

**Water Resources Research Center
Annual Technical Report
FY 2011**

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 WRRRA, 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 the home of the Water Sustainability Program, one of three programs making up the Water, Environmental and Energy Solutions (WEES) program, funded from the UA's Technology and Research Initiative Fund (TRIF). The WRRC is also the home for Arizona Project WET (Water Educations for Teachers). Initiated at the WRRC in 1991, APW is Arizona's premier water education program. As a Research and Extension unit, the WRRC maintains a mutually beneficial relationship with the Cooperative Extension system.

Research Program Introduction

The University of Arizona's WRRC provides support in the form of "seed" grants for researchers at all three state universities in Arizona, through the WRRRA, 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 and expand understanding of water and water-related phenomena.

During the project year (March 2011 through February 2012) the WRRC funded three projects. One project, awarded through a subcontract to researchers at Northern Arizona University is looking at conditions mediating bioavailability and transport of specific uranium species in non-regulated water sources on Navajo lands. A second subcontract was granted for research at Arizona State University into the effectiveness of constructed wetlands for wastewater treatment in semi-arid environments. The third project, for research done at the University of Arizona, is looking at the potential for formation of iodinated disinfection by-products in water that is treated and recharged to groundwater before reuse (indirect reuse). All three projects received no-cost extensions of the end date because of delay in the start of funding in 2011. Consequently, the research reports document interim results.

The WRRC also administers any WRRRA National Competitive Grants (104(g)) awarded to researchers in Arizona. In 2010, Ty Ferre, UA Department of Hydrology and Water Resource, was awarded a three-year grant for the project "Improving Hydrologic Investigations through Multi-Model Analysis and Discriminatory Data Collection."

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:	AZ-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.

Cooperative Agreement No. 08HQAG0058 Transboundary Aquifer Assessment Program

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.
15. 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.
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 Gastelum Ceballos, 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.

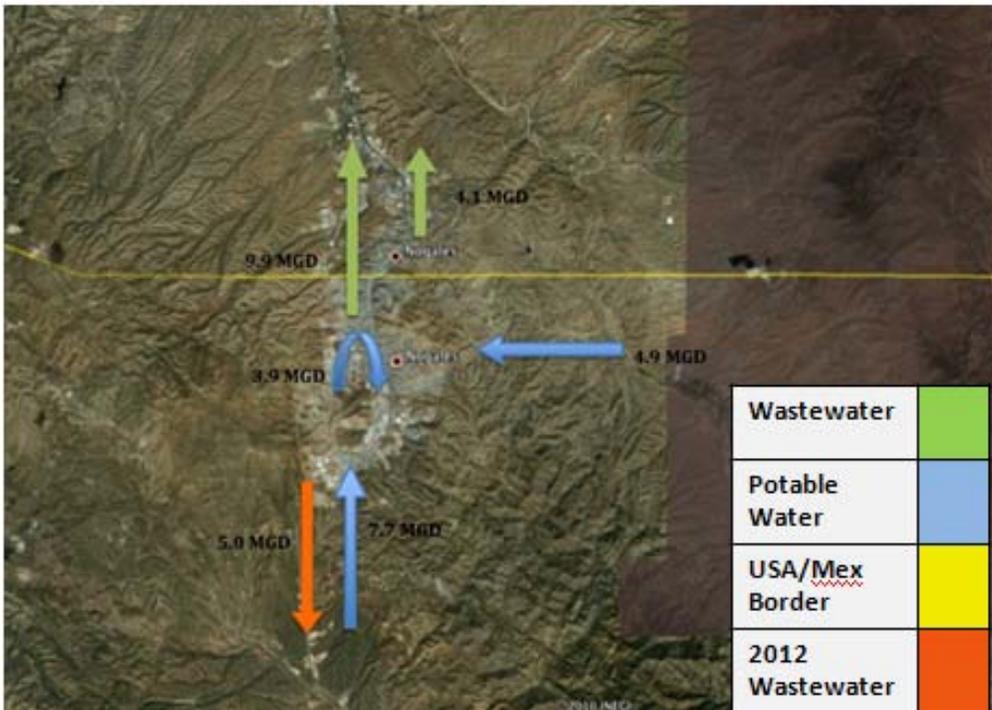


Figure 1. Transboundary and Inter-basin current and projected flows of potable and wastewater.

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 WRRRC 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.

Summary of Activities Completed:

- “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.

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.

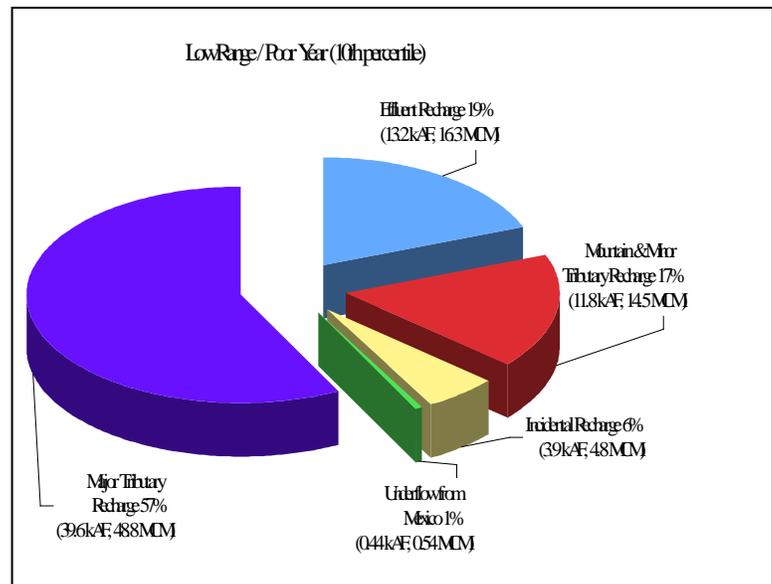


Figure 2. Estimated recharge & inflow for Santa Cruz AMA, low precipitation

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.

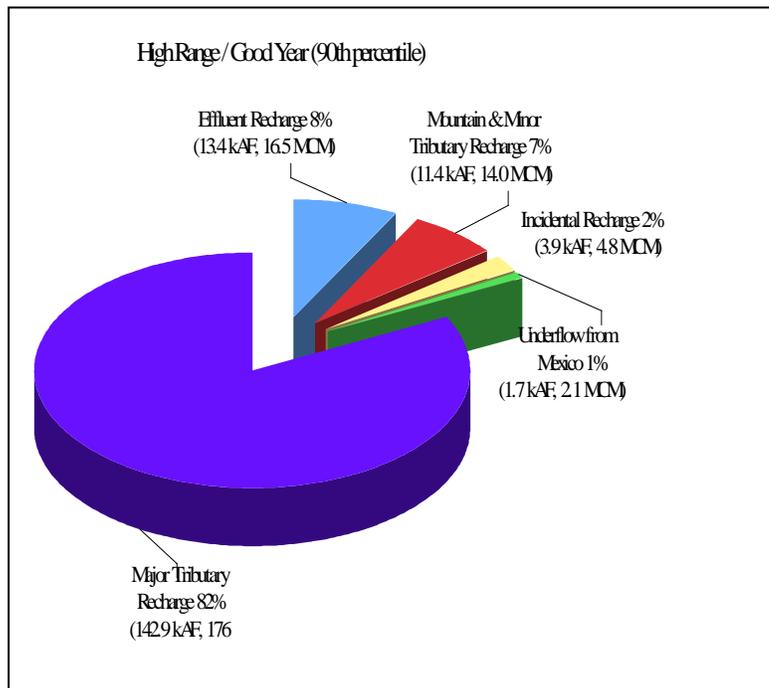


Figure 3. Estimated recharge & inflow for Santa Cruz AMA, high precipitation

The upper San Pedro River basin in Mexico has an area of 1750 km² (CNA 2009a) and the Sierra Vista subwatershed (as defined by the US Geological Survey) has an area of 2460 km² (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 km² (Towne 2003), while the extension of the river basin in Mexico has a surface area of 952 km² (CNA 2010b). The Nogales Wash, classified in Mexico as a separate basin from that of the Santa Cruz River, has an area of 120 km² (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 km² (ADWR 2010). In total, the area of both upper binational basins of the Santa Cruz and San Pedro Rivers covers 7581 km².

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 hm³ (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 assess 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.

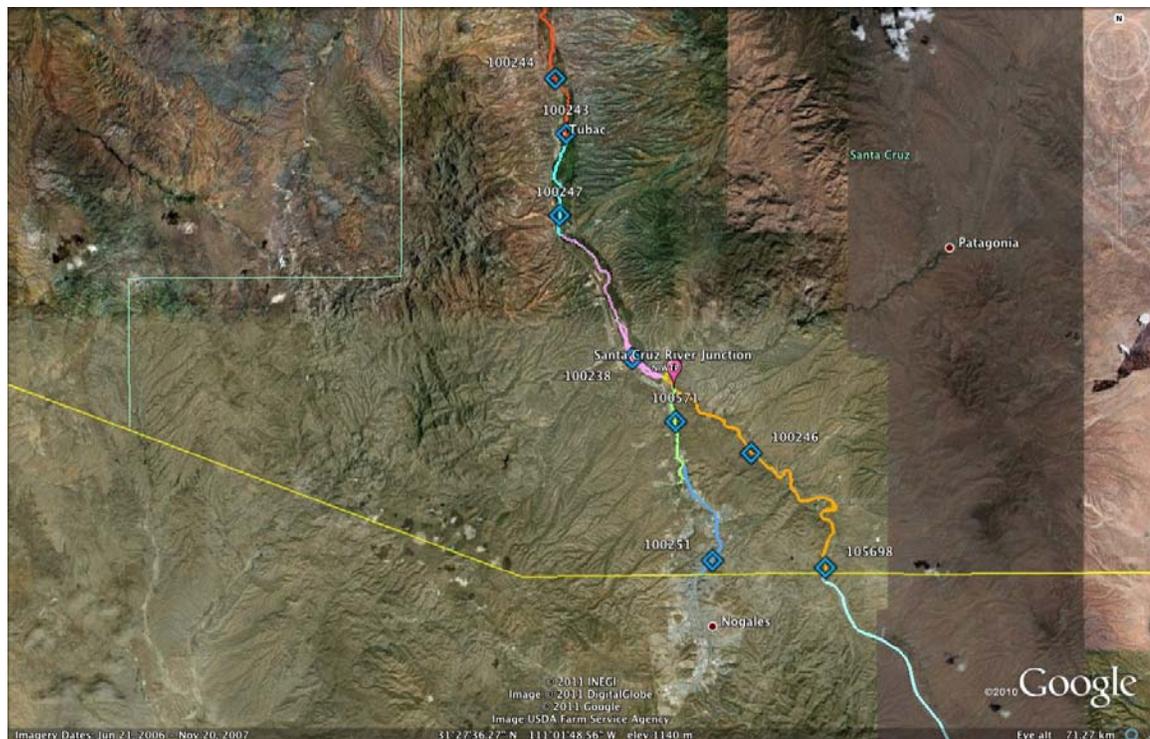


Figure 5. Water Quality Sampling Locations (FOSCR)

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. Senci3n, C.A. Scott, F. D3az, 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. Senci3n, C.A. Scott, F. D3az, L. Oroz, J. Callegary, R.G. Varady. 2010. Evaluaci3n Institucional de los Acu3feros Transfronterizos Santa Cruz y San Pedro en la Frontera M3xico – 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 Energ3a y Sistemas de Agua (session moderator) and speaker “La escasez de energ3a y agua: impactos sobre la infraestructura, el crecimiento y el desarrollo econ3mico 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.

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.

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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
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Research Category:	Ground-water Flow and Transport
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Descriptors:	None
Principal Investigators:	Paul Andrew Ferre

Publications

There are no publications.

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

NIWR/USGS 104(g) National Competitive Grant Program, Grant Number 2010AZ412G

Paul A. Ferre

Problem and Research Objectives

Practicing hydrogeologists are called upon to make specific predictions about future hydrologic conditions that will form the basis for social, economic, and political decisions. The major challenges to accurate hydrologic prediction are: 1) capturing the inherent complexity of hydrogeologic systems in models; and 2) acquiring sufficient informative data to characterize the critical hydrologic processes. Commonly, these modeling and measurement bottlenecks are seen as two interacting, yet separate, aspects of hydrologic science. We propose a novel approach that combines cutting edge tools in hydrologic modeling with a new approach to monitoring network design that addresses both of these fundamental limitations jointly. Specifically, *we propose to test whether multi-model analysis combined with a discriminatory approach to data collection to design leads to the selection of more informative hydrogeologic measurement and monitoring networks.*

Our work on this topic has been divided into two phases. The objectives for Phase I are to develop a mathematical foundation for multi-model analysis and discriminatory data collection, and to assess this novel methodology on both synthetic test problems and data from previously published field experiments. The objectives for Phase II are to apply the methodology in Phase I to field studies in Arizona and Alaska. The field study in Arizona is a reanalysis of hydrologic monitoring data in the San Pedro River Basin, and the field study in Alaska is a hydrologic characterization study for West Twin Creek, a headwaters catchment underlain by discontinuous permafrost. To date, the work on Phase I is complete, and work on Phase II of the project will begin in June 2012.

Principal Findings and Significance

As part of the work in Phase I, computer code was developed to compute Data Discrimination Index values for potential observations, given a user-specified model ensemble. The relatively simple problem of one-dimensional transport of a conservative solute was selected to test the use of the Data Discrimination Index. From very early on in the study, it was clear that (a) it was possible to issue acceptable predictions of solute breakthrough with relatively few conditioning data, and (b) results were sensitive to the choice of likelihood-weighted model averaging technique used to predict solute concentrations. These results showed promise for our technique, subject to the limitations of likelihood-weighted model averaging.

