge of Water for the Environment: Innovative Tools for Restoration Practitioners." Arizona Riparian Council Annual Meeting, Yuma, AZ, March 2011.
39. Schwartz, Kerry, "School Water Audit Program Volunteer Training", Mansfeld Middle School SWAP, Tucson, Arizona, March 9, 2010.

40. Schwartz, Kerry, “UA Student Volunteer Training for the Science Pavilion”, Festival of Books at the University of Arizona, Tucson, Arizona, March 12, 2010.
41. Schwartz, Kerry, “Water Education for the 21st Century: Arizona Project WET”, Public Perceptions & Acceptance Working Group of the Blue Ribbon Panel, Phoenix, Arizona, March 26, 2010.
42. Schwartz, Kerry, “Arizona Conserve Water Professional Development”, Mesa School District Teachers, Mesa, Arizona, April 3, 2010.
43. Schwartz, Kerry, “The Salt River: From H to OH”, Professional Development delivered with Center for Teacher Success at SRP s PERA Club, Stewart Mountain Dam, April 17, 2010.
44. Schwartz, Kerry, “Water Education for the 21st Century: Arizona Project WET”, White Mountain Nature Center Board, Show Low Library, Show Low, Arizona, May 15, 2010.
45. Schwartz, Kerry, “Water Education for the 21st Century: Arizona Project WET” for the Blue Ribbon Panel Public Perception/Acceptance Working Group, Tucson, Arizona, March 26, 2010.
46. Schwartz, Kerry, “Water Education for the 21st Century: Arizona Project WET,” White Mountain Nature/Wildlife Center Board, Tucson, Arizona, May 15, 2010.
47. Schwartz, Kerry, “Integrating Sustainability into Extension Programs”, Tucson, Arizona, May 19, 2010.
48. Schwartz, Kerry, “Middle School Student Presentation on their School Water Audit Program”, Tucson Energy Commission Board Meeting, Tucson, Arizona, May 20, 2010.
49. Schwartz, Kerry, “Middle School Student Presentation on their School Water Audit Program”. U.S. Green Business Council, Tucson Chapter, Tucson, Arizona, May 20, 2010.
50. Schwartz, Kerry, “Colorado River: One River Many Voices”, FAIR Pima County Teachers Conference, Tucson, Arizona. June 2, 2010.
51. Schwartz, Kerry, “Colorado River Watershed One River Many Voices”, at Pima County Educators’ Fair, Tucson, Arizona, June 2, 2010
52. Schwartz, Kerry, “Fostering Community Leadership through Action Education: The School Water Audit Program (SWAP) at Mansfeld Middle School”, UA WRRC Environmental Leadership Conference, Tucson, Arizona, June 9, 2010.
53. Schwartz, Kerry, “Fostering Environmental Leadership in K-12 Education Working Session”, WRRC Annual Conference, Tucson, Arizona, June 10, 2010.
54. Schwartz, Kerry, “Yuma K-8 English Language Learner Professionals Development Using Arizona Project WET”, Teacher Professional Development for Yuma District 1, Yuma, Arizona, June 11, 2010.
55. Schwartz, Kerry, “Full Option Science System Integrated Water Kit Training”, Professional Development for 3rd Grade Teachers, Tucson, Arizona, June 15, 2010.
56. Schwartz, Kerry, “An Advanced Water Education Workshop: Water and Agriculture”, Arizona State University GIOS Program, Tempe, Arizona. June 17, 2010.
57. Schwartz, Kerry, “A Scientific Investigation Workshop Focused on Water”, Professionals Development for RET G-K-12 Students at the University of Arizona, Tucson, Arizona. June 21, 2010.
58. Schwartz, Kerry, “STEM-focused Water Education for K-3 Teachers”. Teacher Professional Development for the B-2 Institute, Arizona Center for STEM Teachers Summer Institute, Biosphere 2, Arizona, July 22, 2010.
59. Schwartz, Kerry, “STEM Education and Arizona Project WET,” for STEM teachers at Biosphere 2, Tucson, Arizona, June 22-23, 2010.
60. Schwartz, Kerry, “Raining Cats and Dogs with Arizona Project WET: a K-3 Professional Development Workshop”, Casa Grande School District, Casa Grande, Arizona, June 24, 2010.
61. Schwartz, Kerry, “H2O Olympics: Exploring Water with Arizona Project WET: a 4-8 Professional Development Workshop”, Casa Grande School District, Casa Grande, Arizona, June 24, 2010.
62. Schwartz, Kerry, “Arizona School Water Audit Program”, Association of Natural Resources Extension Professionals Conference, Fairbanks, Alaska, June 29, 2010.

