Water Resources Research Center
Annual Technical Report
FY 2015

Introduction

A Research and Extension unit of the College of Agriculture and Life Sciences, the University of Arizona Water Resources Research Center (WRRC) has a mission to promote understanding of critical state and regional water management and policy issues through research, outreach, engagement and education. It accomplishes its mission by assisting communities in water management and policy; educating teachers, students and the public about water; and conducting scientific research on state and regional water issues. The WRRC is known statewide as a hub for water resources research and information transfer in Arizona. It is the designated state water resources research institute established under the 1964 Federal Water Resources Research Act, and as such, the WRRC administers research grant programs and maintains a strong information transfer program that includes publications, presentations, conferences and other public events.

In addition to these activities, the WRRC conducts programs of research on topics such as planning assistance for local communities, environmental water needs, managed aquifer recharge, transboundary aquifer management, and groundwater governance. Collaborations and cooperative arrangements are vital for accomplishment of the WRRC's active research, education and outreach goals. Among its key partners is the Water Sustainability Program, one of three programs making up the Water, Environmental and Energy Solutions (WEES) program, which is housed at the WRRC and funded from the UA's Technology and Research Initiative Fund (TRIF). The WRRC also houses Arizona Project WET (Water Education for Teachers), which was initiated at the WRRC in 1991. Arizona Project WET is Arizona's premier water education program. In addition the WRRC is closely linked with Arizona Cooperative Extension.

Research Program Introduction

The University of Arizona (UA) WRRC provides support through the WRRA, Section 104(b) research grant program in the form of small research grants. Investigators at the three state universities in Arizona are encouraged to apply for these grants. The WRRC typically selects two to four research projects for funding. Selected projects address water research judged to provide value statewide on resolving water resource issues. Selection criteria include importance, potential impact, technical merit, and feasibility, as well as provision for student education and information transfer to research users.

A wide range of projects have been funded over the years, emphasizing mandated program goals of improving water supply reliability and quality, and exploring new ideas to address water problems and expanding understanding of water and water-related phenomena. For the 2015-16 grant cycle, the WRRC selected three research projects for funding from the eight proposals received:

• Water Sources over Time for a Semi-Arid River – Implications for Water Resources and Groundwater Modeling, Principal Investigator: Thomas Meixner, University of Arizona; • Impact of Upgraded Wastewater Reclamation Facilities on Chemicals of Emerging Concern in the Effluent-dependent Lower Santa Cruz River, Principal Investigator: David M. Quanrud, University of Arizona; • Characterization of Uranium and Arsenic in Unregulated Water Sources on the Navajo and Hopi Reservations, Principal Investigator: Jani Ingram, Northern Arizona University.

The WRRC issued its call for proposals in September for the 2016-2017 cycle (March 1, 2016-February 28, 2017). The Technical Review Committee met on December 18th to evaluate the five proposals received and two projects were recommended for funding:

• Sunlight-driven reactive oxygen species production for natural attenuation of wastewater trace organic compounds, Principal Investigator: Robert Arnold, University of Arizona; • Recycled water use for agriculture: on-farm demonstration and evaluation research, Principal Investigator: Channah Rock, University of Arizona.

Grants awarded to Arizona investigators from the nationally competitive grants program, the 104g program are administered by the WRRC, which is responsible for submitting the proposals from Arizona. No Arizona 104g projects were funded in 2015.

Water Sources Over Time for a Semi-Arid River- Implications for Water Resources and Groundwater Modelling

Basic Information

Title:	Water Sources Over Time for a Semi-Arid River- Implications for Water Resources and Groundwater Modelling
Project Number:	2015AZ540B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	2
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Quantity, Climatological Processes, Floods
Descriptors:	None
Principal Investigators:	Thomas Meixner, Steve Leavitt, Kiyomi Morino

Publications

There are no publications.

Problem and Research Objectives

Recent research on the sources of water in perennial streams in arid and semi-arid climates have identified flood-driven recharge from intense precipitation events as critical sources of water for sustaining streamflow (Baillie et al. 2007, Plummer at al. 2004, Simpson 2007). The variation in this source of water could have important implications for the effect of climate change and variability on sustaining water resources in riparian areas of the Southwest United States. Riparian areas of the Southwest are critical biodiversity locations that are under threat from human changes to their hydrology (Stromberg et al. 2009). Because of human threats to these systems it is critical to understand the past hydrologic conditions that sustained these ecosystems. A concerted effort to link current hydrologic information to paleorecords of water source could provide crucial information about how these systems have evolved and how much change currently observed is due to human impacts versus due to climate variability and change. A setting where this approach could be successful is the San Pedro River valley in southern Arizona. Detailed studies on water sources for the San Pedro River exist (Baillie et al. 2007, Simpson and Meixner 2012). Additionally, paleorecords of system hydrology in the form of cottonwood tree rings exist for the San Pedro River offering an ideal setting to demonstrate the proof of concept (Potts and Williams 2004).

Importantly, paleohydrology studies have gained recent currency in the western United States as key ingredients in good water resource planning (Meko et al. 2007). Existing studies have depended on tree rings to uncover hydrologic patterns by using upland tree species. Given the complexities of hydrologic systems tree growth corresponding to wet upland conditions may not correspond to local changes in streamflow particularly for biologically important low flows (Stromberg et al. 2009). Paleo-records of in-stream flows would be a notable improvement to understanding hydrologic responses to climate variation and the intersection of this variability with human management.

In this project we sought to achieve two objectives: First, quantify with high temporal resolution the variability of water source to the San Pedro River over the past 60 years. Second, the water source results will be used to drive a simple surface-groundwater interaction model that will be used to infer past hydrologic conditions using the results from the tree-ring analysis.

Methodology

Sampling for this project has been completed and we are currently waiting for a backlog of analyses in the Geosciences Isotope Geochemistry laboratory to be cleared so our samples can be analyzed. Samples were collected from 5 trees at the three identified locations on the San Pedro River. This work focused on using the San Pedro basin as a test basin for understanding how to link paleo hydrologic records with models of how river systems work. The length of perennial river flow on the San Pedro has declined by approximately 30% over the last 30 years due to the effects of groundwater pumping for industrial (copper ore), agricultural and urban purposes (Stromberg and Tellman 2009). Declining base flow was one of the motivating causes for the founding of the San Pedro River National Conservation Area. Recent years have seen widespread retiring of pumping in an attempt to restore dewatered areas. The abundance of scientific studies conducted on the San Pedro River makes it an ideal site to generate knowledge of coupled abiotic and biotic processes and their control on vegetation dynamics. Long stream flow records exist at three locations along the river. Water isotopic data exist and show a link

between storm events and groundwater recharge (Baille et al 2007). Our work focused on three specific locations along the San Pedro River, Palominas which is currently a losing reach of the river and has streamflow dominated by waters of similar isotopic composition to summer storms, Lewis Springs which is a strongly gaining reach and more strongly influence by basin groundwater, and the reach of the river near Fairbank, AZ which has a current isotopic composition intermediate between the other two locations. All three locations have USGS stream gauges established and have been observed to have different degrees of surface groundwater connection (Simpson and Meixner 2013).

Quantify with high temporal resolution variability of water source to the San Pedro River over the past 60 years: Tree rings from approximately 5 trees were sampled at each of 3 sites along the San Pedro using increment borers in the spring and summer of 2015. Four cores were taken per tree to better identify rings for tree-ring dating and to provide sufficient material for isotopic analysis. Core samples were surfaced with sandpaper (or razor blades) to bring out microfeatures, and then dated (Stokes and Smiley 1968). Rings were separated with a razor knife, pooled within trees from each site, and ground to a powder for each year of the chronology. We collected approximately 60 years total at each site.

Tree-ring samples were converted to holocellulose by the Jayme-Wise method through a procedure slightly modified from Leavitt and Danzer (1993). These samples are currently awaiting analysis at the Geosciences Isotope laboratory. Cellulose samples will be analyzed on a Finnigan Delta-Plus mass-spectrometer in flow-through mode.

Principal Findings and Significance

Since we are currently waiting for these analyses, we have not yet simulated the conditions that created the tree ring patterns observed. We hope to have results soon and will update our report at that time.

It is hoped that improved understanding of the variability of flood recharge will enable better management of SPRNCA.

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Impact of upgraded wastewater reclamation facilities on chemicals of emerging concern in the effluent-dependent Lower Santa Cruz River

Basic Information

Title:	Impact of upgraded wastewater reclamation facilities on chemicals of emerging concern in the effluent-dependent Lower Santa Cruz River
Project Number:	2015AZ541B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	Seventh
Research Category:	Not Applicable
Focus Category:	Toxic Substances, Water Quality, Wastewater
Descriptors:	None
Principal Investigators:	David Matson Quanrud, Shane Snyder

Publication

1. VanDervort, Darcy, 2015, “Downstream trends of glucocorticoid and aryl hydrocarbon receptor activities in a wastewater effluent-dependent stream,” Department of Chemical and Environmental Engineering, College of Engineering, University of Arizona, Tucson, AZ, 71pp.

Problem and Research Objectives

Municipal wastewater contains an assortment of pharmaceuticals and personal care products (PPCPs) along with a myriad of other contaminants of emerging concern (CECs) that are sometimes poorly attenuated during wastewater treatment. A subset, the endocrine disrupting compounds (EDCs), have been shown to cause environmental impacts, e.g. feminization of fish, and there is speculation that chronic exposure among humans to EDCs is associated with elevated incidences of attention deficit disorder, asthma and diabetes. In Arizona and elsewhere in the arid southwest, municipal wastewater treatment facilities commonly discharge to waterways that are effluent dominant or effluent dependent. With little to no opportunity for dilution with natural base flow, the fate and transport of CECs in effluent-impacted watersheds in Arizona is an especially important issue and a question of broad interest for both ecological and human health.