The initial code was extended to benchmark measurement selection by the Data Discrimination Index against an exhaustive search of all possible solute concentration measurement sequences, to demonstrate that our method would identify globally optimal measurement sequences for providing information on model likelihoods. The results of this analysis indicate that solute breakthrough curve predictions conditioned upon a small, highly informative subset of concentration measurements - selected using the Data Discrimination Index - are equally accurate to those conditioned upon much larger datasets. One limitation of this method is that results are sensitive to the population of the model

ensemble used to make predictions. Therefore, we also tested the performance of our method while drawing the true condition from different locations in the model parameter space. We found that the highly informative measurement sequences identified by the Data Discrimination Index were minimally affected by these variations, building confidence in our method.

To provide a more realistic test case for this method, we acquired data from a field-scale bromide transport experiment through unsaturated soils at the Etiwanda field site, California (Butters *et. al.*, 1989). We modified the existing code for compatibility with this dataset as the true condition from which concentration measurements were sampled. We formulated the measurement selection as follows: given a set of five measurements sequential time, to be performed at any depth, the goal is to predict attributes of the solute breakthrough curve at a target depth (3.05 m) beyond the range of available measurements. Predicted attributes included the peak concentration, peak arrival time, and exposure time (the length of time when solute concentration is above some threshold). We then repeated the same benchmarking procedure described above for this case. We found that solute breakthrough curves conditioned upon data from the first five depths were subject to greater error than the solute breakthrough curve conditioned upon data at the target depth. However, the small subset of measurements from the first five depths, selected using the Data Discrimination Index, led to predictions equally accurate to those conditioned upon a much larger measurement set. This is a similar result to that obtained using synthetic data.

The results of synthetic numerical experiments and post-audit analysis of the bromide transport field data were presented at the American Geophysical Union Fall 2011 meeting. We received substantial feedback which we have since incorporated into our code and analyses. We are finalizing a manuscript, to be submitted to the journal *Water Resources Research*, which describes this work. The computer code developed during Phase I of this project is modular and broadly suitable for use with problems different from the specific solute transport problem that we considered. Flexible computer code is essential for the field studies to be undertaken in Phase II of the project.

Work on Phase II of the project during summer 2012 will primarily be focused on the development of hydrologic conceptual models for the West Twin Creek catchment in interior Alaska. To date, a simple transient groundwater flow model has been developed for the West Twin Creek catchment, and accurately captures some features of streamflow hydrograph recorded at the catchment outlet. The suite of future conceptual models will likely include variable depth of the unfrozen soil active layer, and the use of conduit-flow equations commonly used in karst studies, but applicable to thermokarst and soil piping in permafrost-affected areas. Consideration of these hydrologic processes will likely improve model fit to existing data. Then, the procedure of computing DDI and identifying informative measurements will be applied using the code developed during phase I of the project. Potential informative measurements, if possible, will be incorporated into fieldwork at the site to be performed during late July and early August, 2012.

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Characterization of Chelating Agents in Non-regulated Water Sources on Navajo Lands

Basic Information

Title:	Characterization of Chelating Agents in Non-regulated Water Sources on Navajo Lands
Project Number:	2011AZ431B
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Descriptors:	
Principal Investigators:	Jani C Ingram

Publications

There are no publications.

Determination of Chelating Agents in Non-regulated Water Sources on Navajo Lands

Jani C. Ingram, PhD

Problem and Research Objectives

Following the approval of the Manhattan Project in 1942, the United States experienced an increased need for uranium. As a result, extensive uranium mining occurred from the mid to late 1900's on Navajo tribal lands in Northern Arizona, an area rich in natural uranium. Although mining activities have ceased and remediation has been attempted, previous open pit mining still affects those living in the area today; environmental uranium contamination persists in the region. Radiological and chemical properties of uranium in combination with a lack of access to regulated drinking water sources present a serious health concern for residents on the Navajo Reservation.

The potential health effects associated with the ingestion of uranium in drinking water are dependent on a number of variables, including solubility and speciation. The speciation and solubility of uranium in an aqueous environment can be altered by various factors, including pH, water hardness, and concentrations of potential ligands. Environmental mobility of uranium can also be heavily influenced by solubility and speciation. Speciation describes the overall chemical state of elements in solutions, solids, and gases. The distribution of chemical elements depends not only on their concentration, but also on the chemical behavior of complexes containing the element (Bernhard, 2005). Thus, a firm grasp on uranium speciation in aqueous environments is crucial in understanding both its solubility and mobility in the environment and also its bioavailability and potential toxicity (Fortin, 2007). In natural waters, uranium can occur in a variety of different species. A number of factors affecting uranium speciation and solubility in groundwater systems have been identified; these factors include content and leachability of uranium in sediments, proximity of water to the uranium source, degree of hydraulic isolation of the water from dilution by fresher water, climatic effects and seasonal variability, pH, concentrations of other species that can either form strong complexes with or precipitate insoluble uranium species, and presence of highly sorptive materials (Elless, 1997). Additional factors described by Bernhard include redox potential, ionic strength, solubility product, formation of colloids, presence of microorganisms, and types of interfaces present during the interaction of solved and sorbed complexes (Bernhard, 2005). Redox potential, pH, and concentrations of potential ligands have been determined to be key variables affecting uranium speciation and solubility in aqueous environments (Kumar et al., 2011).

The behavior of a metal, such as uranium, may be drastically altered as a result of variations in oxidation state and/or association with specific ligands (Reeder, 2006). In reducing environments, uranium in groundwater is typically present in the tetravalent state, as U(IV), which has a low solubility. U(IV) tends to precipitate as uraninite or UO_2 (s) and remain immobile in waters with low redox potentials (Markich, 2002). In oxidizing environments, however, uranium is more commonly present in the hexavalent state, which has a much higher solubility in comparison to U(IV) (Langmuir, 1997). The higher solubility of the hexavalent state is attributed to the tendency of the +6 cation to form uranyl di- and tri-carbonate anions (Osmond, 1976). The most common U(VI) species is the linear uranyl dioxocation, UO_2^{2+} (Van Horn, 2006). This cation forms stable, soluble complexes that are mobile and greatly affect uranium transport (Markich, 2002).

With respect to aqueous environments, the uranyl cation is one of the most important species. In natural waters, the uranyl cation is the predominant form of uranium; however, its speciation is very complex and highly dependent on various factors, including pH and water hardness (Antunes, 2007). Due to the capacity of the uranyl ion to form extremely stable complexes, it is highly soluble over a wide pH range. In natural waters, the uranyl species can complex with a number of different compounds, including sulfate, silicate, chloride, nitrate, and fluoride; most of the complexes that form possess very high

mobility in aqueous solution (Birke, 2009). However, most of these complexes are weak compared to the complexes that the uranyl cation forms with carbonate and phosphate anions (Markich, 2002).

Uranium, along with other elements in the actinide series, has a strong tendency to form complexes with oxygen-containing ligands; hydroxide, carbonate, and phosphate are ligands most commonly present in natural water sources (Sandino, 1992). In the majority of water sources, uranyl hydroxyl and carbonate species are the most predominant. The importance of these species, however, is highly determined by a number of other factors, including the total concentration of U(VI), redox potential, ligand concentration, and pH (Langmuir, 1978). The effect of pH on uranyl solubility and complexation is two-fold. Increasing pH results in increased complexation of the free uranyl cation by hydroxides and carbonates; increased complexation of heavy metals typically results in decreased bioavailability (Fortin, 2004). However, decreased pH, and thus an increase in protons competing with uranyl ions for binding sites of transport systems on the plasma membrane, has been shown to prevent uranium internalization (Fortin, 2007). The effects of pH counteract one another and make it difficult to interpret data related to the accumulation and toxicity related to the uranyl cation (Fortin, 2004).

At a higher groundwater pH ($\text{pH} > 5$), carbonate will replace any weakly bound hydroxyl species, resulting in a higher concentration of uranyl carbonate complexes. Also, the solubility of any surrounding uranyl minerals in contact with the aqueous environment will increase when carbonate concentration is high, due to the preference of the uranyl cation to form uranyl carbonate complexes in aqueous solution. Unlike uranyl hydroxyl species, uranyl carbonate species do not adsorb strongly to mineral surfaces, and thus, the formation of uranyl carbonate complexes greatly enhances the mobility of uranium in the environment (Abdelouas, 2006). To summarize, the presence of carbonate species in the aqueous environment has two main effects (increasing uranium concentration in solution, and decreasing surface concentrations of uranium), both of which contribute to increased uranium mobility and bioavailability (Langmuir, 1997).

Cationic species present in aqueous solution can also affect uranium speciation. In relation to uranium speciation in ground and surface waters, calcium is one of the most important cations to consider. Under solution conditions in which carbonate complexes overcome all other complexes, calcium content is noted to be one of the primary speciation parameters; concentrations of carbonate complexes, such as $\text{UO}_2(\text{CO}_3)_3^{4-}(\text{aq})$, $\text{CaUO}_2(\text{CO}_3)_3^{2-}(\text{aq})$, and $\text{Ca}_2\text{UO}_2(\text{CO}_3)_3(\text{aq})$, vary with calcium concentration when the system is at equilibrium (Prat, 2009). Equilibrium conditions are described by the equation $\text{UO}_2(\text{CO}_3)_3^{4-} + n\text{Ca}^{2+} = \text{Ca}_n\text{UO}_2(\text{CO}_3)_3^{2n-4}$ (Prat, 2009). These calcium uranyl carbonate complexes are thought to be the predominant form of dissolved hexavalent uranium in numerous uranium containing groundwaters (Stewart, 2010).

Because of their large formation constants ($\log_{10}K^\circ \sim 25 - 30$) (Prat, 2009), calcium uranyl carbonate complexes may play a significant role in the aqueous mobility of U(VI) species at alkaline pH values. Calcium cations may also affect the adsorption of hexavalent uranium through competition for sorption sites, alteration of the surface charge of minerals, and changing the aqueous speciation of U(VI), as described (Fox, 2006). An experimental study conducted by Zheng and colleagues clearly demonstrated the effect of the presence of calcium carbonate in soils on U(VI) sorption; decreased sorption was attributed to the presence and formation of calcium uranyl carbonate complexes, particularly the neutral $\text{Ca}_2\text{UO}_2(\text{CO}_3)_3$ specie (Zheng, 2003).

The overall objective of this work was to collect information that will lead to the determination of uranium speciation in unregulated wells in the southwestern region of the Navajo reservation. This information is needed to assess the bioavailability of uranium from a health standpoint as well as providing an understanding of the transport of uranium in the environment. Both of these concerns are highly dependent on the molecular nature of uranium species present, which is environment dependent. The approach for achieving this objective is to identify specific chelating agents present in the waters.

We had proposed to collect information on both the organic and inorganic chelating agents; however, the instrument that was to be used for the organic work (liquid chromatography/mass spectrometry) was not operational for these studies. Thus, we focused our efforts on the inorganic chelating agents.

Methodology

Water samples were collected from 18 unregulated water sources, located in the southwest region of the Navajo Reservation in Northern Arizona. Table 1 lists the name of the wells, their locations, and the time frame they were collected.

To characterize and quantify anionic species present in various well waters, various analytical techniques will be used. For the analyses of chloride and sulfate anions, ion chromatography (IC) will be utilized; this is a chromatographic technique based on charge interactions. Negatively charged components in the mobile phase interact with the positively charged surface of the stationary phase, allowing for the effective separation of uniquely charged analyte species. For the analysis of nitrate and phosphate anions, flow injection analysis colorimetry will be utilized. Lachat Instruments makes an instrument specifically for the analysis of nitrate and phosphate, which combines sample preparation and colorimetric analysis into one instrument. Bicarbonate concentrations of well water samples will be determined through the use of a simple acid/base titration, a method utilized by the U.S. EPA for the determination of alkalinity in natural water samples.

Table 1. GPS coordinates and sampling months of sampling locations for unregulated water sources in the southwestern region of the Navajo Reservation.

Well Number	Well Name	Latitude (degrees)	Longitude (degrees)	Month(s) sampled 2011/2012
5T-526	Hwy 99W	35.24	-110.98	July, Sept
5T-506	Hwy 99E	35.24	-110.97	July, Sept
5M-108	Leupp Windmill	35.30	-111.10	Feb, Sept
5T-518	Leupp Corral	35.31	-111.00	Feb
	El Paso	35.31	-111.08	July, Sept
5K-315		35.29	-111.15	July
	Phelps Well	35.35	-111.23	July, Sept
5T-529	Blackfalls Windmill	35.43	-111.11	Feb
5T-537		35.49	-111.16	Oct
5M-74	Box Springs	35.50	-111.24	Feb, Oct
	Tohatchi Springs	35.69	-111.10	Feb, Oct
	Badger Springs	35.64	-111.20	Feb, Oct
	Balokai	35.68	-111.28	Feb, Oct
3K-331	3K-331	35.77	-111.41	Aug, Oct
3T-539	6730 Windmill	35.84	-111.36	Feb, Aug, Oct
3T-527	Hwy 64	35.85	-111.45	Feb, Oct
	Tappen Springs	35.88	-111.45	Aug, Oct
	Cameron Trading Post	35.87	-111.41	Aug, Oct

To quantify cationic species present in various well waters, a spectroscopic technique was employed. Flame atomic absorption spectroscopy (AAS) is an analytical technique, based on the absorption of light by a metal in the ground state, commonly used to quantify trace metals in solution. All of the instrumentation necessary to complete both the anion and cation analyses was available through the Merriam Powell Center for Environmental Research at Northern Arizona University. In the past, there has been collaboration between the Ingram laboratory and the Merriam Powell Center for the analyses of anionic content of previous well water samples from the Reservation; collaboration will again be essential for the completion of this work.