63. Schwartz, Kerry, “School Water Audit Program Pinal County Teacher Cohort Professional Development Workshop Series”, Pinal County, Arizona, September 7, 2010.
64. Schwartz, Kerry, “Water Investigations Program Teacher Cohort Professional Development Workshop Series”, Arizona, September 11, 2010
65. Schwartz, Kerry, “Americorps Sweetwater Wetland Water Festival Facilitator Training”, Water Resource Research Center, Tucson, Arizona, September 14th/17th/24th 2010.
66. Schwartz, Kerry, “Americorps 6th Grade Groundwater Flow Model Facilitator Training”, Water Resource Research Center, Tucson, Arizona, October 14, 2010
67. Schwartz, Kerry, “Part of the Worldwide Well: the Arizona Water Story”, Teacher Professional Development delivered with Center for Teacher Success at the Arizona Audubon Center, Phoenix, Arizona, October 16, 2010.
68. Schwartz, Kerry, “Arizona Project WET: 21st Century Learning for 3rd through 7th grades”, Teacher Professional Development at Paradise Learning Center, Paradise Valley, Arizona. October 19, 2010.
69. Schwartz, Kerry, “Arizona Project WET Water Education Workshop for Navajo County Teachers”, Teacher Professional Development for Navajo County Teachers, Show Low, Arizona, October, 23, 2010.
70. Schwartz, Kerry, “Pinal County Water Education Teacher Cohort Professional Development Workshop Series”, Pinal County, Arizona, October 25, 2010.
71. Schwartz, Kerry, “Energy & Environmental Science 6th Grade Unit” Professional Development Workshop for Teachers, Tucson, Arizona, January 12, 2011.
72. Schwartz, Kerry, “Full Option Science System Integrated Water Kit Training”, Professional Development for 3rd Grade Teacher, Tucson, Arizona, January 14, 2011.
73. Schwartz, Kerry, “School Water Audit Program with 6th Grade Students”, Mansfield Middle School SWAP, Tucson AZ, January 15, 2011.
74. Schwartz, Kerry, “School Water Audit Program Professional Development” Mesa School District Teachers, Mesa, Arizona, February 6, 2011.
75. Schwartz, Kerry, “6th Grade Arizona Water Festival Pilot Project”, Direct Student Outreach Program at Gridley Middle School, Tucson, Arizona, January 26, 2011.
76. Schwartz, Kerry, “Water Resources in Tucson” Tohono Chul Docent Training Class, Tucson, Arizona, February 10, 2011.
77. Schwartz, Kerry and Mike Crimmins, “Adapting to Climate Change: What can we Learn from the History of Drought in the West”, Professional Development Workshop for Teachers at the B-2 Institute, Arizona Center for STEM Teachers Summer Institute, Biosphere 2, Arizona, April 25, 2010.
78. Schwartz, Kerry, M.A. Stoll and Candice Rupprecht, “In-classroom Water Audit Presentation Program, Water Resources Research Center, Tucson, Arizona, February 15, 2011.
79. Schwartz, K. and Rupprecht, C. “Arizona’s School Water Audit Program.” Association of Natural Resource Extension Professionals 7th Biennial Conference, Fairbanks, AK, June 2010
80. Uhlman, Kristine, Agua Fria Community Watershed Group, Cordes Junction – “Isotopes on Groundwater Age-Dating” March 2, 2010
81. Uhlman, Kristine, Santa Cruz River Researcher’s Day, Tucson - “NEMO Santa Cruz Watershed-Based Plan” March 19, 2010
82. Uhlman, Kristine, ‘Science Saturday’ Pima County Extension and Santa Rita Experimental Station, “What’s IN your Water?” May 8, 2010
83. Uhlman, Kristine, Arizona County Supervisors Association, “Proof of Concept: Aquifer Vulnerability and the Importance of Well Head Protection,” May 26, 2010, Phoenix
84. Uhlman, Kristine and Renee Johns, “Arizona Rural Water Association Annual Meeting Presentations”, ARWA, Small Utilities Association, Han Dah, Arizona, August 10, 2010.