Nine streams in the state of Arizona are classified as "effluent dependent," comprising a total river distance of 91 miles (Uhlman et al., 2012). In southern Arizona, the Upper Santa Cruz River (SCR) is effluent dependent flowing north from Nogales, and, farther downstream, the Lower SCR is again effluent dependent flowing north from Tucson. Riparian ecosystems and groundwater quality along these reaches of the SCR are impacted by the quality of effluent discharged to these waterways.

In June 2009, a $66 million upgrade was completed at the Nogales International Wastewater Treatment Plant (NIWWTP) to meet tightened state regulatory standards for total nitrogen discharge and total suspended solids (TSS). The improved effluent quality resulted in substantial changes to the river environment downstream of the NIWWTP outfall (Sonoran Institute, 2009). With ammonia no longer present, fish species, including Longfin Dace and Western Mosquitofish, have again been observed in the river. A somewhat unanticipated result of the NIWWTP upgrade was a shortening of the length of the wetted reach below the NIWWTP outfall. Infiltration rates along the Upper SCR have increased as consequence of the improved effluent quality (Treese, 2008).

Similar outcomes are occurring as a result of recent (2014) upgrades at the two main wastewater reclamation facilities (WRFs) located along the Lower SCR (Figure 1) that serve the Tucson metropolitan area. To meet tightened effluent discharge requirements, Pima County replaced the Roger Road Wastewater Treatment Plant with the Agua Nueva WRF (ANWRF) and substantially upgraded the Ina Road WRF and renamed it the Tres Rios WRF (TRWRF). Both facilities began discharging Class A effluent to the Lower SCR beginning in early spring 2014. The ANWRF and the TRWRF are both operated by Pima County Regional Wastewater Reclamation Department (PCRWRD) and together discharge about 62 million m^3 (~50,000 ac-ft.) of effluent per year to the Lower SCR. Most of this water recharges the local Tucson aquifer.

Figure 1. Lower Santa Cruz River study area. Sampling sites are represented by circles (small circles—river sites; large circles—WRF outfall sites).

Within the first four months of operation of the new and upgraded WRFs, substantial impacts to the Lower SCR were apparent. Notably, effluent from the Agua Neuva WRF completely infiltrates into the riverbed prior to traversing the 7.6 km distance to the downstream Tres Rios WRF outfall, leaving a reach of dry riverbed between the two WRFs. Farther downstream, the Lower SCR is at times going dry near the vicinity of Sanders Road. The improved effluent quality has led to an apparent increase in infiltration rates along the river and consequently a shortening of the distance along which aquifer recharge occurs (Sonoran Institute, 2015).

In addition to the potential loss of some riparian habitat along the Lower SCR, the increased hydraulic loading (percolation) rates may reduce opportunity for natural processes, including biodegradation, sorption, and photolysis, to attenuate CEC concentrations during surface transport. Previous work by the PIs has shown that concentrations of several CECs are substantially reduced during surface flow in the Lower SCR and that indirect photolysis plays an important role in destruction of the estrogen hormone ethinyl estradiol (EE2) (Dong et al., 2015). The role of sunlight was also observed by Hanamoto et al. (2013), who found that photolysis attenuated some CECs by 20% or more during transport along a 7.6 km river reach.

The goal of this project was to assess impacts of wastewater treatment upgrades on occurrence and fate of a suite of CECs during river transport along the Lower SCR. The study represents a first step toward a broader understanding of impacts to the subsurface and the watershed. Specific project objectives were as follows:

1. Measure CEC concentrations in effluent from the Agua Nueva and Tres Rios WRFs to establish baseline understanding of current CEC loading rates to the lower SCR watershed and how they have changed as consequence of the upgraded wastewater treatment facilities

2. Obtain preliminary information on transport and fate of a suite of CECs along the current wetted reach of the Lower SCR through multiple sampling campaigns over a one year period.

Methodology

The time period of the project was March 2015 through February 2016. Water samples were collected along the Lower Santa Cruz River (SCR) at nine sites (Table 1), including at the ANWRF and TRWRF effluent outfalls, during May, September, December, and February. Sampling conformed to methods described in the USGS Field Manual (Section 5.6.1.F; USGS, 2010) pertaining to collection of Wastewater, Pharmaceuticals, and Antibiotic Compounds. There was no surficial flow upstream of the ANWRF effluent outfall during any of the collection events, hence there was no dilution of effluent during the days of sampling.

Table 1. Water sample collection sites along the Lower Santa Cruz River.

Sampling Location	Distance downstream (km)[1]	Notes
Agua Nueva WRF	0.0	effluent outfall
El Camino del Cerro	1.3	bridge[2]
Belmont Rd.	6.4	bridge[2]
Tres Rios WRF	7.6	effluent outfall
N. Cortaro Rd.	10.2	bridge[2]
Twin Peaks Rd.	13.5	bridge[2]
Avra Valley Rd.	17.8	bridge[2]
Sanders Rd.	27.1	bridge[2]
N. Trico Rd.	34.0	bridge[2]

[1]distance downstream (km) from the Agua Nueva WRF effluent outfall
[2]samples were collected upstream from bridges to minimize potential for sample contamination

The suite of CECs included in this study, along with their uses and method reporting limits, is provided in Table 2. The list includes pharmaceuticals, personal care products, flame retardants, and compounds used in industrial applications and consumer products. Atenolol is a beta-blocking pharmaceutical used to treat cardiovascular disorders. Diphenhydramine is a first generation antihistamine pharmaceutical used to treat allergies. Perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) are global pollutants and are used in industrial compounds and consumer products. PFOA is used in non-stick and water-proof coatings, while PFOS is used as a stain repellent. Triclocarban is a personal care product commonly used as an antibacterial ingredient in soap products. Trimethoprim is a bacteriostatic antibiotic used to treat urinary tract infections by preventing bacterial reproduction.

Table 2. Suite of CECs measured in this project.

Compound	Use	Method reporting limit (ng/L)
Atenolol	*Beta blocker*	4.4
Benzophenone	*UV blocker*	4.4
Bisphenol A	*Plastic additive*	42
DEET	*Mosquito repellent*	18
Diphenhydramine	*Antihistamine*	5.4
fluoxetine	*Antidepressant*	55
Ibuprofen	*Nonsteroidal anti-inflammatory*	4.0
Naproxen	*Anti-inflammatory*	6.0
PFHxA	*Flame retardant*	1.1
PFOA	*Surfactant*	2.2
PFOS	*Surfactant*	2.5
TCEP	*Flame retardant*	19
Triclocarban	*Anti-microbial*	4.2
Triclosan	*Anti-microbial*	8.6
Trimethoprim	*Antibiotic*	20

At each river sampling location, samples were collected in 1-L amber glass bottles that had been pre-washed with methanol (MeOH) and triple-rinsed with Milli-Q water. At each location, the sampling bottles were triple-rinsed with river water at that site and samples were then collected using a polypropylene bucket then poured into the bottles, or collected directly into the bottles. As a quality assurance measure, triplicate samples were collected at one site per sampling event. All samples were preserved on ice in coolers. Samples were filtered using 0.7 µm glass fiber filter membranes (Whatman) after return to the laboratory, after which they were stored at 4ºC pending sample analysis.

Target analytes were prepared using on-line solid phase extraction (OSPE) and then measured using ultra-high performance liquid chromatography coupled with tandem mass spectrometry (UHPLC-MS/MS, 6460Agilent Technologies, Santa Clara, CA) using published methods (Anumol et al. 2013, Anumol and Snyder 2015). Quantification limits varied between 0.5-20 ng/L (ppt) in water. Analytical laboratory QA/QC procedures included use of method blank samples, blank and matrix spiked samples, and replicate laboratory samples. Surrogate compounds were added to samples prior to extraction to monitor method performance (isotope dilution method). Data were analyzed using a Masshunter Workstation Software (Agilent Technologies, Santa Clara, CA). All analytical work was performed in the Snyder Research Laboratory on the University of Arizona campus.

Principal Findings and Significance

Objective 1: Comparison of effluent CEC concentrations from the old and new WRFs. Average concentrations (ng/L) for all of the CECs measured during this study in effluent outfalls at the Agua Nueva and Tres Rios WRFs are summarized in Table 3. CEC concentrations of eight of the fifteen analytes were higher from the ANWRF and atenolol, benzophenone, DEET, diphenhydramine, and triclocarban were substantially higher at the Agua Nueva facility.

Table 3. Average CEC concentrations (ng/L) at effluent outfalls of the Agua Nueva and Tres Rios WRFs.

Compound	ANWRF	TRWRF
atenolol	1,036	241
benzophenone	420	82
bisphenol A	<MRL	51
DEET	1,093	215
diphenhydramine	1,825	12
fluoxetine	104	171
ibuprofen	9	6
naproxen	173	<MRL
PFHxA	26	44
PFOA	14	26
PFOS	3	45
TCEP	210	298
triclocarban	158	14
triclosan	90	41
trimethoprim	327	380

A comparison of effluent CEC concentrations from the "old" (2011 study) and the "new" (this investigation) WRFs is provided in Table 4. The "old" WRF data is from an investigation performed by the PIs as part of a 2011 project funded by a University of Arizona Water, Environment, and Energy Sustainability (WEES) program grant. Results from the 2011 study are included in the publication Dong et al. (2015). Six CECs were measured in both the 2011 and in the current studies; values shown in Table 4 are averages from four sampling events conducted during each study. Overall, effluent CEC concentrations were similar in magnitude from the "old" and "new" WRFs for the six compounds common to both studies. Comparison of the Roger Road and Agua Neuva WRF data shows a decreased concentration for three of the six CECs measured. For the comparison of the Ina Road and Tres Rios WRF CEC data shown, just two of the six compounds were reduced in concentration after the facility upgrade. These admittedly limited data suggest that despite the substantial improvements in performance of the new WRFs with respect to BOD, TSS, nutrients, and other regulated water quality parameters, there is not a concomitant improvement with respect to reduction in CEC concentrations being discharged to the Santa Cruz River. It should be noted that this comparison is based on limited

data and other factors may have affected these results, such as possible differences in timing of sampling (diurnal and seasonal fluctuations) during the two studies (Nelson et al., 2011).