Following the completion of anion and cation analyses, Stiff diagrams were constructed. These plots are typically utilized by hydrogeologists and provide a visual representation of the ionic composition of a water sample. They can be useful in efficiently discovering similarities and differences in the water chemistry of natural water samples. In addition, charge balances were determined for filtered samples from each of the eighteen sample locations. Aqueous solutions are electrically neutral, implying that the total equivalents of anions should equal the total equivalents of cations in solution. Charge balances are an effective way to determine whether a significant error has occurred either in sample analysis or collection procedures; charge balance error can also indicate the presence of additional ions in solution that should be considered for analysis.

Elemental uranium concentrations were determined through the use of inductively coupled plasma mass spectrometry (ICP-MS). This technique employs the basic principle of elemental differentiation based on atomic mass, and is generally accepted as the most powerful multi-element analytical technique (Linge, 2009). Previous techniques utilized for the determination of uranium in environmental samples include alpha-spectroscopy, spectrophotometry, fluorescence spectrometry, laser-induced fluorescence, and neutron activation analysis; each of these techniques has limitations, however, including large sample volume, high cost, long analysis times, and high detection limits. Alternatively, analysis via ICP-MS requires small sample volumes, and allows for the detection of uranium at trace levels with relatively quick analysis times (Himri, 2000).

Based on the data obtained through the aforementioned analyses, uranium speciation is proposed (see Principal Findings and Significance). Because the mobility and bioavailability of uranium is dictated in part by the speciation, having an understanding of the dominant complexes present in the studied aqueous environments is essential to determining the potential health threat imposed by the consumption of water from unregulated sources located on Navajo tribal lands.

Principal Findings and Significance

Various aspects of the water chemistry of filtered water samples from 18 different unregulated sources on the Navajo Reservation were studied in this work. Concentrations of numerous analytes were determined, including both anions (bicarbonate, chloride, nitrate, sulfate, and phosphate), and cations (sodium, potassium, magnesium, and calcium). A wide array of analytical techniques was employed to obtain these data, including acid/base titration, ion chromatography, flow injection analysis, and flame atomic absorption spectroscopy. Results of the various analyses are summarized in Table 2

Stiff diagrams were constructed using AqQa software (Rockware; Golden, CO); average ion concentrations were utilized as the input for these plots. A number of select Stiff diagrams (Figures 1 to 6) are presented below to visually demonstrate the similarities and differences in water chemistry among the eighteen unregulated water sources analyzed

As is clearly demonstrated through Figures 1 to 6, there are some significant similarities and differences in the water chemistry of the unregulated water sources sampled. Tohatchi Springs (Figure 1) and Badger Springs (Figure 2) are both located in the remote Blackfalls region of the Navajo Reservation and are

within approximately 15 miles of one another. They appear to have very similar water chemistry. Both wells contain a significant amount of both bicarbonate and sodium, but have a much lower concentration of calcium and magnesium. The high bicarbonate content of these locations is important to consider, as bicarbonate is one of the strongest complexing agents for uranium in aqueous environments and plays a large role in uranium speciation. The low calcium content of these two wells is also an important result to consider; various groups have shown that calcium may decrease the potential toxicity of uranyl carbonate complexes by trapping the uranium in a nontoxic or nonbioavailable form (Carrière, 2004; Prat, 2009). Tohatchi Springs and Badger Springs also have chloride and sulfate concentrations similar to one another.

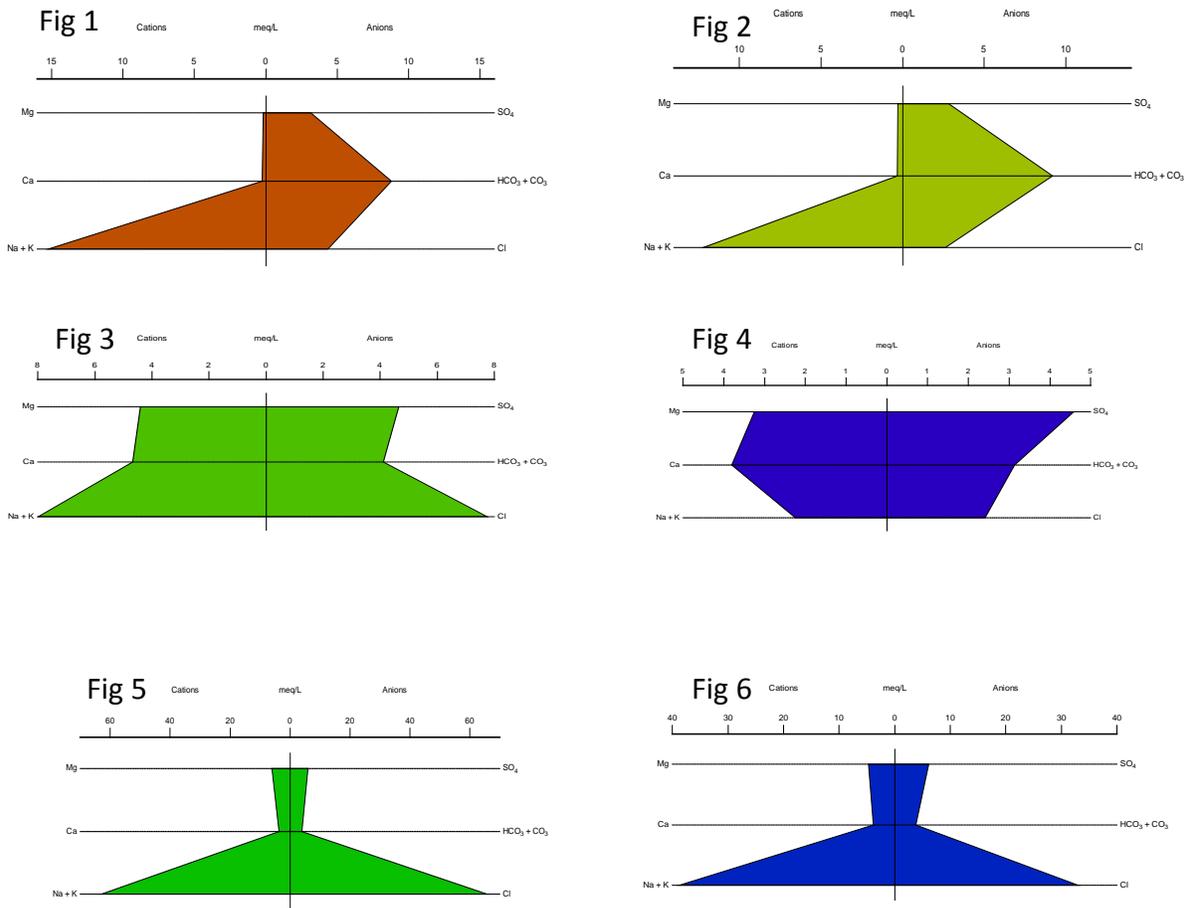
Table 2. Ionic Content and pH of Water Samples from Unregulated Sources on the Navajo Reservation.^a

	Hwy 99W (5T-526)	Hwy 99E (5T-506)	Leupp Windmill (5M-108)	Leupp Corral (5T-518)	El Paso	5K-315	Phelps Well	Blackfalls Windmill (5T-529)	5T-537	Box Springs (5M-74)	Tohatchi Springs	Badger Springs	Balokai	3K-331	6730 Windmill (3T-539)	Hwy 64 (3T-527)	Tappen Springs	Cameron Trading Post	Trading Post Bathroom
pH	7.9	7.7	7.7	7.6	7.7	7.8	8	8	8.2	7.8	8.2	8.4	7.6	7.5	8.2	8.4	7.8	7.7	7.8
HCO ₃ ⁻ (mg/L)	215	204	218	262	199	183	213	265	240	347	540	557	341	248	250	280	225	284	311
Cl ⁻ (mg/L)	110	190	323	274	85	37	58	468	2330	24	154	93	132	1171	521	46	11	210	235
NO ₃ ⁻ (mg/L)	0.2	0.18	0.28	0.25	0.26	0.22	0.19	0.13	0.03	2.5	1.28	1.04	0.05	0.25	0.02	1.28	4.11	0.06	0.08
SO ₄ ²⁻ (mg/L)	270	276	297	223	220	262	277	245	288	195	151	136	364	293	226	177	107	263	326
PO ₄ ³⁻ (mg/L)	BDL	0.01	0.01	0.01	BDL	BDL	BDL	BDL	0.02	0.01	0.07	0.01	BDL	BDL	0.01	BDL	0.03	0.08	0.09
Na ⁺ (mg/L)	67	113	200	181	50	29	44	312	1443	156	349	280	301	887	388	71	20	281	337
K ⁺ (mg/L)	3.5	4.8	3.1	3.2	2.8	3.4	3.8	3.6	5.5	3.8	2.1	1.2	1.8	6.6	5.1	6.1	4.2	2.9	3.2
Mg ²⁺ (mg/L)	43	52	48	54	39	44	51	60	74	13	2	4	4	57	22	39	25	11	2
Ca ²⁺ (mg/L)	93	79	90	94	76	83	71	100	74	32	5	7	27	78	49	40	48	21	4

^aAll measurements were taken at room temperature. Bicarbonate was determined via acid/base titration. Cl⁻ and SO₄²⁻ were determined via ion chromatography. NO₃⁻ and PO₄³⁻ were determined via flow injection analysis. For PO₄³⁻, BDL indicates the concentration was below the detection limit of 0.01 mg/L. Na⁺, K⁺, Mg²⁺, and Ca²⁺ were determined via flame atomic absorption spectroscopy.

The water chemistries of Tohatchi Springs and Badger Springs, although similar to one another, differ drastically from those of Leupp Corral (5T-518) (Figure 3) and El Paso (Figure 4); Leupp Corral (5T-518) and El Paso are also different from one another in terms of ionic content. These wells are located east of Flagstaff, AZ in the Leupp region of the Navajo Reservation within roughly 10 miles of one another. With respect to anions, the water from Leupp Corral (5T-518) is dominated by chloride, whereas the water from El Paso is dominated by sulfate. The primary cations in the water from Leupp Corral (5T-518) are sodium and potassium; the primary cation in the water from El Paso is calcium. The utilization of Stiff diagrams allows for an efficient comparison of the water chemistry present at various sampling locations, thus simplifying comprehension of regional water chemistry variations that could potentially impact uranium speciation, mobility, and bioavailability.

Another interesting comparison can be observed in the Stiff diagrams for 5T-537 (Figure 5) and 3K-331 (Figure 6). As was seen when comparing the water chemistries of Tohatchi Springs and Badger Springs, there is an apparent similarity in the water chemistries of 5T-537 and 3K-331. Both of these wells appear to have high concentrations of chloride, sodium, and potassium, but lower concentrations of all other ions analyzed, including bicarbonate and calcium. The striking similarity between the water chemistries of these wells is interesting due to their geographical locations; 5T-537 is located towards the southernmost edge of the Blackfalls region of the Navajo Reservation, whereas 3K-331 is located further north, closer to the town of Cameron. The similarity in water chemistries seen for these two unregulated water sources, in spite of their relatively large distance from one another, suggests that these wells are both supplied by the same aquifer.



Figures 1 – 6: Stiff Diagrams of Tohatchi Spring (Fig 1), Badger Spring (Fig 2), Leupp corral (5T-518) (Fig 3), El Paso (Fig 4), 5T-537 (Fig 5), and 3K-331 (Fig 6).

ICP-MS was utilized to determine the uranium content of water samples from each of the eighteen different unregulated sources. Filtered, acidified samples were utilized for these analyses. From an external calibration curve constructed prior to analyses, uranium concentrations were determined. Figure 7 shows the results of these analyses. For locations that were sampled on multiple days, an average analyte concentration is reported. Error bars are included; these represent the standard deviation of all measurements associated with the average analyte concentration.

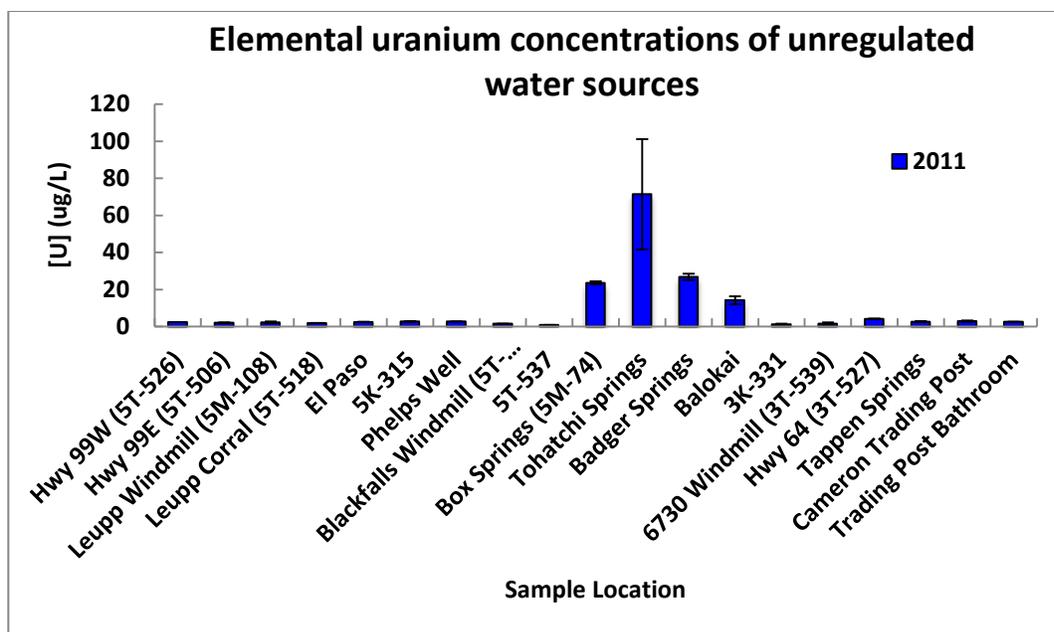


Figure 7. Uranium concentrations of acidic filtered water samples from unregulated water sources on the Navajo Reservation determined via inductively coupled plasma mass spectrometry.