85. Uhlman, Kristine, “University of Wisconsin, Stout Campus, Community Outreach Program”, Water Quality: People and Science Collaborating for our Future. Menominee, Wisconsin. September, 15, 2010.
86. Uhlman, Kristine, “CEU Lecture: ADEQ Water System Certification Program, Drinking Water Professional Development”, Arizona Water Resources, BioSphere II, Arizona, October 10, 2010.
87. Uhlman, Kristine, Mike Crimmins, Chris Eastoe, Zack Guido and Anne Purkey, “Water Supply Drought Vulnerability in the Arizona Desert”, Global Land Project 2010 Open Science Meeting, Land Systems, Global Change and Sustainability, Phoenix, Arizona, October 18, 2010.
88. Uhlman, Kristine, “Audubon National Round-Up In-Service: Isotopes and Groundwater Age-Dating”, Saguara Lake Ranch, Arizona, November 12, 2010.
89. Uhlman, Kristine, “Pima County Extension and Santa Rita Experimental Station Science Saturday”, Santa Rita, Arizona, May 8, 2010.
90. Uhlman, Kristine, “Arizona County Supervisors Association”, Phoenix, Arizona, May, 26, 2010.
91. Uhlman, Kristine and Renee Johns, “CEU Lecture: Az Rural Water Association, Water Systems Certification Program: Arizona Water Resources” Han Dah, Arizona, August, 10, 2010.
92. Uhlman, Kristine, Mike Crimmins, Chris Eastoe, Zack Guido, Anne Purkey and Carie Deatherage, “Rural Water Supply Drought Vulnerability Assessment in the Deseart Southwest, Abstract and Presentation”, Water Education Foundation International Groundwater Conference, Toward Sustainability Groundwater in Agriculture, San Francisco, California. June 16, 2010.
93. Uhlman, Kristine, Mike Crimmins, Chris Eastoe, Zack Guido and Anne Purkey, “Groundwater Drought Vulnerability Assessment in an Arizona Desert Aquifer, Abstract and Presentation”, Peer-reviewed, 2010, UCOWR/NIWR Annual Conference. Seattle, Washington, July 14, 2010.
94. Uhlman, Kristine, Mike Crimmins, Chris Eastoe, Zack Guido and Anne Purkey, Arizona Hydrologic Society Presentation and Abstract Publication, “Groundwater Age-Dating to Assess Drought Vulnerability of the Arivaca Aquifer”, Arizona Hydrological Society Symposium co-hosted with the International Association of Hydrologists, Dryland Hydrology: Global Challenges, Local Solutions. Arizona, Scottsdale, Arizona, August 1-3, 2010
95. Uhlman, Kristine, “Science Saturday - 'What's IN your Water?”, Pima County Extension and Santa Rita Experimental Station, Santa Rita Experimental Station, Green Valley, Arizona, May 8, 2010.
96. Uhlman, Kristine, Agua Fria Community Watershed Group-Cordes Junction, “Isotopes on Groundwater Age-Dating”, March 2, 2010;
97. Uhlman, Kristine, Santa Cruz River Researcher’s Day-Tucson, “NEMO Santa Cruz Watershed-Based Plan”, March 19, 2010;
98. Uhlman, Kristine, Gila Watershed Partnership-Safford, “Chemicals, Toxins, Pathogens What s IN your Water?”, September 8, 2010;
99. Uhlman, Kristine, Central Arizona Geology Club-Prescott, “Arsenic in Arizona Groundwater: Fate and Transport Characteristics”, October 12, 2010;
100. Uhlman, Kristine, Maricopa Mountain Water Company-Amarillo Valley “Arizona Groundwater Resources”, November 14, 2010.
101. Uhlman, Kristine, “NEMO Program Workshops/Trainings”, Oak Creek Watershed Improvement Council, “AGWA Modeling”, Tucson, Arizona, March 15, 2010;
102. Uhlman, Kristine, San Francisco Watershed Improvement Council, “GIS/GPS Mapping”, Menges Ranch (Clifton), April 22, 2010; Oak Creek Watershed Improvement Council “GIS/GPS mapping”, Sedona, Arizona, May 29, 2010; San Francisco Watershed Improvement Council, “GIS/GPS mapping”, June 7, 2010; Oak Creek Watershed Improvement Council, “GIS/GPS mapping”, Oak Creek Canyon, Arizona, June 12, 2010;
103. Uhlman, Kristine, “Wet/Dry Mapping of the Agua Fria”, June 19, 2010;