Table 4. Comparison of CEC concentrations (ng/L) from effluent outfalls at "old" and "new" Pima County WRFs. Values shown are averages obtained from the 2011 and current studies, respectively.

Location	DEET	Fluoxetine	PFOA	PFOS	TCEP	Trimethoprim
RRWRF (2011)	786	42	11	19.9	326	547
ANWRF (2015)	1,093	104	14	2.5	210	327
IRWRF (2011)	347	71	12	9.2	319	310
TRWRF (2015)	215	171	26	45	298	380

Objective 2: Assessment of CEC fate during transport in the Lower SCR. Similar to the 2011 study by the PIs, the CECs examined in this investigation were ubiquitous in the studied reach of the Lower SCR. However, most CECs exhibited substantial attenuation during transport along the 34-km study reach. The five CECs detected at highest concentrations, in descending order, were diphenhydramine (antihistamine), DEET (insect repellant), atenolol (beta blocker), benzophenone (UV blocker), and trimethoprim (antibiotic), all of which occurred in the ug/L to high ng/L range (Figure 2). The other CECs in this study, including pharmaceuticals and perfluorinated organics, had concentrations ranging from 1 to a few hundred ng/L (Figures 3 and 4). Data shown in these figures represent averages obtained from four sampling events during the 12-month study period.

The Lower Santa Cruz River is effluent-dependent and there was no flow upstream of the ANWRF during the days of sampling, so dilution is ruled out as a mechanism of attenuation. The possible removal mechanisms for CECs during surface transport include biodegradation, sorption to sediments, and solar-driven photolysis. Travel time across the 34-km study reach has not been established but is estimated to be on the order of 10-14 hours, allowing good opportunity for occurrence of sunlight-driven reactions (photolysis). Except for the flame retardant TCEP, all other CECs shown in Figures 2 and 3 were substantially attenuated during river transport. Previous investigation by the PIs was not able to establish correlations between attenuation rates and compound properties such as hydrophobicity or biodegradability index (Dong et al., 2015). However, sunlight-driven reactions are suspected of playing an important role in compound removal; triclocarban, diphenhydramine, trimethoprim, and atenolol all contain aromatic rings potentially amenable to breakdown by photolysis and future research is warranted to identify possible reaction pathways.

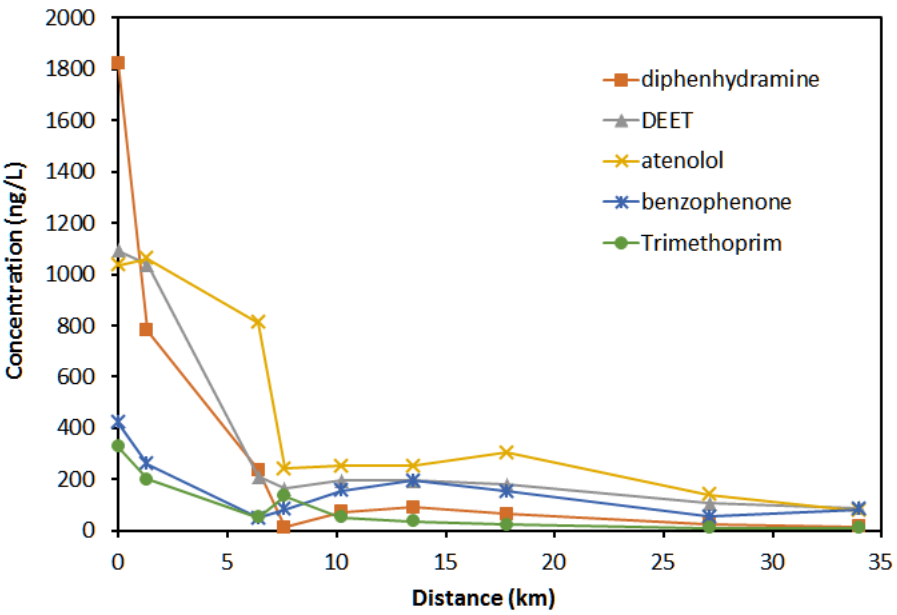

Figure 2. Top five CECs, based on measured concentrations in the Lower SCR. Data shown represent average values at each location from four sampling events. The ANWRF outfall is at km 0 and the TRWRF outfall at km 7.6.

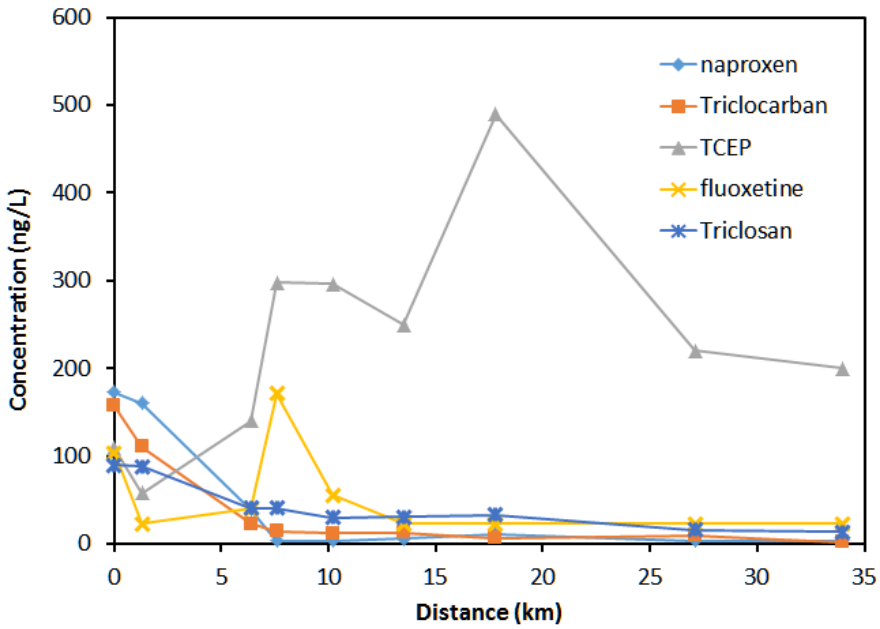

Figure 3. Mid-tier CECs, based on measured concentrations in the Lower SCR. Data shown represent average values at each location from four sampling events. The ANWRF outfall is at km 0 and the TRWRF outfall is at km 7.6.

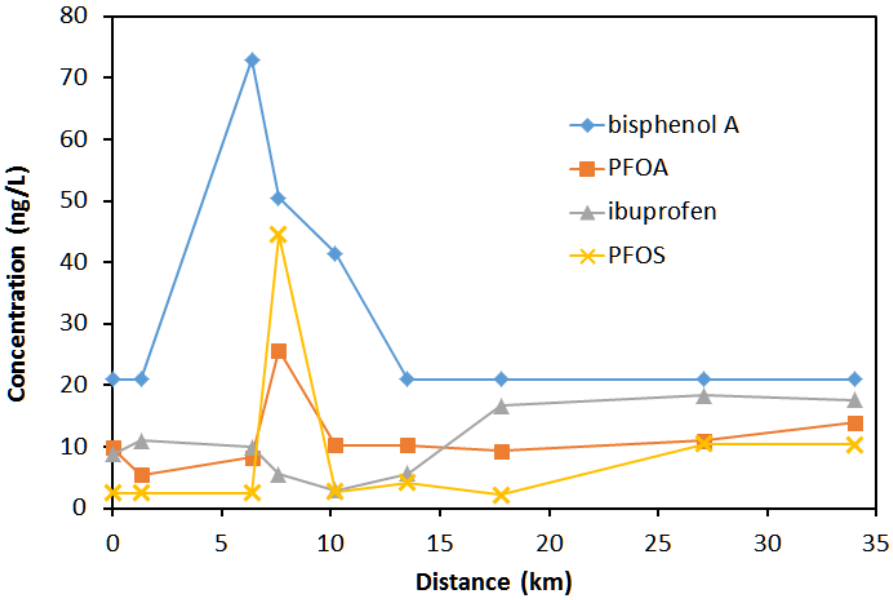

Figure 4. The four CECs exhibiting lowest concentrations in the Lower SCR. Data shown represent average values at each location from four sampling events. The ANWRF outfall is at km 0 and the TRWRF outfall is at km 7.6.

CEC fates during transport along the Lower SCR in the 2011 and present studies are compared in Figure 5. Data points are averages obtained from each study. Overall, the CECs shown in the figure displayed similar behaviors in both studies. Differences mainly occurred in initial CEC concentrations discharged to the river by the two WRFs (positioned at km 0 and at km 7.6, respectively). Compounds with faster attenuation rates during river transport included DEET, fluoxetine, and trimethoprim.