As seen in Figure 7, most of the water sources sampled have relatively low uranium concentrations. There are four locations that were found to have uranium concentrations exceeding 10 µg/L; all other sample locations have uranium concentrations of approximately 5 µg/L or lower. One of the locations sampled has a uranium concentration that exceeds the U. S. EPA MCL of 30 µg/L; Tohatchi Springs was found to have a uranium concentration of approximately 70 µg/L. The large error bar associated with the uranium concentration of Tohatchi Springs can be attributed to the significant variation in concentration determined for samples collected at two different times during 2011. The concentration of uranium determined in February (100 µg/L) was higher than the concentration of uranium determined in October (45 µg/L). This seasonal variation could possibly be attributed to dilution of well water by runoff in months during which more precipitation was received.

The uranium concentrations in water samples from the Cameron region of the Navajo Reservation were much lower than expected. Considering that Cameron was a site of previous mining activity on the Reservation, uranium concentrations in this area were expected to be significantly higher than uranium concentrations in the Leupp area. One potential explanation for the surprisingly low concentrations seen in the Cameron region is contributions from runoff. Dilution of well water with runoff from seasonal precipitation could play a role in decreasing the uranium concentrations of these water sources.

Current results were compared with uranium concentration data previously collected in the Ingram laboratory, as well as data collected by the Army Corps of Engineers from 1994 to 2000. Figure 8 represents this comparison. Previous data was not available for all water sources. For locations that were sampled on multiple days within the same year, an average analyte concentration is reported. Error bars are included for 2011 data; these represent the standard deviation of all measurements associated with the average analyte concentration.

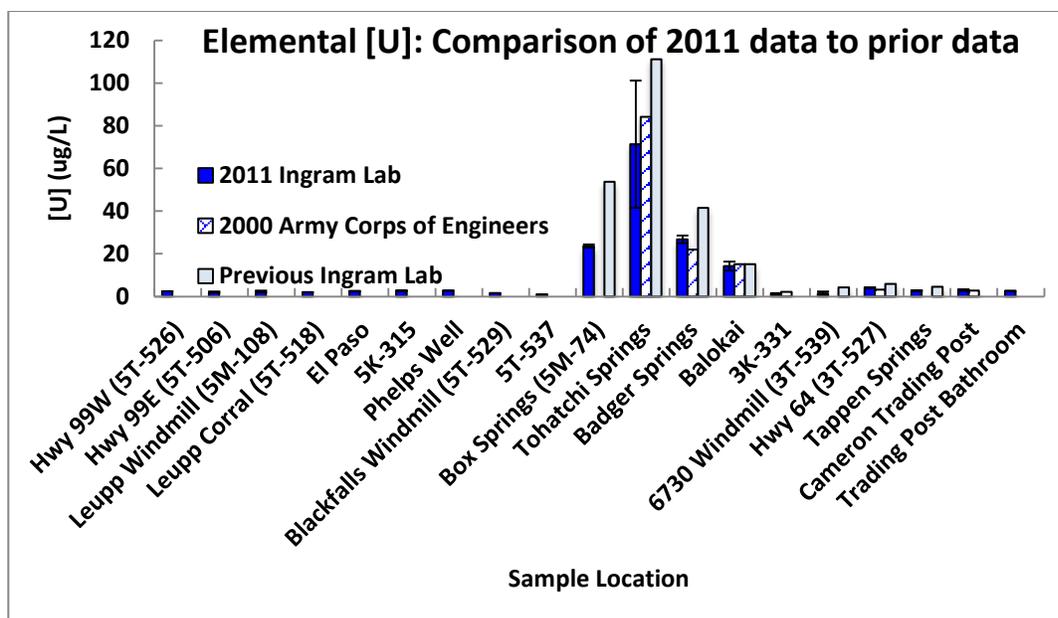


Figure 8. Comparison of uranium concentrations of water samples from unregulated sources on the Navajo Reservation (2011 data) with previously reported values from the Ingram laboratory and the Army Corps of Engineers.

As demonstrated in Figure 8, there is some discrepancy among the uranium concentrations determined in the Ingram laboratory, both in 2011 and previously, and the values reported by the Army Corps of Engineers. For example, the uranium concentration determined for water from Box Springs (5M-74) in 2011 was approximately half of the concentrations previously determined by the Ingram laboratory for that location. There is no data from the Army Corps of Engineers for this water source. The uranium concentration of water collected from Tohatchi Springs is different for all three data sets; the 2011 data from the Ingram laboratory resulted in an average concentration of approximately 70 µg/L, whereas previous Ingram laboratory data suggests a higher concentration of approximately 110 µg/L. The value of approximately 85 µg/L reported by the Army Corps of Engineers is between the two values from the Ingram laboratory. The large error associated with the 2011 result for Tohatchi Springs suggests that the true value is likely somewhere between 85 and 110 µg/L.

There are numerous factors that could explain the discrepancies in the data presented in Figure 8. As mentioned, the values reported prior to 2011 by the Ingram laboratory are averages determined for samples originating from multiple sample collections. It was not clearly indicated in the data whether the same student executed the collection and analyses or whether identical sample collection, preparation, and analysis procedures were utilized each time. Additionally, seasonal variations could have an effect on the previous values obtained in the Ingram laboratory. Data obtained from the Army Corps of Engineers also appears to be somewhat inconsistent with the 2011 results from the Ingram laboratory. This disagreement could be due to the fact that the Army Corps of Engineers reported the results of a single measurement as the determined uranium concentration. Additionally, the analytical method employed by the Army Corps of Engineers is not stated in the project atlas; this is another potential source of uncertainty between the concentrations determined by the Ingram laboratory and those reported by the Army Corps of Engineers.

The findings of this project were quite interesting and provided some important insight in regards to the potential health hazards associated with unregulated water sources on the Navajo Reservation in northern Arizona. Numerous aspects of the water chemistry in eighteen unregulated wells from the southwestern region of the Navajo Reservation were studied. Various factors, including pH and ionic content, can have

a significant impact on the speciation of heavy metals in aqueous environments. Two ionic species in particular, bicarbonate (HCO_3^-) and calcium (Ca^{2+}), play a crucial role in uranium speciation at alkaline pH values; as described, all of the water sources sampled in this work fall within a pH range of roughly 7.5 to 8.5. The complexation of uranium with bicarbonate is relevant in this pH range, and will most likely overcome complexation of uranium with other potential ligands, such as phosphate and hydroxyl ions and humic substances. Two sample locations in particular, Tohatchi Springs and Badger Springs, have much higher bicarbonate concentrations (~500 mg/L) than any of the other water sources sampled. Box Springs (5M-74) and Balokai have lower bicarbonate concentrations (~350 mg/L); however, the presence of bicarbonate at these two locations could still be relevant in the mobilization and solubility of uranium.

In wells containing significant amounts of bicarbonate, it is also important to consider the calcium cation; formation of calcium uranyl carbonate compounds has been proposed to decrease the toxicity and bioavailability of uranium (Carrière, 2004; Prat, 2009). Tohatchi Springs and Badger Springs do not have high calcium content (~5 mg/L), and it is thus unlikely that uranium at these sites will be trapped in a nontoxic form. Box Springs (5M-74) and Balokai have higher calcium content (~30 mg/L); uranium at these two locations likely has a higher potential to form nonbioavailable complexes with calcium and bicarbonate ions than does uranium at the previously mentioned locations.

Uranium concentrations were also determined for each of the eighteen different unregulated water sources sampled. Based on the results obtained in 2011, only one of the eighteen wells sampled has a uranium concentration above the U.S. EPA MCL of 30 $\mu\text{g/L}$; the water from Tohatchi Springs has an average uranium concentration of approximately 70 $\mu\text{g/L}$. However, after comparison to previous data from both the Ingram laboratory and the Army Corps of Engineers, it is possible that other wells, including Badger Springs and Box Springs (5M74), may also have uranium concentrations above the MCL.

The high uranium content of particularly Tohatchi Springs and Badger Springs, in combination with the previously determined high bicarbonate and low calcium concentrations, makes these wells a serious potential health threat to residents of the Navajo Reservation. These wells are located within approximately 15 miles of one another in an extremely remote area of the Navajo Nation. Based on the comparison of Stiff diagrams constructed for each of these locations, it appears that the water chemistries of Tohatchi Springs and Badger Springs are very similar. This leads to the conclusion that uranium in these water sources, most likely present as hexavalent uranium in the form of a uranyl-hydroxyl or uranyl-carbonate complex, will have similar speciation. For many individuals, these wells in the remote Blackfalls region of the Navajo Reservation serve as the closest available water source; however, the water from these wells may indeed be unsafe for human consumption and not suitable as a drinking water source.

Future avenues for aqueous uranium research in the Ingram laboratory could include theoretical modeling and the utilization of different analytical techniques to gain a deeper understanding of the uranyl complexes that are in fact present in water sources on the Navajo Reservation. The 2009 publication from Odette Prat and colleagues focuses on modeling and characterizing uranyl carbonate complexes in drinking water from drilled wells in southern Finland. A computer simulation program, CHES (chemical equilibrium speciation with surface), was used to predict the most probable uranium species present based on various aspects of the water chemistry of the wells. Following this simulation, time-resolved laser-induced fluorescence spectroscopy (TRLFS) was employed to experimentally determine whether the predicted complexes were in fact present in the well water. Theoretical modeling has been utilized for the purpose of simulating and predicting uranium speciation in various other works as well (Frelon, 2005; Sutton, 2004); TRLFS has also been employed by other groups to determine aqueous uranium speciation (Moulin, 1995). It would be interesting to follow a similar experimental approach to study the uranium complexes present in the unregulated wells on the Navajo Reservation.

Another direction for future work in the Ingram laboratory related to contaminated water sources on the Navajo Reservation includes qualitative and quantitative determination of other heavy metals in the previously studied water sources. These studies have already been initiated. ICP-MS was utilized to conduct survey scans on well water samples in an effort to identify trace metal contaminants other than uranium. The multi-element capabilities of ICP-MS make it an ideal technique for this type of analysis. Future work will involve quantitative studies of additional metal contaminants.

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Hydrology Versus Ecology: The Effectiveness of Constructed Wetlands for Wastewater Treatment in a Semi-arid Climate

Basic Information

Title:	Hydrology Versus Ecology: The Effectiveness of Constructed Wetlands for Wastewater Treatment in a Semi-arid Climate
Project Number:	2011AZ436B
Start Date:	3/1/2011
End Date:	10/31/2012
Funding Source:	104B
Congressional District:	AZ-5
Research Category:	Not Applicable
Focus Category:	Hydrology, Wetlands, Acid Deposition
Descriptors:	
Principal Investigators:	Daniel L Childers, Laura Turnbull

Publications

There are no publications.

Hydrology Versus Ecology: The Effectiveness of Constructed Wetlands for Wastewater Treatment in a Semi-arid Climate

Laura Turnbull, Dan Childers and Ben Warner

Progress Report – 1st May 2012

Background/Questions/Methods

Increasingly, wetlands are being constructed for tertiary wastewater treatment, to “polish” treated wastewater. In arid climates, high evaporation rates will concentrate solutes in the water column while high transpiration rates will concentrate solutes in wetland soils. The evapoconcentration of bioactive and non-bioactive solutes via these processes may exceed the ability of wetland biological processes to transform and remove bioactive solutes, thus reducing the treatment efficacy of the wetland. Because of the amplification of evaporation and transpiration in arid systems, lessons learned from the use of constructed wetlands in more mesic settings may not translate well to arid settings. In this study, we seek to answer the following question: *Is wetland uptake and transformation of bioactive solutes sufficient to counteract the effects of evapoconcentration in arid climates, to improve wastewater quality?* To answer this question, we have implemented a monitoring campaign at the Tres Rios constructed wetland system in Phoenix, AZ, in collaboration with the City of Phoenix. Tres Rios is one of the first constructed wetlands in an arid climate. We have been monitoring wetland primary production (as biomass accrual), species composition, transpiration rates and water quality throughout the wetland every other month. We have also measured soil characteristics and below ground biomass. We have obtained high-resolution flow and climate data from the City of Phoenix for this study site. Using these data, we are deriving hydrological and solute budgets for this wetland system.