104. Uhlman, Kristine, Oak Creek Watershed Improvement Council, “NEMO Fuzzy Logic Decision Tools”, Sedona, Arizona, July 7, 2010;
105. Uhlman, Kristine, AGWA Training of ADEQ Staff”, w/ Phil Guertin. Phoenix, Arizona. August 19, 2010;
106. Uhlman, Kristine, San Pedro Targeted Watershed Improvement Council, “NEMO Support and Trainings”, St. David, Arizona, November 18, 2010; Little Colorado/Coyote Creek Targeted Watershed Improvement Council, “NEMO Support and Trainings”, Eagar, Arizona. December 15, 2010.
107. Uhlman, Kristine and Janick Artiola, "WELL, What do we know? Workshop Series”, Arizona Water Well Association, Graham County, Arizona, March 27, 2010. Pinal County, Arizona. May 1, 2010. Pima County, Arizona. June 5, 2010. Gila County, Arizona. November 8, 2010 and November 10, 2010. Arizona. December 16, 2010.
108. Uhlman, Kristine, L. Masters, S. Tuttle, C. Martinez, J. Waits, G. Farrell and M. Adolf, “Are Participatory Methods of Extension Education Sustainable?” 2010.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	8	0	0	0	8
Masters	2	0	0	2	4
Ph.D.	2	0	0	1	3
Post-Doc.	0	0	0	0	0
Total	12	0	0	3	15

Notable Awards and Achievements

Kerry Schwartz's poster, Fostering Community Leadership through Action Education: The School Water Audit Program (SWAP) at Mansfeld Middle School, won the most Innovative Project Award, presented at UA WRRC Environmental Leadership Conference on 6/9/2010.

Kerry Schwartz received the 2010 Individual Program Leadership Gold Award in recognition of exemplary leadership of an individual natural resource program, given by Association of Natural Resource Extension Professionals, 6/30/2010

Kerry Schwartz, Candice Rupprecht and Mary Ann Stoll received the 2010 Innovative Program Gold Award for the School Water Audit Program (SWAP) in recognition of an innovative natural resources Extension program which addresses critical community issues and needs, given by Association of Natural Resource Extension Professionals, 6/30/2010.

Ms. Lucy Mullin, the Ph.D. student supported 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 piloted in the City of Tucson with 60 pilot participants. This pilot effort with the City of Tucson has been enhanced through a new linkage with the existing donation checkbox on the Tucson Water bill. Partnerships have expanded significantly with interest from cities in Colorado. Working in collaboration with non-profits and local municipal water professionals in Prescott, and several other Western communities in addition to Tucson, she has succeeded in designing Conserve to Enhance pilot programs tailored to local communities. The evaluation of pilots will result in a report in 2011, to be used in expanding the program to more communities.

Publications from Prior Years

1. 2001AZ213B ("Sources of Nitrate in Groundwaters of the Tucson Basin") - Dissertations - Dejwakh, Navid, 2008, Using nitrogen-15, oxygen-18, and oxygen-17 to determine nitrate sources and removal processes from groundwater, MS Thesis, Department Of Hydrology and Water Resources, The University of Arizona, Tucson, Arizona.