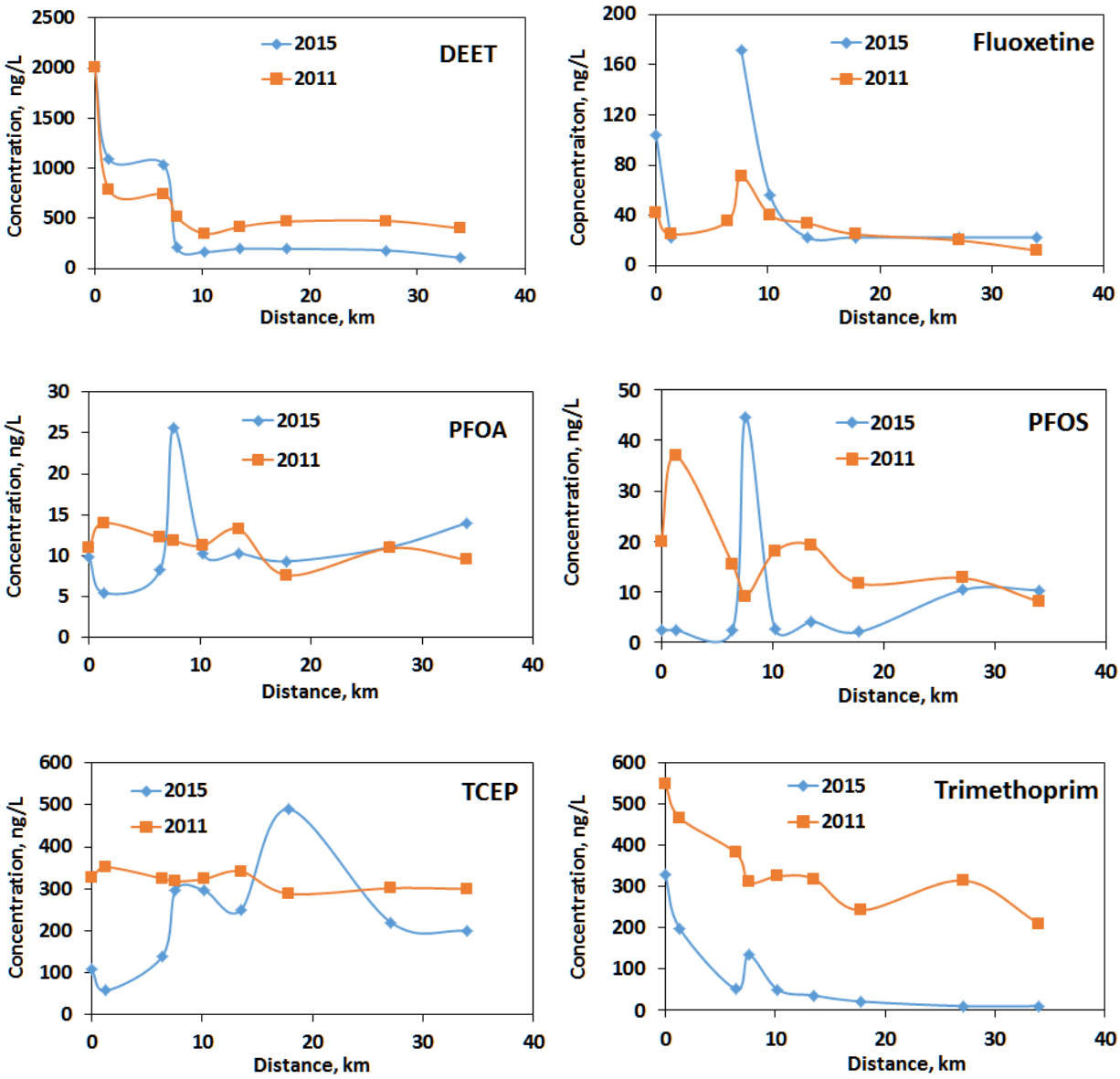

Figure 5. Comparisons of CEC concentrations along the Lower SCR during the 2011 and current studies for DEET, fluoxetine, PFOA, PFOS, TCEP, and trimethoprim. Data points shown represent average values from each study. The ANWRF outfall is at km 0 and the TRWRF outfall is at km 7.6.

In summary, comparison of results to those in a 2011 study conducted by the investigators revealed that effluent concentrations discharged to the river were reduced for only about half of the examined CECs. In other words, loading of at least some CECs to the river appears to continue at rates similar to that observed prior to the wastewater reclamation facility upgrades. This is not an unexpected result as WRFs are not currently designed to remove these unregulated trace chemicals. Observed compound attenuation rates during river transport were similar in

both studies. Assessment of the ecological significance of CEC discharges to the Lower Santa Cruz River was beyond the scope of this project and is an important topic for future investigation.

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Characterization of Uranium and Arsenic in Unregulated Water Sources on the Navajo and Hopi Reservations

Basic Information

Title:	Characterization of Uranium and Arsenic in Unregulated Water Sources on the Navajo and Hopi Reservations
Project Number:	2015AZ544B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	Arizona Congressional District 1
Research Category:	Water Quality
Focus Category:	Groundwater, Water Quality, Radioactive Substances
Descriptors:	None
Principal Investigators:	Jani C Ingram

Publications

There are no publications.

Problem and Research Objectives

The geologic profile of the western United States lends itself to naturally elevated levels of arsenic and uranium in ground water; some wells have been shown to exceed the Environmental Protection Agency Drinking Water limit of 10 parts per billion (ppb) for arsenic and 30 ppb for uranium (AUMPA 2000). Mining can exacerbate this problem by introducing waste high in arsenic and uranium into groundwater systems (US DOE 1997). From 1948 to 1956, uranium mining took place on the Colorado Plateau and the Navajo Reservation. It is estimated that 1200 mines were dug on the Navajo Reservation (O'Rear 1966). These mines spanned the whole Reservation; however, most of them were concentrated in the Four Corners area and the southwestern region near Cameron, AZ. Uranium deposits in the Cameron area extend about 30 miles north-south and 12 miles east-west (EIA, 2005). The area extends across parts of the Painted Desert and Ward Terrace in the western part of the Navajo Reservation. In the Ward Terrace area east of Cameron, uranium minerals were discovered in 1950 on an outcrop of the Kayenta Formation (Lower Jurassic). Additionally, uranium was discovered on Chinle Formation (Upper Triassic) outcrops near Cameron. The deposits in the Cameron area occurred mainly in the lower 60 feet of the Petrified Forest Member and the upper 30 feet of the underlying Shinarump Member of the Chinle Formation. The ore occurred mainly in poorly consolidated sandstone and in clay-pellet sandstone and conglomerate beds in intraformational channel and scour structures. Ore-grade material occurred in pod- and lens-shaped tabular bodies up to 10-15 feet thick at depressions and bends along 'channel and scour' trends and was often associated with bentonitic clay. Higher grade ore was associated with carbonaceous trash. Uranium-mineralized fossil logs were mined in some deposits. The deepest open pit mine was 130 feet deep. The average depth for mines in the area ore was about 60 feet. The largest ore body mined contained about 40,000 tons of ore, and the average size for the mined deposits was reported to be about 7,000 tons of ore. The 'channel and scour' environment accounted for over 95 percent of the ore mined from the Cameron area. During the period between 1951 and 1963, ~289,300 tons of ore were mined in the Cameron area. As stated on the Navajo Abandoned Mine Lands web site (Navajo AML 2005), "The Cameron area is also an area of concern, because the mine sites are located close to the groundwater; thus, concerns are for the geologic structure being the host to the uranium and not necessarily the uranium mine waste."

The Navajo and Hopi people are examples of communities that are well-aware of the potential for exposure to heavy metals in their drinking water as uranium and arsenic are naturally occurring in the region where both the Navajo and Hopi Nations are located. From the 1940s through the 1980s, extensive uranium mining occurred there and the predominant purchaser of the uranium was the US government (Pearson 1980; Brugge 2002) . While the Navajo people were initially optimistic about the employment opportunities, the lack of communication about potential health hazards and poor and under-regulated working conditions resulted in harm to the communities. For the past three decades, the Navajo have been trying to get the US government to take responsibility for their role and to help with the decontamination efforts (Brugge 2002). This has been partially successful and in recent years, the US government spent over $100 million on remediation efforts as called for by two Five Year Plans (2008-2013, 2014-2018) developed in collaboration with the Navajo Nation (Brugge 2002; Kane 2013; USEPA/NNEPA 2014). Despite some progress, there is still extensive contamination near the abandoned uranium mines across the Navajo Nation which can threaten the groundwater quality. Access to safe drinking water is further compromised by the fact that nearly one-third of the population is not served by public water systems. Instead, approximately 54,000 people rely on hauled water or water obtained from unregulated wells and springs (USEPA 2016). There is thus public concern that the well water is contaminated with heavy metals.

The overall objective of the study was to collect information to the determine uranium and arsenic levels from a large number of unregulated wells in the western region of the Navajo reservation and parts of the Hopi reservation. This information is needed to assess the extent of potential uranium and arsenic contamination from a health standpoint as well as providing an understanding of the transport of these elements in the environment. Once the results were verified through multiple sample collections and analyses, mapping of the information was done. The next steps in the work is to disseminate the information to the communities and tribal leader.

Methodology

Standard field water collection will be utilized for this work as described below. The main issue is collecting water from the Navajo and Hopi Reservations as these are sovereign nations. We received formal permission from the Navajo Nation to collect and characterize water samples;

we have provided our results to the communities as well as the tribal leaders and natural resource departments. Our recent work has also been motivated by Navajo students in the Ingram lab to characterize uranium and arsenic in wells from their home communities. We have been gotten requests from Hopi community members to investigate their wells. Our approach has been to provide our results to the communities.

Water from 218 wells was characterized. Water samples were collected from unregulated water sources located in the western region of the Navajo Reservation in Northern Arizona (Figure 1) as well as the Hopi Reservation. In Figure 1, the map is of the Navajo and Hopi Reservations, and the dots on the map represent sampling locations. We worked with community members from both Tribes to locate and sample from the wells. In an effort to observe any potential seasonal variations, samples were collected at in January, March, and August 2014 as well as March and June 2015. The sampling procedure involves collecting two 250 mL of water samples as well as recording the location using a global positioning system (GPS). All the water samples are filtered (BD 60 mL syringe, Luer-Lok tip; Whatman syringe filter 25 mm GD/X, 0.45 µm pore size). One sample from each location is acidified with approximately 2 mL of concentrated (69 – 70%) nitric acid (EMD, OmniTrace) to maintain metal ions in solution. The other sample is filtered only in order to determine the natural pH. Until further preparation, water samples were stored at 18°C. Inductively coupled plasma mass spectrometry (ICP-MS) is utilized to determine elemental uranium and arsenic concentrations in the filtered, acidified water samples. Analyses are performed on a ThermoScientific X Series 2 quadrupole ICP-MS, equipped with an ESI Apex HF sample introduction apparatus. Samples are allowed to equilibrate to room temperature before preparation. All samples are appropriately diluted with 18 MΩ·cm purified water prior to analysis. An internal standard (bismuth) was added to all samples at a concentration of approximately 0.50 µg/L.