Results/Conclusions

Total biomass in the system was highest in July 2011, at 607000 kg. Biomass declined 67% from July to September, which we attributed to ‘thatching,’ a phenomenon where large stands of *Typha latifolia* and *Typha domingensis* grew excessively and toppled over throughout the wetland. *Typha spp.* Made up the largest proportion of biomass in all months, at its height accounting for 64% (July) (Figure 1). Transpiration rates were highest during the hot summer months when the plants were responsible for a water loss rate equivalent to 4 – 6 cm water depth per day. Water loss from the entire wetland due to evaporation and transpiration was about 50% lower in winter months. Water samples collected along 10 sampling transects in the wetland showed average declines in inorganic nitrogen concentrations at the patch scale, from the water’s edge to the interior of the vegetation, of 73% for ammonium and 80% for nitrate+nitrite. Chloride concentrations increased an average of 15%, suggesting that evapoconcentration of non-bioactive solutes is occurring within the vegetated portions of the wetland. Nutrient budgets show that in summer, the wetland retains 90% of ammonium, 49% nitrate, and 48% nitrite. In winter months, retention of ammonium decreases by 50%, while retention of other forms of inorganic nitrogen decreases only marginally. Derived budgets show no significant difference between input and output of chloride at the wetland scale, indicating that evapoconcentration has no significant effect at the whole system scale. Results indicate that even in arid climates, constructed wetlands do improve water quality; however, the longer term implications of “evapoconcentration hot spots” of non-bioactive solutes have yet to be determined.

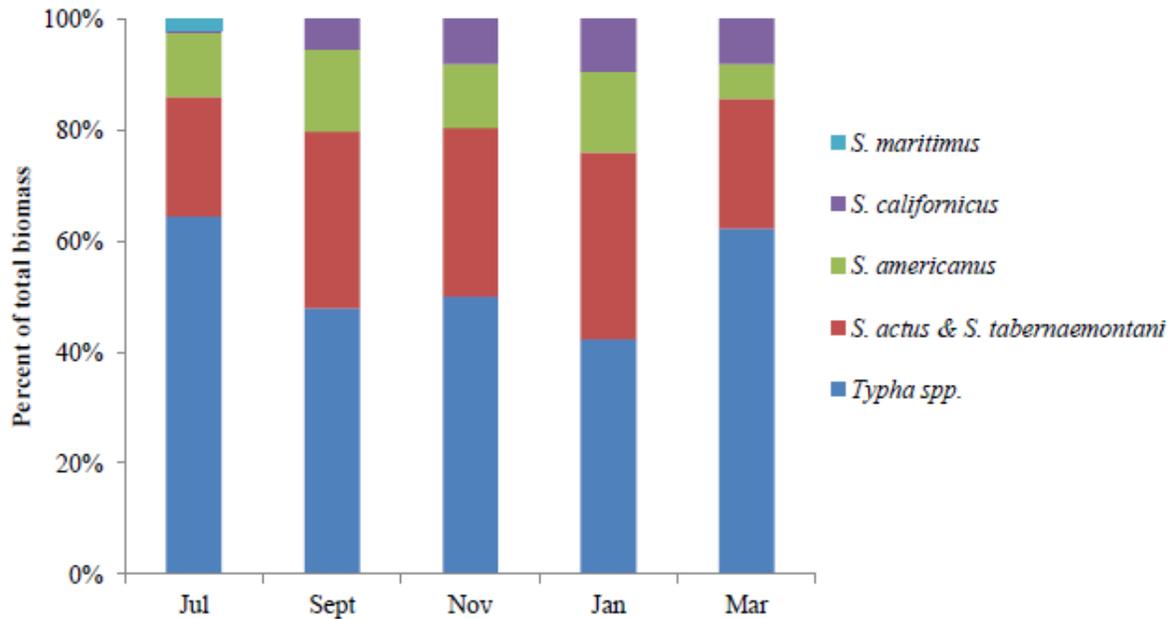


Figure 1. Relative species abundance in the Tres Rios Constructed wetland, from July 2011 to March 2012.

Outputs

To date, we have presented preliminary results of this research at the Ecological Society of America Annual Meeting, 2011 (Weller and Sanchez). We have strengthened our links with the City of Phoenix, and as a result, this research project is anticipated to continue into the future, under the umbrella of the Central Arizona Phoenix Long-Term Ecological Research program. Multiple undergraduate and undergraduate students have become involved in this research project. Chris Sanchez worked with us for several months (from Florida) and Nich Weller (funded through this grant) has become a key player in this research project. Graduate students Jorge Ramos and Eric Chapman have become involved in our monitoring campaign and have secured extra funding to investigate gaseous emissions of nitrogen (N) from the system, which will help to close the N budget for this system. Childers and Turnbull are presenting results from this project at international conferences later this year. We anticipate multiple peer-reviewed publications from the research funded by this grant, the first of which will be submitted in November this year, with others to follow.

Iodinated Disinfection By-product Formation from Water Reuse Practices

Basic Information

Title:	Iodinated Disinfection By-product Formation from Water Reuse Practices
Project Number:	2011AZ450B
Start Date:	3/1/2011
End Date:	3/1/2012
Funding Source:	104B
Congressional District:	AZ-7
Research Category:	Water Quality
Focus Category:	Acid Deposition, Groundwater, Water Use
Descriptors:	
Principal Investigators:	Shane Snyder

Publications

There are no publications.

Iodinated Disinfection By-product Formation from Water Reuse Practices

Professor Shane A. Snyder – Principal Investigator

Progress Report – 1st May 2012

The objective of this project is to evaluate the formation of iodinated disinfection byproducts (IDBPs) in potential potable water reuse scenarios. In order to accomplish this objective, our laboratory has developed state of the art analytical techniques to analyze for IDBPs. Specifically, we developed a novel GC-ICP/MS method which can effectively monitor both IDBPs as well as brominated DBPs (BrDBPs). Samples were collected two different water reuse systems. To evaluate an infiltration scenario, samples were collected from the Santa Cruz River (SCR) and groundwater wells influenced by the SCR. In order to evaluate another water quality, we collected secondary wastewater treatment plant effluent which is subsequently processed using filtration and desalting membranes prior to aquifer injection.

Water samples from the Santa Cruz River and from a groundwater well under the influence of the Santa Cruz River were collected on March 6th. The samples were filtered and then refrigerated until experimentation. The river and well samples were chlorinated and chloraminated. Two different chlorine and monochloramine doses were evaluated. The natural level of bromide and iodide, as well as two elevated bromide/iodide levels were tested. After 24 hours of reaction time with disinfectant, the samples were extracted for THMs and I-THMs with liquid-liquid extraction. The extracts are current scheduled for analysis.

Water samples also were collected from the West Basin Municipal Water District's Edward C. Little water recycling facility in Los Angeles, California. This site was selected for ozonation studies since the utility is constructing the first known ozone pre-oxidation potable reuse system in the USA (perhaps in the world). These samples were collected from water entering the advanced treatment process train (essentially secondary WWTP effluent). Samples ozonated and chloraminated, then compared for IDBP levels.

Our results thus far demonstrate that IDBPs in recycled water occur at elevated levels. The speciation between IDBPs is remarkably different depending on the treatment process applied (i.e., ozone to chloramine). Lastly, preliminary data show that groundwater influenced by recycled water also can generate IDBPs; however, the number and quantify formed appear to be greatly reduced through subsurface transport of recycled water.

Information Transfer Program Introduction

The WRRC maintains an information transfer program well-known 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. The WRRC-based Arizona Project WET continues to build its education activities for teachers and students throughout the state by providing interactive in-service workshops, Water Festivals and development of program initiatives such as the Water Investigations Program.

There there has been continued public interest in Arizona in water issues, particularly water sustainability, climate variability and change, water harvesting, environmental water needs, statewide water planning, water reuse and the fate of emerging contaminants.

Details on the accomplishments of the past year follow.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2011AZ455B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	AZ-7
Research Category:	Not Applicable
Focus Category:	Law, Institutions, and Policy, Management and Planning, Economics
Descriptors:	
Principal Investigators:	Sharon Megdal, Susanna Eden

Publications

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Information Transfer

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Information Transfer

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Information Transfer

Sharon B. Megdal and Susanna Eden

The WRRC's Information Transfer Program has continued to produce its major component products in the project year. These include the Arizona Water Resource and Arroyo newsletters, the Annual Conference, Brown Bag seminars, and the website. Collaborations will continue with the Water Sustainability Program, now a part of the Water, Environmental and Energy Solutions Initiative, and with Arizona Project WET.

Ongoing programs of research and outreach continued and expanded. A program that links conservation with environment, "Conserve to Enhance," has expanded its reach beyond the Tucson area, where a pilot program is underway. A related program intended to provide basic information on assessment of environmental water needs has moved into its second phase at the end of 2011. These programs are largely grant funded, but they received some support for outreach from the Information Transfer Program. The U.S.-Mexico Transboundary Aquifer Assessment Program is continuing binational discussions leading to two parallel reports to Congress on activities to date in each of the two priority aquifers.

Annual Conference:

The 2011 conference, held in collaboration with the US Bureau of Reclamation, explored the role of desalination in expanding water supplies. The conference was held in Yuma, at the Hilton Hotel and Pivot Point Conference Center. Participants heard the latest information on the Yuma Desalting Plant pilot run and also learned of regional, national, and international perspectives on key policy issues relating to desalination. Presenters spoke on current environmental concerns, regulatory matters, technical and cost challenges involved in desalination. Sponsors were Befesa Water, Carollo Engineers, APS, Agri-Business Council of Arizona, Inc., BKW Farms, CAP, CH2MHill, Montgomery & Associates, Southern Arizona Water Users Association, Salt River Project, USGS, WSP, CALS, and Arizona Cooperative Extension. Approximately 175 people attended including 20 local K-12 teachers. Participation included attendees from 40 communities in Arizona and the US, and from Mexico and Israel. Seventeen poster presentations were viewed and discussed at the reception sponsored by Befesa Water.

The WRRC's Annual Conference for 2012 was held in January in collaboration with Arizona State University's Morrison Institute for Public Policy. The conference, "Urbanization, Uncertainty and Water: Planning for Arizona's Second Hundred Years," was held January 24 at the UA Memorial Student Union. The conference was organized in cooperation with the Morrison Institute following their recently released report, "Watering the Sun Corridor: Managing Choices in Arizona's Megapolitan Area." The conference broadened the focus beyond the ASU report, encompassing the whole state. Two other recently released reports were featured: "Arizona at the Crossroads: Water Scarcity or Water Sustainability," published by the Grand Canyon Institute, and the Final Report of the Water Resources Development Commission (WRDC). The conference was held at the University of Arizona's Student Union Memorial Center in Tucson, for approximately 330 participants from 40 communities across Arizona.

Brown Bag Seminars:

The WRRC expanded its series of Brown Bag Seminars to fulfill demand for disseminating information. The Brown Bag Seminars provide a forum for researchers, students and community members to learn

about and discuss water resources issues. The WRRC's brown bag seminar series offers information and opportunities for two-way dialogue and for community-university interaction. The focus is on topics of broad interest. Nineteen Brown Bags were held in the project year. Average attendance was 27 people, with about 40 percent representing the community and 60 percent from the University. Dates and titles of the Brown Bags from March 1, 2001 through February 29, 2012 are listed below:

03/08/11	Successfully Reducing Your Groundwater Footprint and Second and Third Order Effects	Kimberlee Mulhern, Chief, Environmental and Natural Resources Division, US Army Corps of Engineers
03/23/11	Arizona's Water Resources 101: How Arizona is Planning and Investing in its Most Important Resource	Warren Tenney, CAP Board Member and Assistant General Manager, Metro Water
04/13/11	Sweetwater Wetlands: A Man-made Oasis; and Sweetwater Wetlands: A Sanctuary	Robert Long, Graduate Student, School of Art, UA Daniel Cheek, Graduate Student, School of Art, UA
05/04/11	Water Stewardship at PepsiCo: Looking In, Out, and Beyond	Liese Dallbauman, Director, Water Stewardship, PepsiCo
07/29/11	Riparian Preservation and Restoration; and Large-scale Projects in Tucson and Pima County	Brittany Choate, Water Resources Research Center, UA Suzanne Shields, P.E, Pima County Regional Flood Control District and Leslie Ethen, Office of Conservation and Sustainable Development, City of Tucson
08/17/11	Drivers of Household Water Conservation in a Decade of Drought	Adam Springer, Ph.D., School of Natural Resources and the Environment, UA
09/15/11	Water Use at the University of Arizona – Sources, Uses, Costs, Challenges and Opportunities; and Estimating the Energy and Greenhouse Gas Emissions Embedded in Metered Water at the University of Arizona	Mark Marikos, Staff Technician - Utilities Management and Services, UA Facilities Management Jaclyn Mendenhall, Undergraduate, Department of Hydrology and Water Resources, UA, and former Research Intern for the Office of Sustainability
09/21/11	Urban Watershed Riparian Restoration; and Tucson Clean and Beautiful; and Restoration in the Sky Islands	Lisa Shipek, Watershed Management Group B.J. Cordova, Tucson Clean and Beautiful, Inc. Kendall Kroesen, Tucson Audubon Society Trevor Hare, Sky Island Alliance
09/27/11	Can Parks Inhibit Outdoor Water Use?	Eve Halper, Ph.D., Tucson Field Office, US Bureau of Reclamation
11/07/11	Water Availability and Use Pilot: Methods Development for a Regional Assessment of Groundwater Availability, Southwest Alluvial Basins, Arizona, with <i>Introduction by Congressman Raúl Grijalva</i>	James Leenhouts, Ph.D., Interim Director, Water Science Center; and Fred Tillman, Ph.D., Research Hydrologist, US Geological Survey
11/15/11	Freshwater Use by U.S. Power Plants: Electricity's Thirst for a Precious Resource	Nadia Madden, Energy-Water Project Associate, Climate and Energy Program, Union of Concerned Scientists, Cambridge, MA ; and Jonathan Overpeck, Ph.D., Co-Director, Institute of the Environment, Professor, Departments of Geosciences and Atmospheric Sciences, UA

11/30/11	Interdisciplinary Earth Science in a Controlled Environment: The Biosphere 2 Landscape Evolution Observatory	Steve DeLong, Ph.D., Lead Scientist, Assistant Research Professor, Biosphere 2, UA
12/09/11	Issues and Opportunities in Arizona's Water Resources Planning and Management	Tom Buschatzke, Assistant Director, Arizona Department of Water Resources
01/18/12	The Cornerstones Report: Market-based Responses to Arizona's Water Sustainability Challenges	Amy McCoy, Senior Associate, Ecosystem Economics
01/25/12	Water Efficiency: Making the Link to Watershed Health	Cindy Dyballa, Project Manager, Alliance for Water Efficiency
02/8/12	Choices and Tradeoffs: Deciding the Future of Our Region – An Interactive Presentation	Patrick Hartley and Camila Thorndike, Imagine Greater Tucson
02/15/12	Reverse Osmosis Concentrate Management through Wetlands	Tom Poulson, Project Manager, Reclamation
02/21/12	The Binational Restoration of the Colorado River Delta, Mexico	Osvel Hinojosa Huerta, Director del Programa de Agua y Humedales, Pronatura Noroeste, San Luis Río Colorado, Sonora, MX
02/29/12	The Arizona-Sonora Border Region: Water Quality Challenges and Priorities for the EPA Border 2012	Hans Huth, Senior Hydrologist, Arizona Department of Environmental Quality, Office of Border Environmental Protection

Other Outreach Events: Two additional outreach events warrant special attention due to their high attendance and significant potential impact:

- USGS Report introduced by Raul Grijalva:* Congressman Raul Grijalva joined USGS hydrologists for a public briefing on Arizona groundwater on Monday, November 7, 2011 at the WRRC. Congressman Grijalva introduced Dr. James Leenhouts and Dr. Fred Tillman, who presented the recently released study, *"Water Availability and Use Pilot: Methods Development for a Regional Assessment of Groundwater Availability, Southwest Alluvial Basins, Arizona."* The USGS Groundwater Resources Program instituted this pilot program to evaluate the availability of groundwater resources in the alluvial basins of Arizona. The principal products of the USGS report are updated groundwater budget information for the study area and a proof-of-concept groundwater-flow model incorporating several interconnected groundwater basins.
- Simulation session with Frank van Weert on the Tragedy of the Commons game:* On October 31, 2011 Bob Varady and Sharon Megdal hosted Frank van Weert of The International Groundwater Resources Assessment Centre (IGRAC). Frank van Weert has over 15 years of experience in groundwater resources management both in academic and consultancy environments. While at the WRRC, he hosted a session of the Tragedy of the Groundwater Commons Game. The WRRC session was open to observers, and many attended along with the 14 students who played the game. The purpose of the simulation was to allow students to learn from one another how to manage a common pool resource, in this case, an area of shared groundwater. In the simulation, Mr. van Weert divided the students in 10 "families"; each one had to make a decision about how much land, out of a possible 100 hectares, to bring under production in a fictional agricultural

community, with more land generating more revenue. Mr. van Weert described the students who attended the 3-hour simulation as “uncharacteristically cooperative.” A feature article about the game will appear in the Winter 2012 *AWR*.

In addition, the WRRC hosts a “Chocolate Fest” get together annually in February for friends of the WRRC. In 2012, the Fest was held on February 10, and was well-attended by University faculty and students, retired WRRC personnel, and friends from the community.

Arizona Water Resource Newsletter (AWR):

With a new look and under a new editorial system, the highly regarded newsletter, Arizona Water Resource, continued as a keystone of the WRRC’s Information Transfer program.

The *AWR* is an 8 to 12-page newsletter focusing on state and regional water issues. In 2011 editorial duties passed to Susanna Eden. The look of the newsletter has been updated and more articles were written by guest authors and by Stephan Przybylowicz, the WRRC’s Graduate Assistant Outreach. Published quarterly, it is sent free of charge to more than 2,700 people. The newsletter has wide distribution; the majority of its readers are from Arizona, but it also is mailed to other states and foreign countries. It is available on-line and emailed to subscribers. The publication regularly includes a feature article, a guest view, news briefs, sections on special projects, and a public policy column written by the WRRC Director, as well as announcements and publication notices. Many issues of the newsletter include a four-page special supplement. The WRRC’s Environmental Programs sponsored a supplement in 2011 and the U.S. Geological Survey sponsored the supplement “Brescia-Pipe Uranium Mining in Northern Arizona—Estimate of Resources and Assessment of Historical Effects” in the Winter 2012 issue. A listing of the key feature articles and authors for each of the four 2011-2012 newsletters appears below:

- *Spring 2011*: “Transboundary Aquifers: Water Wars or Cooperative Conservation?” by Stephan Przybylowicz; “Winners of the Joe Gelt Undergraduate Writing Competition: Joni Northam, UA; Deborah Englisch, NAU”;
- *Summer 2011*: “Reclamation Completes Successful Pilot Run of the Yuma Desalting Plant,” by Jennifer McCloskey, US Bureau of Reclamation Yuma Area Office Manager; “WRRC Desalination Conference Highlights”;
- *Fall 2011*: “Protecting Resources - Satisfying Consumers: New Corporate Water Strategies,” by Stephan Przybylowicz; “Through Dry Times,” by Alanna Riggs;
- *Winter 2012*: “Interview with Tom Buschatzke, Assistant Director of ADWR,” by Stephan Przybylowicz; “Global Water Brigades”.

AWR articles picked up by UA’s College of Agriculture and Life Sciences Newline in 2011 include “*Transboundary Aquifers: Water Wars or Cooperative Conservation?*” and “*Sustainable Water for All: Lessons in Hydrophilanthropy.*”

Arroyo:

The 2011 edition of the annual *Arroyo*, a newsletter focusing on a single topic of timely interest to Arizona, was published in the spring. Titled, “*Desalination in Arizona - A Growing Component of the State’s Future Water Supply Portfolio,*” it was written by Susanna Eden, Tim W. Glass, and Valerie Herman. The newsletter was released in time to be handed out to participants at the WRRC’s Annual

Conference on the same topic, and provided basic information on desalination technology, as well as a discussion of the opportunities and challenges presented by use of desalination to augment Arizona's water supplies.

The topic for the 2012 *Arroyo*, Arizona-Mexico Border Water Issues, was chosen by the External Advisory Committee. The 2011 Montgomery & Associates Summer Intern at the WRRC, Josue Sanchez Esqueda, began the process of research and writing by traveling to Mexico and interviewing water managers there. Another student, Becky Witte, hired in the summer, continued the research and had a major role in writing the paper.

The topic for 2013 will be contaminants of emerging concern. Topics are chosen by the WRRC's External Advisory Committee.

Montgomery & Associates Summer Internship at the WRRC:

The summer writing internship was created to support and encourage students interested in writing for the general public about water. Planned as an annual opportunity for a student to learn from experience working with WRRC personnel, the internship supports one student each summer. Internship applicants are bright and talented students and applications, with the permission of the applicants, are kept as a rich pool of talent for potential future projects at the WRRC and partners. The process of soliciting and evaluating applications begins in March and the summer intern is announced in May.

Joe Gelt Student Writing Competition:

In the same spirit of encouraging student writers and improving communication with the public on water topics, the WRRC inaugurated a feature article writing contest in 2009. Open to undergraduate students at all three Arizona universities, the contest offers publication of the winning articles as prizes to the winners. In an effort to generate more interest in 2011, cash prizes of \$50 and \$100 were offered in addition to publication. The year saw increased efforts at outreach to undergraduates and a new contest registration process allowing reminders and tips to be sent to interested students. These efforts produced increased interest, but final submission numbers were disappointing. The program is being reexamined in 2012 to assess its potential for increasing the number of entries.

Fact Sheets:

The WRRC has initiated a series of Fact Sheets, which are designed as a two-page summary of an important water resources topic, in a visually appealing format. The first Fact Sheets summarize and update the information in past *Arroyos*, and there are plans to include other topics of current interest such as rainwater harvesting and gray water. The sheets will be posted on the WRRC's new web site and will be distributed in printed form at conferences and other events, and at locations where information sheets and brochures are available to the public.

Web Site:

In keeping with general trends in communication, the WRRC is placing increasing emphasis on the internet as a public information tool. The WRRC makes 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 links to many other water sites. The site also offers information about WRRC activities such as the Annual

Conference, the Brown Bag Seminar series, the Summer Internship competition and Writing Contest, as well as the 104(b) Small Grants Program. Staff profiles and information about WRRC products are also easily accessible. The WRRC web site underwent a complete redesign to update the look and improve navigability. Updates take advantage of DRUPAL (an open content management system) modules and demonstrate consistency with the UA brand.

Registration for the WRRC conference is made available through the web site, as well as instructions and forms associated with other WRRC programs, including the WRA 104(b) program. The website also provides a way to order products distributed by the WRRC such as the Arizona Water Map and Curriculum Guide. A website for the Arizona component of the U.S.-Mexico Transboundary Aquifer Assessment Program will continue to be supported by the WRRC and linked through the WRRC website. The water events calendar is updated on a regular basis. Web management protocols call for continuous evaluation of the website to improve its efficiency and effectiveness.

Facebook:

Since its development in early 2011, the WRRC Facebook presence has increased substantially. In approximately one year, the page had 57 total “likes” (people who choose to follow the site regularly), including people in the US, Egypt, Saudi Arabia, Palestine, the UK, and Australia; and 1,468 lifetime “post views” (total number of people who viewed any post on the site).

Arizona Project WET (APW):

The WRRC-based Arizona Project WET (Water Education for Teachers) is a comprehensive water education program with a long history of successful teacher/educator training and student engagement. The program has developed relationships with school districts and communities throughout Arizona. It reaches out to teachers and students across Arizona by providing programs, workshops, mentoring and partnership activities to teachers and students, including Water Festivals designed around hands-on learning for children. Collaboration with Arizona Project WET has been mutually beneficial in expanding the reach and effectiveness of outreach and education projects, and this collaborative relationship will continue in the up-coming project year.

Water Security Extension and Education:

An additional project worthy of mention is a collaborative effort funded by the U.S. Department of Agriculture. The Director of the Water Resources Research Center at Colorado State University, Reagan Waskom, was awarded a two-year planning grant for the project entitled, “*Addressing Agricultural Water Security in the Colorado River Basin: Planning for Water Research, Extension and Education*” and Dr. Megdal serves as a co-PI for this effort, which has representatives from each of the seven Colorado River basin states. Beginning in February 2012, the project will identify potential partners and opportunities to enhance water security for all sectors to reduce pressure on agriculture, and identify promising pilot projects that address legal, institutional and technical roadblocks that stand in the way of innovative water conservation and sharing arrangements.

Other Information Transfer:

In addition to all of the above, WRRC personnel continued their public service activities. They were called upon regularly to give lectures and make presentations to diverse audiences across Arizona. WRRC personnel participate on community and regional boards and commissions, serve on state and local task forces and study committees, and regularly attend important water resources meetings. In addition, the WRRC extends its research, outreach and education role through its collaboration with the university-wide Water Sustainability Program, a component of the Water, Environmental and Energy Solutions (WEES) initiative. The WRRC Director serves as one of two co-Directors of WEES.

WRRC personnel also respond to inquiries from the public on issues of concern. Water reuse and contaminants of emerging concern, environmental water needs, climate variability and change, water supply planning, water harvesting, and water salinity were topics of particular concern in the project year.

Presentations by WRRC personnel and students:

Choate, Brittany, November 2011, *University of Arizona Graduate Research Blitz*, Tucson, AZ.

Choate, B., January 2012, Conserve to Enhance, presentation at the Environmental Science Careers Class, Tucson, Arizona.

Choate, Brittany, J.B. Nadeau, and C. Rupprecht, November 2011, *University of Arizona Student Showcase*, Tucson, AZ.

Isaak, Marissa, April 2011, *Association of American Geographers Annual Conference*, Seattle, WA.

Isaak, Marissa, March 2011, Playing Politics at the World Bank: The Red-Dead Canal.

Isaak, Marissa, September 2011, Prospects for Desalination in Israel, *American-Israel Cooperative Institute Conference*, Washington, DC.

Lacroix, Kelly M., September 2011, Assessing Water Supply Vulnerability in a Water Scarce State: The Arizona Water Sustainability Evaluation, *International Water Resources Association 14th World Water Congress*, Porto de Galinhas, Brazil.

Lacroix, Kelly M., September 2011, Arizona Water Management Along the Adaptive Cycle: What can the ebb of water governance teach us about future flows? Watersheds Near and Far, *Annual Meeting of the Arizona Hydrological Society*, Flagstaff, Arizona.

Lacroix, Kelly M., February 13, 2012, Connecting the Environment to Arizona Water Planning. Presentation at the Santa Cruz Groundwater Users Advisory Council meeting, Nogales, AZ.

Lacroix, Kelly M., February 2012, Connecting the Environment to Arizona Water Planning. Presentation at the Tucson Groundwater Users Advisory Council meeting, Tucson, AZ.

Lacroix, Kelly M., February 13, 2012, Connecting the Environment to Arizona Water Planning, Tucson and Santa Cruz Active Management Area Meeting, Tucson, AZ.