The Ingram lab is equipped with an inductively coupled mass spectrometer (ThermoScientific X Series 2 quadrupole) capable of determining trace level elemental detection in natural water. Additionally, the Ingram lab has access to departmental instruments (inductively coupled plasma optical emission spectrometer) and graphite furnace atomic absorption spectrometer.

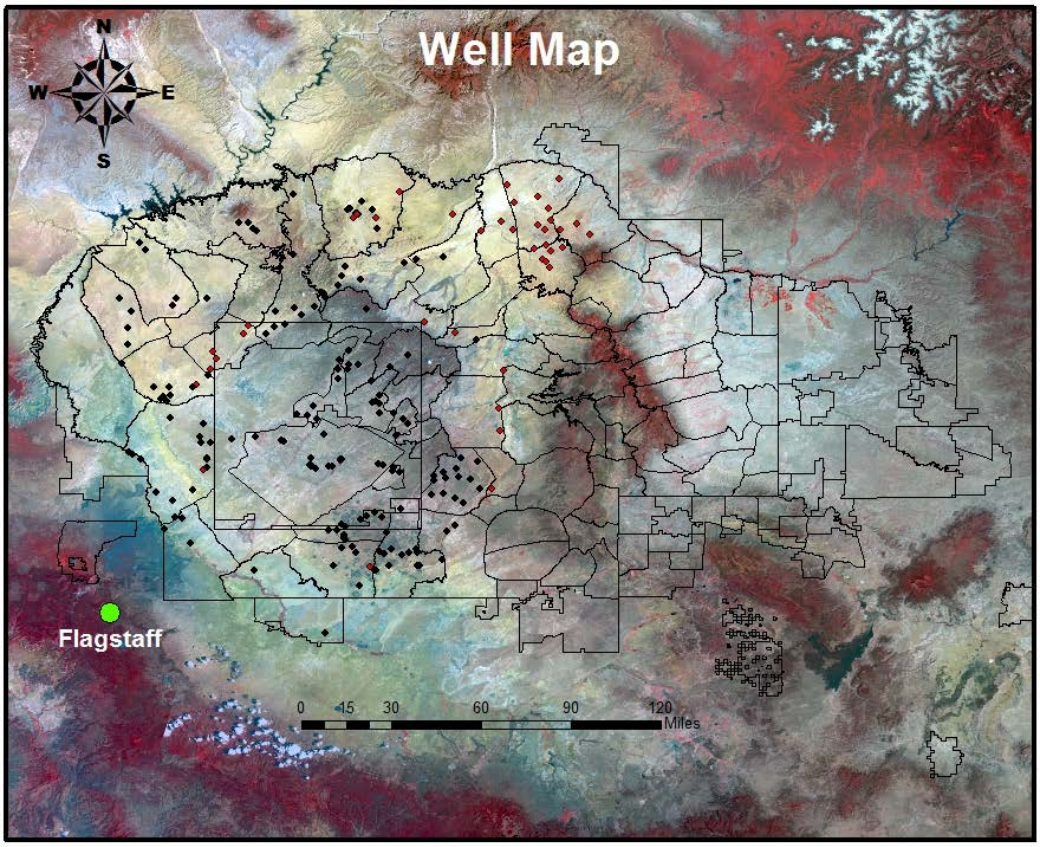

Figure 1. Map of the Navajo and Hopi reservations along with water sampling sites represented by the diamonds. The black diamonds are wells sample at least three times during times of the year; the red diamonds are wells sampled twice.

Principal Findings and Significance

To test the pervasiveness of uranium and arsenic contamination in drinking water, we obtained 218 water samples between 2013 and 2015 from 164 wells identified by community members across the Navajo and Hopi Nations. Samples in 2015 (n=6) were taken only from wells with elevated uranium and arsenic levels to confirm elevated levels. Uranium and arsenic concentrations were measured using an inductively coupled plasma mass spectrometer. Well depth was known for 21% of all samples. Geographic coordinates were obtained for all wells.

In Figure 2, the results of the study are mapped according to the level of arsenic and uranium determined from an average of multiple samples. Figure 2 shows wells that are below the EPA drinking water standard (10 ppb for arsenic and 30 ppb for uranium), approach the EPA standard, or exceed the EPA water standard. We found that the mean uranium concentration (±1 standard deviation) was 9.9 ± 21.4 µg/L and the mean arsenic concentration was 8.2 ± 15.1 µg/L.

Nearly 26% of wells had concentrations exceeding the US EPA standards. This included 6% of wells that exceeded the 30 µg/L uranium standard, 22% of wells that exceeded the 10 µg/L arsenic standard, and 3% of wells that exceeded both standards. These proportions are generally consistent with another water quality monitoring campaign on the Navajo Nation (Murphy 2009) and the locations where wells were more likely to exceed US EPA guidelines corresponded to locations where naturally occurring arsenic and uranium might be expected based on geomorphological characteristics.

To see if there were external factors that affected the metal concentrations, we considered precipitation, season, and well depth. In models of log-transformed metal concentrations accounting for repeated sampling of certain wells, average precipitation was a predictor of arsenic concentration ($p = 0.051$) but season was not a significant predictor of arsenic or uranium concentrations ($p > 0.05$ for all tests). There was some evidence that well depth was correlated with concentrations of uranium in a curvilinear fashion and that well depth was correlated with arsenic in a linear fashion. Nevertheless, well depth was not known for the wells with metal concentrations exceeding the US EPA standards and it might not have a consistent relationship with metal concentrations in different geographic areas. As with other studies (Pfeiffer 2014), (natural log) arsenic and uranium concentrations were found to be highly correlated ($r = 0.312$, $p < 0.001$).

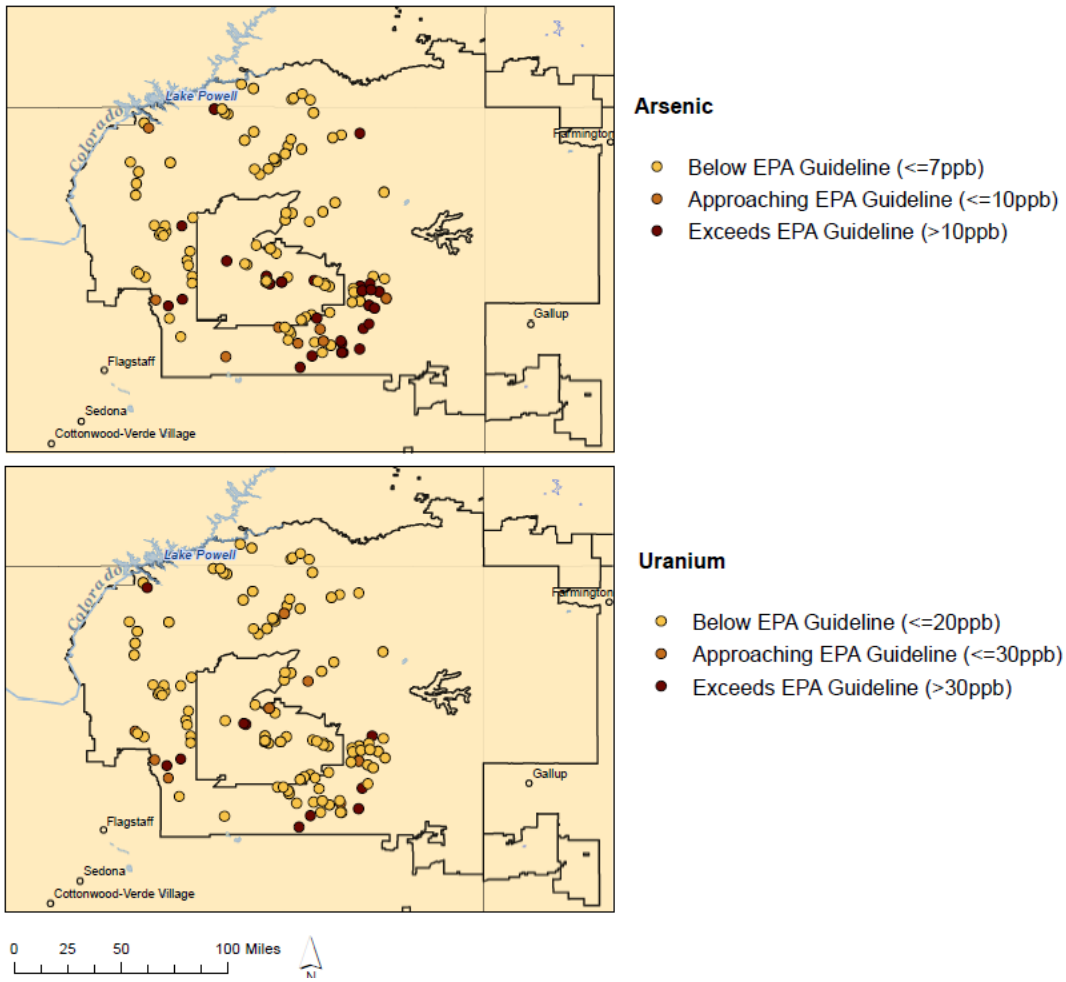

Figure 2. Mapped results of arsenic (top) and uranium (bottom) at the wells sampled. The legend indicates the wells below the EPA drinking water standard (arsenic at 10 ppb and uranium at 30 ppb) are shown in yellow. The wells that have levels near the EPA water standard are shown in brown, and the wells exceeding the EPA water standard are shown in red.