Lien, Aaron, J.B. Nadeau, C. Rupprecht, and S.B. Megdal, October 2011, Water Efficiency: Environment or Growth? Panel, *WaterSmart Innovations Conference*, Las Vegas, NV.

Lien, A., February 23, 2012, Conserve to Enhance: Linking Water Conservation to the Environment, presentation at the Environmental Protection Agency WaterSmart Webinar, by phone.

Lien, A., February 21, 2012, WRRC Conserve to Enhance Webinar: Webinar hosted by WRRC from Tucson, AZ

Lien, A., January 11, 2012, Sonoran Institute Rocky Mountain Programs Webinar: Webinar hosted by Sonoran Institute

Lien, A., January 12, 2012, Utah Water Conservation Forum: Presentation via teleconference (meeting in Salt Lake City)

McLain, J.E., February 15, 2012, Public health safety of reclaimed municipal wastewater: current research, invited Presentation, Arizona State University School of Sustainability SOS 326.

Megdal, Sharon B., March 2011, Arizona's Water Future: Challenges and Opportunities, *Arizona House of Representatives Committee on Agriculture and Water*, Phoenix, AZ.

Megdal, Sharon B., March 2011, The Energy-Water Nexus, *Workshop on Water Security Challenges Emanating from the Intersections of Climate and Water Scarcity in the Arid Americas*, Los Cabos, Mexico.

Megdal, Sharon B., March 2011, International Energy, Water, Environment/Clean Technologies (EWE CT) Center R&D Projects/Initiatives Workshop, *Royal Scientific Society supported by USAID Jordan Economic Development Program*, Amman, Jordan.

Megdal, Sharon B., March 2011, The Importance of Water for Arizona's Future, *San Xavier Kiwanis*, Tucson, AZ.

Megdal, Sharon B., April 2011, The Future of Arizona's Built Environment: The role of the Design and Planning Professionals, *College of Architecture and Landscape Architecture Seminar*, University of Arizona, Tucson, AZ.

Megdal, Sharon B., April 2011, *Salinity and Desalination in the Southwest: Challenges and Solutions*, Annual Conference of the Water Resources Research Center, Yuma, AZ.

Megdal, Sharon B., April 2011, Uncertainty and Sustainable Water Management in Arizona, *Flinn-Brown Civic Leadership Academy*, Phoenix, AZ.

Megdal, Sharon B., April 2011, Water Pricing and Public versus Private Water Company Ownership: Meeting Water Policy Goals, *Environmental Law and Economics Seminar*, University of Arizona, Tucson, AZ.

Megdal, Sharon B., May 2011, Water and Sustainable Communities ULI Sustainable Development Council, *National ULI Real Estate Summit: Adapting for the Future —Today*, Phoenix, AZ.

Megdal, Sharon B., June 2011, The State of the River: Understanding Supply and Demand, *Navigating the Future of the Colorado River Conference*, University of Colorado Law School, Boulder, CO.

Megdal, Sharon B., June, 2011, Update on the Arizona-Sonora Portion of the United States-Mexico Transboundary Aquifer Assessment Program, Water Committee of the Arizona-Sonora Commission, Litchfield Park, AZ.

Megdal, Sharon B., August 2011, *Agricultural-Environmental Cooperation and Fact-Finding Field Trip to Oregon*, Participant and Project PI/Leader.

Megdal, Sharon B., September 2011, CAP and Sustainability in the Tucson Region, *Southern Arizona Environmental Management Society Seminar*, Tucson, AZ.

Megdal, Sharon B., September 2011, Current and Emerging Policy Issues Relevant to Planning Professionals: Short Course on Planning for Water, *Arizona Planning Association State Conference*, Tucson, AZ.

Megdal, Sharon B., September 2011, GEF Project on “Groundwater Governance: A Global Framework for Country Action,” *Inception Meeting*, UNESCO, Paris, France.

Megdal, Sharon B., September 2011, Program on the Report of Regional Water Assessment Task Force “Think Tank” Process, Tucson, AZ.

Megdal, Sharon B., September 2011, Uncertainty and Sustainable Water Management in Arizona, *Arizona Housing Forum*, Scottsdale, AZ.

Megdal, Sharon B., October 18, 2011, Career Experiences, for the Strategy and Planning for Academic Success Colloquium, Department of Agricultural and Resource Economics, University of Arizona, Tucson, AZ.

Megdal, Sharon B., October 2011, Arizona and Israeli Water Policy: Some Similarities and Differences, *Arizona Center for Judaic Studies Seminar*, University of Arizona, Tucson, AZ.

Megdal, Sharon B., October 2011, Challenges to Sustainable Water Management in Arizona, *Institute of the Environment Honors Seminar*, University of Arizona Tucson, AZ.

Megdal, Sharon B., November 20, 2011, Options for Meeting Growing Water Demands in Water-scarce Regions, Workshop on Clean Technology Applications in Energy, Water and Environment, Royal Scientific Society, Amman Jordan.

Megdal, Sharon B., November 16, 2011, Options for Meeting Arizona’s Future Water Needs in the Context of Colorado River Water Management, WATEC 2011, The 3rd International Conference on Water Technologies, Renewable Energy, and Environmental Control, Tel Aviv, Israel.

Megdal, Sharon B., November 9, 2011, Conserve to Enhance: Linking Water Conservation to the Environment, Panel on Water Efficiency and Instream Flows, American Water Resources Association Annual Conference, Albuquerque, NM.

Megdal, Sharon B., November 8, 2011, The Santa Cruz and San Pedro Aquifers, Panel on Transboundary Aquifer Assessment Program, American Water Resources Association Annual Conference, Albuquerque, NM.

Megdal, Sharon B., November 4, 2011, Opportunities for Regional Collaboration: Water, Greater Tucson Leadership Class, Tucson, AZ.

Megdal, Sharon B., December 2011, Institutional Assessment of the Transboundary Santa Cruz and San Pedro Aquifers on the United States-Mexico Border, *ISARM2010 International Conference on Transboundary Aquifers: Challenges and New Directions*, Paris, France.

Megdal, Sharon B., December 2011, Integrated Transboundary Groundwater Management, Tools and Methods, *UNESCO Second Pilot Course*, Paris, France.

Megdal, Sharon B., December 31, 2011, Television Interview, by Jim Rogers for Inside Nevada, KSNV, Las Vegas NBC Affiliate, Nevada, December 14, 2011, aired in five segments the week of January 16, 2012.

Megdal, Sharon B., January 6, 2012, Water Policy Considerations Associated with Meeting Future Water Demands, Farm Foundation Round Table, Sedona, AZ.

Megdal, January 19, 2012, Sharon B., Television Interview, Horizon, KAET PBS TV8, Phoenix, AZ.

Megdal, Sharon B., January 20, 2012, Television Interview, Arizona Week, KUAT PBS TV6, Tucson, AZ.

Megdal, Sharon B., January 23, 2012, Conference Host and Moderator, Urbanization, Uncertainty and Water: Planning for Arizona's Second Hundred Years, 2012 Annual Conference of the Water Resources Research Center, The University of Arizona, Tucson, AZ.

Megdal, Sharon B., January 23, 2012, Radio Interview, Bill Buckmaster Show, KVOI Radio, Tucson, AZ.

Megdal, Sharon B., January 26, 2012, Uncertainty and Sustainable Water Management in Arizona; Water Company Regulation, Water Pricing and Conservation; and Quantifying and Funding Water for the Environment, Thomas R. Brown Foundation Teacher Workshop, The Economics of Water, Tucson, AZ.

Megdal, Sharon B., A. Lien, J.B. Nadeau, and C.L. Rupperecht, September 2011, Conserve to Enhance - Tucson AZ Pilot Overview, *Metropolitan Water District of Southern California Water Use Efficiency Meeting*, Los Angeles, CA.

Megdal, Sharon B., A. Lien, J.B. Nadeau, and C.L. Rupperecht, November 2011, Conserve to Enhance: Linking Water Conservation to the Environment, *American Water Resources Association*, Albuquerque, NM.

Megdal, Sharon B. and J.B. Nadeau, June 2011, Inspiring Water Conservation for Environmental Enhancement, *American Water Works Association Annual Conference & Expo*, Washington, DC.

Megdal, Sharon B. and J.B. Nadeau, July 2011, Quantifying and Funding Water for the Environment: Researchers Assisting Practitioners, *Universities Council on Water Resources (UCOWR)/National Institutes for Water Resources (NIWR) Annual Conference*, Boulder, CO.

Megdal, Sharon B., J. B. Nadeau, and B. Choate, April 2011, The Forgotten Sector: Defining and Securing Water for the Environment, *WRRC Annual Conference*, Yuma, AZ.

Megdal, Sharon B., J.B. Nadeau, and C.L. Rupprecht, June 2011, *Walton Family Foundation Water Conservation Meeting*, Denver, CO.

Nadeau, Joanna B., S.B. Megdal and B. Choate, June 2011, *The Forgotten Sector: Defining and Securing Water for the Environment* (poster), *Navigating the Future of the Colorado River Conference*, University of Colorado Law School, Boulder, CO.

Nadeau, Joanna and S.B. Megdal, July 2011, *Quantifying and Funding Water for the Environment: Researchers Assisting Practitioners*, *UCOWR/NIWR Annual Conference: Planning for Tomorrow's Water: Snowpack, Aquifers, and Reservoirs*, Boulder, CO.

Nadeau, Joanna B., S.B. Megdal, and C. Rupprecht, AZ, February 2011, *Securing Water for the Environment*, *Water Resources Research Center (WRRC) Brown Bag*, Tucson.

Nadeau, Joanna B., C. Rupprecht, and S.B. Megdal, January 2011, *Southern California Office, Bureau of Reclamation*, Temecula, C,.

Nadeau, Joanna B. and S.B. Megdal, January 2011, *Water Resources Development Commission (WRDC) Environmental Condition Subcommittee*, Phoenix, AZ.

Nadeau, Joanna B., C. Rupprecht, and S.B. Megdal, February 2011, *Tucson Pilot Program Participant Orientation*, Tucson, AZ.

Nadeau, Joanna B. and S.B. Megdal, April 2011, *Conserve to Enhance, Roaring Fork Watershed Collaborative*, Carbondale, CO.

Nadeau, Joanna B. and S.B. Megdal, May 2011, *Arizona Environmental Water Needs Assessment and Methodology Guidebook*, *The Instream Flow Council FLOW Conference*, Nashville, TN.

Nadeau, Joanna B. and S.B. Megdal, June 2011, *Arizona Environmental Water Needs Assessment, Science on the Sonoita Plain*, Sonoita, AZ.

Nadeau, Joanna B., B. Choate, C.L. Rupprecht, and S.B. Megdal, July 2011, *WRRC Brown Bag/C2E Listening Session*, Tucson, AZ.

Nadeau, Joanna B., K. Mott Lacroix, and S.B. Megdal, December 2011, *Connecting the Environment to Arizona Water Planning, Stakeholder meeting*, Tucson, AZ.

Nadeau, Joanna B., K. Mott Lacroix, and S.B. Megdal, December 2011, *Connecting the Environment to Arizona Water Planning, Stakeholder meeting*, Phoenix, AZ,.

Prichard, Andrea, November 2011, *Interbasin Water Transfers at the U.S.-Mexico Border City of Nogales, Sonora: Implications for Aquifers and Water Security*, *UA Environmental Research Grad Blitz*.

Rupprecht, Candice, and B. Choate, February 2, 2012, *Connecting the Environment to Arizona Water Planning*, *Little Colorado River Winter Watershed Conference*, Show Low, AZ.

Rupprecht, Candice, and K.M. Lacroix, February 11, 2012, *Connecting the Environment to Arizona Water Planning*, *CWAG (Citizens Water Advisory Group) Meeting*, Prescott, AZ.

Rupprecht, Candice, J.B. Nadeau, and S.B. Megdal, March 2011, Meeting the Challenge of Water for the Environment: Innovative Tools for Restoration Practitioners, *Arizona Riparian Council*, Yuma, AZ.

Rupprecht, Candice, J.B. Nadeau, and S.B. Megdal, June 2011, *Tucson-Pima Metropolitan Energy Commission*, Tucson, AZ.

Rupprecht, Candice, J.B. Nadeau, and S.B. Megdal, July 2011, *Cienega Watershed Partnership*, Tucson, AZ.

Rupprecht, Candice, E.M. Brott, A. Lien, S.B. Megdal, and J.B. Nadeau, October 2011, *WaterSmart Innovations Conference*, Las Vegas, NV.

Rupprecht, Candice, J.B. Nadeau, A. Lien and S.B. Megdal, November 2011, Conserving Water for the Environment in Tucson, Arizona: A Pilot Program, *University of Arizona Cooperative Extension County Directors Meeting*, Phoenix, AZ.

Schwartz, Kerry and C.L. Rupprecht, July 2011, Arizona Project WET: Lessons that Bring Water Concepts in to the Classroom using 21st Century Learning Strategies, *Tucson Water's Summer Internship Program for Teachers*, Tucson, AZ.

Schwartz, Kerry and C.L. Rupprecht, July 2011, STEM-focused Water Education for 4-6 Grade Teachers, *Arizona Center for STEM Teachers Summer Institute*, Biosphere 2, Oracle, AZ.

Schwartz, Kerry, C.L. Rupprecht, and H. Thomas-Hillburn, January 2011, APW-FOSS Integrated 3rd Grade Water Unit, *Tucson, Sunnyside and Flowing Wells Unified School Districts*, UA Environmental Research Laboratory, Tucson, AZ.