Based on our water quality work, we found that arsenic contamination, and to a lesser extent uranium contamination, are widespread in currently unregulated wells used regularly for drinking water. While it is unclear whether these levels of groundwater contamination are associated directly with biological levels of these metals (Yard 2015) or with health effects, the high concentration within drinking water poses a critical environmental justice concern. It suggests the need for more extensive monitoring of water quality in currently unregulated wells, especially in regions where contamination is likely and where populations are most likely to face other environmental hazards.

While the local community tends to be concerned about the potential for uranium contamination of groundwater, it may be more important to consider the potential for arsenic exposure in groundwater since the percent of wells that exceeded the standard was much higher and since the health effects of arsenic are more well-established (ATSDR 2007). It is certainly possible that the uranium, arsenic, and other contaminants interact within the groundwater. With future research, which should be done either after or concomitantly with clean-up action, it may become evident that the current levels of uranium contamination are too high. Additionally, there are other reasons to support clean-up efforts of the abandoned uranium mines as the radiological characteristics make exposure to uranium potentially dangerous.

The benefit of the study is to provide the communities utilizing these wells information pertaining to uranium and arsenic levels in their water sources. This information provides a foundation for future efforts to provide guidance for the Navajo and Hopi people for ways to begin to minimize their exposure to uranium and arsenic as well as providing insight on potential remediation needs. Currently, the work reported here has been drafted into a manuscript and submitted to Current Environmental Health Reports. Additionally, we are working with a group from University of New Mexico to build a database of water analyses information to provide to the Navajo and Hopi Tribes.

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Information Transfer Program Introduction

The University of Arizona WRRC maintains a robust Information Transfer program that includes two newsletters: a weekly email digest, and a quarterly newsletter published in both digital and hard copy form. The WRRC also develops, posts, prints, and distributes annually a publication that each year covers a different single topic of concern to the water community in Arizona. The WRRC's Information Transfer program also features an annual conference and a series of Brown Bag seminars, along with other special events. In addition, the WRRC regularly updates its web site with news and events, builds and maintains WRRC program web pages, and provides many resources such as a directory of UA expertise in water. Outreach on social media is growing and keeps subscribers informed in a timely manner on various items of interest to the water community.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2015AZ547B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	AZ003
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Sharon B. Megdal, Susanna Eden, Jean E.T. McLain

Publications

1. Cusimano, J., J. McLain, C. Rock, and S. Eden, 2015. Agricultural use of recycled water for crop production in Arizona. Arizona Cooperative Extension Publication, AZ1670.
2. Eden, S. and S. B., Megdal, 2015. Climate change-driven stakeholder engagement in Arizona, Box 2.1. In OECD, Stakeholder Engagement for Inclusive Water Governance, p.58, OECD Studies on Water. OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264231122-en.
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During the reporting period, the WRRC's Information Transfer Program continued to produce its major component products. These include the *Weekly Wave* and *Arizona Water Resource* newsletters, the annual *Arroyo* publication, the Annual Conference, Brown Bag seminars, and the website. The WRRC engages stakeholders on multiple projects with relevance to water resource management and collaborates with partners within the university and beyond. In addition, the WRRC has been working with a team from the University of Arizona College of Agriculture and Life Sciences and Arizona Public Media on a multi-faceted project to raise awareness and knowledge about water issues in Arizona and the Southwest.

Periodic Publications

Inaugurated in 2014, the Weekly Wave e-news digest was sent to subscribers regularly throughout 2015. Thirty-two editions of the Weekly Wave and seven editions of the bi-monthly Summer Wave were sent. Each edition included updated WRRC and water community events, news, media appearances, announcements, and social media interaction opportunities. The distribution lists grew by nearly 265 recipients to more than 2,000, resulting in increased website traffic, event attendance, and dissemination of WRRC news through other outlets. The Weekly Wave was redesigned for better mobile compatibility in time for the first Weekly Wave of 2016.

The WRRC's quarterly newsletter, *Arizona Water Resource* (*AWR*), appeared in January, April, July, and October, 2015. In addition to electronic distribution, print copies were mailed to approximately 1,800 subscribers. The Winter 2015 issue contained a 4-page fact sheet from the WRRC's WaterRAPIDS program, "Roadmap for Considering Water for Arizona's Natural Areas." A spring insert described a NOAA funded project "Groundwater, Climate and Stakeholder Engagement (GCASE)" carried out by the WRRC and the Hydrologic Research Center in San Diego, CA, and the summer insert was "2014 At-a-Glance," an infographic showing highlights from the WRRC's 2014 Annual Report. Several WRRC students contributed substantive articles to the *AWR* in 2015. In addition, the AWR provided an opportunity to shine a spotlight on some of the WRRC's exceptional students. Guest Views were provided by Chuck Graf, Senior Hydrologist at the Arizona Department of Environmental Quality, and Joseph Olsen, General Manager of the Metro Water District. Following up the WRRC's Annual Conference, *Indigenous Perspectives on Sustainable Water Practices*, the *AWR* dedicated its fall 2015 issue to views of the conference and fostering continued dialogue. The Agnese Nelms Haury Program in Environment and Social Justice funded the printing of this 16-page newsletter, and printed copies were distributed to all participants at the November 2015 Arizona Town Hall on water. Electronic copies were sent to all the WRRC's Annual Conference attendees. Each year the *AWR* includes summaries of 104(b) research projects.

The topic for the *Arroyo*, WRRC's annual publication on a single topic of timely interest to Arizona, is selected each year with EAC guidance. In 2015, the topic selected was "Closing the Water Demand-Supply Gap in Arizona." Publication was delayed until early in August 2015 because of the need for multiple reviews of this complex topic. External reviews were provided by individuals from many of EAC member organizations, including Tom Buschatzke and Michelle Moreno (Arizona Department of Water Resources), Chuck Cullom (Central Arizona Project), Rebecca Davidson (Salt River Project), Ron Doba (Northern Arizona Municipal Water Users Association), Kathy Ferris (Arizona Municipal Water Users Association), Carly

Jerla (U.S. Bureau of Reclamation), Juliet McKenna (Montgomery & Associates), and Bill Plummer (Agribusiness and Water Council of Arizona).

Nejlah Hummer, an MS student in Planning, was selected from a highly talented applicant pool as the Montgomery & Associates Summer Intern at the WRRC to work on the 2016 Arroyo on potable reuse of water, its potential and challenges. She produced a first draft over the summer, which has undergone revisions and will be sent out for review in February 2016. Printing and mailing of the 2016 Arroyo will be funded by a donation from Carollo Engineers. The intern is supported by an annual donation from Montgomery & Associates, water resource consultants.

Annual Conference

The 2015 Conference, Indigenous Perspectives on Sustainable Water Practices, was held June 9-10 at the Wild Horse Pass Hotel and Casino in Chandler, AZ, in partnership with the Gila River Indian Community. The conference attracted more than 330 participants from six states, 49 cities, and 13 tribal nations. Thirty-three speakers with ties to Native American communities across Arizona presented diverse perspectives. The agenda was developed through the efforts of conference co-chairs WRRC Associate Director Jean McLain and Dr. Karletta Chief, Department of Soil Water and Environmental Science, with guidance from a conference advisory committee made up of individuals with links to Arizona's tribal nations. Eighteen sponsors provided support that allowed for a reduced registration fee to encourage broad participation. Sponsors included: BKW Farms, San Xavier Co-op Farm, Water Asset Management, U.S. Bureau of Reclamation, UA Water Sustainability Program, EPCOR, Arizona Public Service, Salt River Project, Arizona Water Company, Southern Arizona Water Users Association, Central Arizona Project, Montgomery & Associates, Tribal Watershed Extension Program, Montgomery & Interpreter PLC, Colorado River Indian Tribes, The Nature Conservancy, Carollo Engineers, and UA Agnes Nelms Haury Program in Environmental and Social Justice.

The 2016 Annual Conference, titled, #AZwaterfuture: Tech, Talk, and Tradeoffs, was scheduled for March 21st at the UA Student Memorial Union in Tucson, the conference focus was innovative ideas and approaches in the realms of technology, communication, and policy. Planning began in mid-2015.

Brown Bag Seminars

The WRRC's Brown Bag seminar series continued to draw a range of speakers on water-related topics of interest to a wide spectrum of audiences. In 2015-16, the WRRC held 16 Brown Bag seminars featuring experts from Arizona and the Southwest, as well as other countries. Average attendance was 20 people (in person), approximately 55 percent from UA and 45 percent from the broader community. Access to the WRRC's Brown Bag series now routinely includes offsite listeners through live webcasts via Go-to-Webinar and in-house video coverage. Offsite attendance grew significantly, and in the project year the WRRC had 247 participants avail themselves of remote observation. Past Go-To-Webinar recorded events at the WRRC can be viewed on the WRRC website. The slide presentations of most seminars are also available for viewing on the website.

Brown Bag Seminars from the reporting period are listed below.

1. March 9, 2015, Tucson Water Recycled Water Program, Jeff Biggs, Tucson Water Interim Deputy Director; Fernando Molina, Tucson Water Public information Officer; Wally Wilson, Tucson Water Chief Hydrologist
2. March 11, 2015, The Surprising Slide in Domestic Demand: Be careful what you wish for, Gary C. Woodard, Senior Water Policy and Economics Consultant, Montgomery and Associates
3. March 26, 2015, A New Paradigm: Electric Utilities Investing in Water Conservation, Lon W House, PhD, Water and Energy Consulting
4. March 31, 2015, Salinity in the Sea of Galilee, Its History, Environmental Challenges, and Management, Alon Rimmer, Israel Oceanographic and Limnological Research, Lake Kinneret Limnological Laboratory
5. April 21, 2015, Shift Happens, Tice Supplee, Audubon Arizona Director of Bird Conservation
6. May 6, 2015, Driving Water Conservation: The Conserve2Enhance Water Use Dashboard, Kelly Mott Lacroix, Senior Research Analyst, Water Resources Research Center, and Brittany Xiu, Outreach Coordinator, Water Resources Research Center,
7. September 15, 2015, 2015 El Nino, Mike Crimmins, Associate Professor, Department of Soil, Water and Environmental Science, University of Arizona
8. September 22, 2015, UA Renewable Energy Network, Ardeth Barnhart, Program Director, Renewable Energy, Institute of the Environment, University of Arizona
9. October 2, 2015, Roosevelt Irrigation District Ground Water Remediation Project (RID Approach to Water Treatment), Donovan Neese, Superintendent, Roosevelt Irrigation District and Joel Peterson, PE, Synergy Environmental
10. October 8, 2015, A Case Study in Efficiency – Agriculture and Water Use in the Yuma, Arizona Area, N.W. “Bill” Plummer, President, Agribusiness and Water Council of Arizona and Dr. Paul Brown, College of Life Sciences, University of Arizona
11. October 29, 2015, Pumps, pipelines, and property rights: legal and political challenges for decentralized groundwater governance in Central Texas, Zach Sugg, PhD Candidate Department of Geography, University of Arizona
12. November 4, 2015, Addressing Water Challenges and Opportunities, Stephen Schoenholtz, Director, Virginia Water Resources Research Center, Virgina Tech
13. November 12, 2015, Conservation Loves A Crisis: Lessons from North America's Driest City, Doug Bennett, Conservation Manager, Southern Nevada Water Authority
14. January 22, 2016, Public Adaptation through the Backdoor: Can We Move to Adaptive Water Governance? Abigail York, PhD, Director, Environmental Social Sciences PhD Program and Associate Professor of Governance and Public Policy, School of Human Evolution and Social Change, College of Liberal Arts and Sciences, Arizona State University
15. February 2, 2016, Tucson Active Management Area Draft Fourth Management Plan, Jeff Tannler, Statewide Director, Active Management Areas, Arizona Department of Water Resources
16. February 25, 2016, Contributions to the ISARM and TWAP Assessment with Examples of ISARM Americas from the Mexico-United States Border, Randy Hanson, Research Hydrologist, U.S. Geological Survey, California Water Science Center, San Diego, CA

Other Outreach Events

The WRRC has sponsored, co-sponsored and hosted a number of events for a broad range of interests.

Our annual February Chocolate Fest provided an opportunity for our friends in the water community to meet informally.

Co-sponsored speakers included Lester Snow, Executive Director, California Water Foundation, who spoke on "Drought and Sustainable Water Management in California: Behind the Scenes."

The WRRC and Water Sustainability Program (WSP) sponsored a Water Policy Forum: "Arizona Solutions to Colorado River Supply Challenges," convened by Senator Jeff Flake on March 10, 2015, at the UA Center for Creative Photography. WRRC Director Sharon B. Megdal spoke and moderated a panel featuring: Tom Buschatzke, Director, ADWR; Marie Pearthree, Deputy General Manager, CAP; and Alan Forrest, then Director, Tucson Water.

On April 14th a film showing and panel discussion, *Restoration of the Colorado River Delta: One Year After*, was co-sponsored with WSP in the Gallagher Theater, UA Student Union Memorial Center. Director Megdal moderated the panel that included Yamilett Carrillo, Executive Director, Delta Water Trust; Karl Flessa, Professor, UA Department of Geosciences and Co-chief Scientist for the Colorado River Delta Monitoring Program; and Francisco Zamora Arroyo, Director, Colorado River Delta Legacy Program, Sonoran Institute.

On November 6th the WRRC, in collaboration with CAP, hosted a community forum to engage citizens of southern Arizona in discussion of regional water issues. Lisa Atkins, President of the CAP Board, opened the forum and the keynote was given by Tom Buschatzke. Megdal moderated a panel of experts and community leaders who provided their perspectives and answered questions from the audience.

The WRRC also co-sponsored the Native Eyes Showcase, on November 8th, which consisted of multiple events including a resource fair and film screening at the Loft Cinema in Tucson.

Program Collaborations

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. Collaborative activities have included co-sponsoring distinguished lecturers, dissemination of information across the more than 300 UA investigators involved in water-related research and development of a web-based UA water hub. The WRRC Director serves as one of two co-Director of WEES. Collaborations with the WRRC-based Arizona Project WET (Water Education for Teachers) has been mutually beneficial in expanding the reach and effectiveness of outreach and education projects, and this collaborative relationship continued through the project year. A comprehensive water education program with established relationships with school districts and communities throughout Arizona, Arizona Project WET reaches out to teachers and students across Arizona by providing programs, workshops, mentoring and partnership activities. The WRRC and Arizona Project WET continued to work toward increase program integration.

Ongoing programs of research and outreach continued and were expanded. The Water Research and Planning Innovations for Dryland Systems (Water RAPIDS) focuses on new approaches to water resource management that integrate traditional planning for natural resources with land use planning at regional, state, watershed, and local scales. The goal is to help balance water demand for human uses with the water demands of ecosystems. In 2015, the Water RAPIDS program included four projects: 1) Conserve2Enhance (C2E), a trademarked program of the WRRC, which links water conservation to funding for local environmental enhancement projects; 2) Understanding Environmental Flow Needs in Water Scarce Regions, which in partnership with Northern Arizona University (NAU), created a geospatial database of environmental flow needs and responses for the deserts of the U.S. and Mexico; 3) Watershed Planning in the Upper Gila Watershed, which in 2015, has been exploring effective mechanisms of stakeholder engagement to promote understanding of water supply and demand and use of this knowledge by rural Arizona communities to build resilience. Outreach is a major function of WRRC research projects, and although they are almost entirely funded from non-program sources, but their outreach receives some support from the Information Transfer Program.

Website and electronic communication

Communications efforts at the WRRC continued to expand in 2015. Externally, the WRRC has been featured over 25 times across a variety of news and media outlets. Efforts continued throughout the year to provide timely posts of water related news on Facebook, Twitter and YouTube, resulting in increased shares, views, retweets, follows, and likes. Twitter followers of the WRRC grew to 217, adding one new follower a day in the last three months of the year, and the WRRC Facebook page surpassed 280 likes.

The WRRC website continues to feature news, events, and programs, as well as publications and other resources. Video recordings of select Brown Bag Seminars are readily available directly through the WRRC website via a searchable video gallery (wrrc.arizona.edu/video-gallery). The website also made available audio recordings from the November 6th community forum and a PDF of the background report for the 107th Arizona Town Hall, created with WRRC participation. A major redesign and update of the website in collaboration with the UA College of Agriculture and Life Sciences information technology team was planned to debut early in 2016.

“Beyond the Mirage”

The WRRC also has been working closely with a team from CALS on an outreach program to spread water knowledge and awareness throughout Arizona and beyond. Its core is an interactive, guided but self-directed learning experience drawing on hundreds of video clips. Clips are presented in smart web environment and users can chose among them according to their interests. Users are then able to create their own documentaries, which can easily be shared on social media. The program also includes a feature length documentary suitable for airing on public media stations and an education component for bringing the content into the classroom in new and engaging ways.

The New Arizona Prize cash award, won by Beyond the Mirage in April, and funding from the WRRC have supported project development. Sheehy completed filming video footage all over

the state and region, as well as footage shot in China in April and Israel in October (funded separately). The team completed about 80 percent of clip editing for the website and building the web infrastructure. More than 240 clips, or about 95 percent of the total, have been created. Each clip has been vetted by the WRRC team, which had approved 168 clips by the end of December. The existing video clips have been transcribed and meta-data has been generated for each clip. This information is used in the smart web interface. Website development was nearly completed during 2015 with beta testing scheduled for January 2016.

A social media campaign was designed to reach the widest possible audience, drawing on the expertise of Phoenix-based marketing consultant Jessica Hall. A Social Media Plan and Distribution Plan were developed and implementation was begun in October with outreach to business/corporate influencers. A 2.5-minute video trailer was created to drive traffic to the website and advertise the project. In addition a narrated "about-this-website" demonstration video explaining the website was developed.

Arizona Public Media is an integral part of the team for the documentary and its distribution. The documentary production process was roughly 90 percent complete by the end of 2015.

Arizona Project WET has plans to engage teachers and schools in using the Beyond the Mirage video content and website as a teaching tool for water education. PBS Learning Media, the premier web resource for curriculum across the country, is hosting selected clips and related curriculum specially designed for the purpose by APW. The clips for posting to PBS Learning Media have been selected and questions developed to accompany the clips and guide their use for educational purposes. As a statewide education program with a large presence in Phoenix, APW is uniquely positioned to spread word about this project at community events.

Multiple presentations have been made across the state by team members. Sheehy presented Beyond the Mirage to the Arizona Town Hall and received positive feedback from several of those in attendance. He also presented to the University of Arizona's Institute of the Environment's Art and Environment lecture series and the Arizona Forward Board.

Other Activities

In addition to all of the above, WRRC personnel carried out various public service activities. They are called upon regularly to give lectures and make presentations to diverse audiences across Arizona. They often collaborate with local, state, regional, and federal agencies and organizations, as a resource for general information and as partners on specific projects. 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. The WRRC facility is open to the public and provides information on water related topics to the public and a space for water related meetings. WRRC personnel also respond to inquiries from the public on issues of concern.

Presentations

Presentations for Information Transfer on 104b projects

Project Number: 2015AZ540B

Title: Water Sources Over Time for a Semi-Arid River- Implications for Water Resources and Groundwater Modelling

Climate and Population Change Impacts on Dryland Rivers, Hydrology and Water Resources Seminar, April 29, 2015.