Schwartz, Kerry, C.L. Rupprecht, and H. Thomas-Hillburn, January 2011, Energy & Environmental Science 6th Grade Unit, *Tucson, Sunnyside and Flowing Wells Unified School Districts*, UA Environmental Research Laboratory, Tucson, A,.

Schwartz, Kerry, C. Rupprecht, and H. Thomas-Hillburn, July and September 2011, *School Water Audit Program Pinal County Teacher Cohort Professional Development Workshop Series*, Pinal County, AZ.

Schwartz, Kerry, C. Rupprecht, and H. Thomas-Hillburn, March 2011, 21st Century Skill Development Using Arizona Project WET lessons, *RET G-K-12 Program*, University of Arizona, Tucson, AZ.

Schwartz, Kerry, C. Rupprecht, and H. Thomas-Hillburn, March 2011, *Americorps - 6th Grade Groundwater Flow Model Training*, *Water Resources Research Center*, Tucson, AZ.

Schwartz, Kerry, C. Rupprecht, and H. Thomas-Hillburn, April 2011, The Colorado River Compact: History Informing the Present, *NAU Colloquium: Teaching American History through Historical Investigations*, Grand Canyon National Park, South Rim, AZ.

Schwartz, Kerry, C. Rupprecht, and H. Thomas-Hillburn, April 2011, Salinity and Desalination: Vehicles to Bring Concepts in to the Classroom, *Water Resources Research Center Annual Conference*, Yuma, AZ.

Schwartz, Kerry, C. Rupprecht, and H. Thomas-Hillburn, April 2011, Water Investigations Program Symposium: Middle School Students Present Results of their Scientific Investigations, *Facilitated Colloquia*, UA Student Union, Tucson, AZ.

Schwartz, Kerry, C. Rupperecht, and H. Thomas-Hillburn, April, May and June 2011, *NASA Earth Camp for Teachers Professional Development Workshop Series*, Environmental Research Laboratory and Sonora Desert Museum.

Schwartz, Kerry, C. Rupperecht, and H. Thomas-Hillburn, May 2011, Energy and Environmental Science 6th Grade Curriculum Unit Revision: Improving the Energy Component, *Facilitated Colloquia*, Tucson Unified School District, Tucson, AZ.

Schwartz, Kerry, C. Rupperecht, and H. Thomas-Hillburn, May 2011, School Water Audit Program (SWAP) Symposium: Middle School Students Present Results of their School Water Audit, *Facilitated Colloquia*, University of Arizona, Tucson, AZ.

Schwartz, Kerry, C. Rupperecht, and H. Thomas-Hillburn, June 2011, *An Advanced Water Education Workshop: Water and Public Perception*, ASU Decision Center for a Desert City, Tempe, AZ.

Schwartz, Kerry, C. Rupperecht, and H. Thomas-Hillburn, June 2011, APW-FOSS Integrated 3rd Grade Water Unit, *Tucson, Sunnyside and Flowing Wells Unified School Districts*, UA Environmental Research Laboratory, Tucson, AZ.

Schwartz, Kerry, C. Rupperecht, and H. Thomas-Hillburn, June 2011, Energy & Environmental Science 6th Grade Unit, *Tucson, Sunnyside and Flowing Wells Unified School Districts*, UA Environmental Research Laboratory, Tucson, AZ.

Schwartz, Kerry, C. Rupperecht, and H. Thomas-Hillburn, July 2011, STEM-focused Water Education for 4-6 Grade Teachers, *Arizona Center for STEM Teachers Summer Institute*, Biosphere 2, Oracle, AZ.

Schwartz, Kerry, C. Rupperecht, and H. Thomas-Hillburn, July 2011, *Water Investigations Program Professional Development Workshop Series*, Hassayampa River Preserve, 91st Avenue Wastewater Treatment Plant and Maricopa County Cooperative Extension Office, Phoenix, AZ.

Scott, Christopher and S.B. Megdal, July 2011, The Challenge of Binational Decision-Making in Arizona-Sonora Transboundary Watersheds, *UCOWR/NIWR Annual Conference Planning for Tomorrow's Water: Snowpack, Aquifers, and Reservoirs*, Boulder, CO.

Thomas-Hilburn, Holly, February 25, 2012, Water festival preparatory workshop, Gilbert, AZ.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	4	0	0	0	4
Masters	4	0	0	0	4
Ph.D.	0	1	0	0	1
Post-Doc.	0	0	0	0	0
Total	8	1	0	0	9

Notable Awards and Achievements

- Sharon Megdal was awarded a Lady Davis Fellowship to fund her one-month sabbatical stay in Israel. • Sharon Megdal was a recipient of a UA Leading Edge award for innovative research. • Sharon Megdal was elected to the board of directors of the National Institutes for Water Resources (NIWR), the association of water institutes/centers authorized by the federal Water Resources Research Act.
- Kerry Schwartz was presented the Individual Program Leadership Gold Award in recognition of exemplary leadership of an individual natural resources program by the national Association of Natural Resource Extension Professionals in 2011. • At the Sustaining the Blue Planet International Water Education Conference, Kerry Schwartz received a One World One Water Award for exemplary service over the last 12 years. This award was presented at the September 2011 conference with 40 countries represented. • At the Sustaining the Blue Planet International Water Education Conference in September 2011, with 40 countries represented, Arizona Project WET had 5 presentations accepted and presented them all. No other state program made any presentations. The Presentations included: - “Destination Inquiry: Paddling Upstream”, Pamela Justice and Mary Ann Stoll - “Grounding Water: Building Student Understanding Through Multi-Modal Assessment”, Holly Thomas-Hilburn and Kerry Schwartz - “STEM Subject Integration: Meeting the Need with Tangible Programming”, Kerry Schwartz, Candice Rupperecht and Holly Thomas-Hilburn - “A Different Animal: Attracting Corporate and NGO Sponsorship”, Kerry Schwartz and Tasha Krecek-Lynch - “Riding the Wave of Student-Driven Inquiry: Terror or Treasure”, Mary Ann Stoll and Pamela Justice
- Nicole Campbell, the chemistry master's student supported by the grant, "Characterization of Chelating Agents in Non-regulated Water Sources on Navajo Lands," Jani C. Ingram PI, gave a public seminar for the Department of Chemistry and Biochemistry at Northern Arizona University on April 23. Her seminar was entitled, "Characterizing $^{234}\text{U}/^{238}\text{U}$ Activity Ratios and Inorganic Complexation in Water Sources on the Navajo Reservation". • Nicole Campbell gave an oral presentation on her work at the 243rd American Chemical Society meeting in San Diego, California on March 25. Her talk was presented in a session entitled "Sustainability and Water Reclamation". • Nicole Campbell was named Outstanding Graduate Scholar by the Northern Arizona University Department of Chemistry & Biochemistry.

Publications from Prior Years

1. 2005AZ114G ("Chemolithotrophic denitrification: The missing link in the biogeochemical cycle of arsenic") - Articles in Refereed Scientific Journals - Sierra-Alvarez R., I. Cortinas, J.A. Field, 2010, Methanogenic inhibition by roxarsone (3-nitro-4-hydroxybenzene arsonic acid) and related aromatic arsenic compounds, *J. Hazard. Mater.* 175:352–358.
2. 2005AZ114G ("Chemolithotrophic denitrification: The missing link in the biogeochemical cycle of arsenic") - Conference Proceedings - Sierra-Alvarez R., W. Sun, P. Rowlette, I. Cortinas, J.A. Field, 2005, Anoxic oxidation of arsenite linked to denitrification, 8th Int. In Situ and On-Site Bioremediation Symp., June 6-9, Baltimore, MD.
3. 2005AZ114G ("Chemolithotrophic denitrification: The missing link in the biogeochemical cycle of arsenic") - Articles in Refereed Scientific Journals - Sun W, R. Sierra-Alvarez, N. Fernandez, J.L. Sanz, R. Amils, A. Legatzki, R. Maier, J.A. Field, 2009, Molecular characterization and in situ quantification of anoxic arsenite oxidizing denitrifying enrichment cultures, *FEMS Microb. Ecol.* 68:72-85.
4. 2005AZ114G ("Chemolithotrophic denitrification: The missing link in the biogeochemical cycle of arsenic") - Articles in Refereed Scientific Journals - Sun W, R. Sierra-Alvarez, L. Milner, R. Oremland, J.A. Field, 2009, Arsenite and Ferrous iron oxidation linked to chemolithotrophic denitrification for the immobilization of arsenic in anoxic environments, *Environ. Sci. Technol.* 43:6585-6591.
5. 2005AZ114G ("Chemolithotrophic denitrification: The missing link in the biogeochemical cycle of arsenic") - Articles in Refereed Scientific Journals - Sun W.J., R. Sierra-Alvarez, J.A. Field, 2008, Anoxic oxidation of arsenite linked to denitrification in sludges and sediments, *Water Res.* 42(17):4569 – 4577.
6. 2005AZ114G ("Chemolithotrophic denitrification: The missing link in the biogeochemical cycle of arsenic") - Dissertations - Sun, W.J., 2006, Anoxic Oxidation of Arsenite to Arsenate linked to Denitrification, MS thesis, Dept. Chemical and Environmental Engineering, The University of Arizona, May 2006.
7. 2005AZ114G ("Chemolithotrophic denitrification: The missing link in the biogeochemical cycle of arsenic") - Dissertations - Sun, W.J., 2008, MICROBIAL OXIDATION OF ARSENITE IN ANOXIC ENVIRONMENTS: IMPACTS ON ARSENIC MOBILITY, PhD dissertation, Dept. Chemical and Environmental Engineering, The University of Arizona, November 2008.
8. 2005AZ114G ("Chemolithotrophic denitrification: The missing link in the biogeochemical cycle of arsenic") - Articles in Refereed Scientific Journals - Sun, W. J., R. Sierra-Alvarez, I. Hsu, P. Rowlette, and J. A. Field, 2010, Anoxic Oxidation of Arsenite Linked to Chemolithotrophic Denitrification in Continuous Bioreactors, *Biotechnol. Bioeng.* 105:909-917.
9. 2005AZ114G ("Chemolithotrophic denitrification: The missing link in the biogeochemical cycle of arsenic") - Conference Proceedings - Sun, W.J., R. Sierra-Alvarez, J.A. Field, 2008, Microbial oxidation of As (III) in anoxic environments: Impact on arsenic mobility in the subsurface, NIEHS Superfund Basic Research & Training Program 2008 Annual Meeting: Innovative Science and Technology for Mitigating Human, Ecol. and Environ. Risks, Pacific Grove, CA. Dec. 7-9. pp. 29-30.
10. 2005AZ81B ("Treatment of Nitrate in Groundwater with Autotrophic Bioreactors") - Articles in Refereed Scientific Journals - Beristain Cardoso, R. Sierra-Alvarez, P. Rowlette, E. Razo Flores, J. Gómez, J.A. Field, 2006, Sulfide oxidation under chemolithoautotrophic denitrifying conditions, *Biotechnol. Bioeng.* 95(6):1148-1157.
11. 2005AZ81B ("Treatment of Nitrate in Groundwater with Autotrophic Bioreactors") - Conference Proceedings - Chairez-Llamas M, O. Moje Amaya, A. Luna, R. Sierra-Alvarez, J.A. Field, 2006, Bioremediation of nitrate in sulfur-based bioreactors, Univ. Arizona Water Forum, 2006, Tools & Technology for Water Sustainability, Nov. 2, Tucson, AZ.

12. 2005AZ81B ("Treatment of Nitrate in Groundwater with Autotrophic Bioreactors") - Dissertations - Chairez-Llamas, M.C., 2008, Application of Elemental Sulfur as Electron Donor for the Remediation of Water Contaminated with Nitrate and Bromate, May 2008, MS Thesis, Dept. Chemical and Environmental Engineering, The University of Arizona.
13. 2005AZ81B ("Treatment of Nitrate in Groundwater with Autotrophic Bioreactors") - Articles in Refereed Scientific Journals - Sierra-Alvarez R., R. Beristain-Cardoso, M. Salazar, Gómez J, E. Razo-Flores, J.A. Field, 2007, Chemolithotrophic denitrification with elemental sulfur for groundwater treatment, *Water Res.* 41(6):1253-1262.
14. 2006AZ132B ("Perfluorinated Chemicals in Municipal Wastewater Treatment Plants in Arizona") - Dissertations - Ochoa-Herrera, V. L. 2008. REMOVAL OF PERFLUOROOCCTANE SULFONATE (PFOS) AND RELATED COMPOUNDS FROM INDUSTRIAL EFFLUENTS PhD dissertation, Dept Chemical and Environmental Engineering, The University of Arizona. November 2008.
15. 2006AZ132B ("Perfluorinated Chemicals in Municipal Wastewater Treatment Plants in Arizona") - Articles in Refereed Scientific Journals - Ochoa-Herrera V, Sierra-Alvarez R. 2008. Removal of perfluorinated surfactants by sorption onto granular activated carbon, zeolite and sludge. *Chemosphere.* 72:1588–1593.
16. 2006AZ132B ("Perfluorinated Chemicals in Municipal Wastewater Treatment Plants in Arizona") - Conference Proceedings - Sierra-Alvarez R, Ochoa V, Field JA, Wysocki V, Jacobsen N, Somogyi A. 2009. Reductive dehalogenation of perfluoroalkyl surfactants in semiconductor effluents. SRC/Sematech Engineering Research Center for Environmentally Benign Semiconductor Manufacturing. 2009 Annual Review. Feb. 19-20, 2009. Tucson, Arizona. [POSTER]
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