Climate Change Impacts on Groundwater in the Western United States, Soil Water and Environmental Sciences Seminar, March 9, 2015

Project Number: 2015AZ541B

Title: Impact of upgraded wastewater reclamation facilities on chemicals of emerging concern in the effluent-dependent Lower Santa Cruz River

Quanrud, D. "Fate of trace organic contaminants in the Lower Santa Cruz River." Presented at *Santa Cruz River Research Days VII*. Tucson, Arizona, March 27, 2015.

Project Number: 2015AZ544B

Title: Characterization of Uranium and Arsenic in Unregulated Water Sources on the Navajo and Hopi Reservations

Peaches, Erik, Brandon Garcia, Jonathan Credo, Jani C. Ingram, Quantification of Uranium in Unregulated Wells on the Navajo & Hopi Reservations, Northern Arizona University 8th Annual Undergraduate Symposium, April 24, 2015, Flagstaff, AZ. (Poster Presentation)

Ingram, Jani C., Jonathan Credo, Tommy Rock, Arsenic and Uranium Exposure from Unregulated Water Sources on Navajo and Hopi Lands, Tribal Stories of Health and the Environment, April 16, 2015, Tucson, AZ. (Invited)

Credo, Jonathan and Jani C. Ingram, Quantification of arsenic and uranium in unregulated water sources on the Navajo and Hopi Reservations, 249th American Chemical Society National Meeting & Exposition, March 23, 2015, Denver, CO.

Presentations by WRRC personnel (chronological order)

March 3, 2015, Sharon B. Megdal. Water Management in Arizona and the Colorado River Basin, Breakfast Club of Tucson, Tucson, AZ.

March 4, 2015, Brittany Xiu. Challenges and Opportunities for Water Management in Arizona, OLLI Green Valley Series: Arizona Water Resources: Introduction, Groundwater, Reclaimed water, and Value, Canoa Ranch Golf Club, AZ.

March 17, 2015, Brittany Xiu. Webinar: Financial Innovations for River and Watershed Conservation Webinar: Driving Water Conservation with Conserve2Enhance, River Network New Ideas and Innovations Quarterly Forum.

March 18, 2015, Sharon B. Megdal. Testimony for the U.S. House of Representatives Committee on Appropriations, Subcommittee on Interior, Environment, and Related Agencies, presented on behalf of the National Institutes for Water Resources, Washington, DC.

March 18, 2015, Susanna Eden. "The Value of Water", Arizona Water Resources: Introduction, Groundwater, Reclaimed Water, and Value, the Osher Lifelong Learning Institute (OLLI) Green Valley, AZ.

March 24, 2015, Jean E. McLain. Science and the general public: how do we bridge this gap? Integrating Science and the Law in Practice, guest lecturer, James E. Rogers College of Law, University of Arizona, Tucson, AZ.

March 25, 2015, Jean E. McLain. Public health and environmental safety of recycled municipal wastewater: current research, Arizona Water Resources: Introduction, Groundwater, Reclaimed Water, and Value, the Osher Lifelong Learning Institute (OLLI) Green Valley, AZ.

March 31, 2015, Jean E. McLain. Canal maintenance effects on irrigation water quality, First Annual Desert Produce Safety Collaborative Field Conference, Yuma, AZ.

April 8, 2015, Sharon B. Megdal. One Size Doesn't Fit All: Why Variation in Hydrology and Legal Structures means that Drought Looks Different across the West "Arizona Water Management and Colorado River Drought", Western Governors' Association Drought Forum Webinar Series.

April 8, 2015, Brittany Xiu and Christopher Fullerton. Overview of the Proposed Watershed Planning Steps, Gila Watershed Partnership Monthly Meeting, Safford, AZ.

April 9, 2015, Brittany Xiu. C2E, Low Impact Development Workshop. Tucson, AZ.

April 10, 2015, Sharon B. Megdal. Moderator, Water Policy Forum: Arizona Solutions to Colorado River Supply Challenges convened by U.S. Senator Jeff Flake, University of Arizona, Tucson, AZ.

April 11, 2015, K. Diaz, B.J. Woodcroft, G.W. Tyson, V.I. Rich and Jean E. McLain. Characterizing natural antibiotic resistance in a pristine permafrost environment, Soil, Water, Environmental Science, Science of the Environment Earth Day Poster Presentation, University of Arizona, Tucson, AZ.

April 13, 2015, E. Garner, Jean E. McLain, M. Edwards, and A. Pruden. Comparison of antibiotic resistance and pathogen gene markers in reclaimed vs. potable water distribution systems, International Symposium on Waterborne Pathogens, American Water Works Association, Savannah, Georgia.

April 16, 2015, Sharon B. Megdal. Keeping Our Water Glass Full, Arizona NOW the Campaign for the University of Arizona, Denver area alumni event, Denver, CO.

April 16, 2015, Kelly Mott Lacroix. Facilitator, University of Arizona, Energy, Water and Food Nexus Workshop, Catalina, AZ.

May 6, 2015, Susanna Eden. Defining the Value of Water in Arizona, It Depends … Arizona Water Association 88th Annual Conference & Exhibition, Glendale, AZ.

May 7, 2015, Kelly Mott Lacroix. Roadmap for Considering Water for Arizona's Natural Areas, Arizona Water Association 88th Annual Conference & Exhibition, Glendale, AZ.

May 7, 2015, Brittany Xiu. Driving Water Conservation with Conserve2Enhance, Arizona Water

Association 88th Annual Conference & Exhibition, Glendale, AZ.

May 7, 2015, E. Malott, K. Nolte, P. Kahn-Rivadeneira, Jean E. McLain, and C. Rock. Pathogen transmission to crops from animals, Western Food Safety Summit, Hartnell College Agricultural, Business, and Technology Institute, Salinas, CA.

May 8, 2015, Jean E. McLain. Antibiotic resistance in treated wastewater reservoirs in Arizona, U.S.A. First Annual Meeting: New and Emerging Challenges and Opportunities in Wastewater Reuse, European Cooperation in the Field of Scientific and Technical Research, COST Action oc-2013-2-16816, Barcelona, Spain.

May 8, 2015, Jean E. McLain, K. Burke, D.M. Engelthaler, R.J. Hart, B. Hill, A. Pruden, C.M. Rock, and S. Snyder, presented by Channah Rock. Separating science from emotion in perceptions of recycled water: a case study of Flagstaff, Arizona, Arizona Water Association 88th Annual Conference & Exhibition, Glendale, AZ.

May 8, 2015, Susanna Eden. Case Study and Transferability Research on a Methodology for Linking Climate with Groundwater Management. Arizona Water Association 88th Annual Conference & Exhibition, Glendale, AZ.

May 29, 2015, Sharon B. Megdal. Briefing with Congresswoman McSally, AZ "The UA WRRC: Our federal role, water issues, and an overview of our programs". WRRC, the University of Arizona, Tucson, AZ.

June 1, 2015, Jean E. McLain. Water quality microbiology: current research (presented to four faculty/student groups), Yangon University, Yangon, Burma and Pathein Technological University, Pathein, Burma.

June 9-10, 2015, Jean E. McLain. Moderator, University of Arizona Water Resources Research Center Annual Conference - Indigenous Perspectives on Sustainable Water Practices, Wild Horse Pass Hotel and Casino, Chandler, AZ.

June 9-10, 2015, Sharon B. Megdal. Moderator, WRRC 2015 Annual Conference – Indigenous Perspectives on Sustainable Water Practices, Wild Horse Pass Hotel and Casino, Chandler, AZ.

June 14, 2015, Garner, E., Jean E. McLain, M. Edwards, and A. Pruden. Antibiotic resistance and opportunistic pathogen gene markers in reclaimed vs. potable water distribution systems, Engineering and Science Professors 2015 Annual Conference, Yale University, New Haven, Connecticut.

June 16-18, 2015, Sharon B. Megdal. Panel Moderator at UCOWR/NIWR/CUAHSI Annual Conference, Water is Not for Gambling: Utilizing Science to Reduce Uncertainty, Henderson, NV.

June 17, 2015, Susanna Eden. "A methodology for informing management decisions in groundwater dependent communities coping with climate uncertainty," 2015 UCOWR/NIWR/CUAHSI Annual Conference, Water is Not for Gambling: Utilizing Science to Reduce Uncertainty, Henderson, NV.

July 6, 2015, Jean E. McLain. Moderator, University of Arizona One Health Symposium, University of Arizona, Tucson, AZ.

July 15, 2015, Garner, E., Jean E. McLain, M. Edwards, and A. Pruden. Metagenomic investigations of antibiotic resistance and opportunistic pathogen gene markers in reclaimed vs. potable distribution systems, 4th Annual Conference on Microbiology of the Built Environment, University of Colorado, Boulder, CO.

August 5, 2015, Sharon B. Megdal. Speaker at Extension Conference: Water Challenges and Solutions in Arizona. College of Agriculture and Life Sciences. The University of

Arizona, Tucson, AZ.

August 21, 2015, Sharon B. Megdal. Water Banking: The Role of Recharge & Recovery in the Mitigation of Colorado River Shortages to Arizona, with Ken Seasholes. Arizona Water Law CLE International, Scottsdale, AZ.

September 2, 2015, Jean E. McLain. How to construct an effective presentation, Topics in Soil, Water and Environmental Science, guest lecturer, University of Arizona, Tucson, AZ.

September 8, 2015, Sharon B. Megdal. Facing an Uncertain Water Future in Pima County, Pima County Energy and Water Summit, Tucson, AZ.

September 9, 2015, Sharon B. Megdal. Importance of jurisdictional issues, guest lecturer, James E. Rogers College of Law, University of Arizona, Tucson, AZ.

September 13-16, 2015, Jean E. McLain. Biological Filtration, Session D7, 30th Annual WateReuse Symposium, Seattle, WA.

September 28, 2015, Jean E. McLain. How to construct an effective presentation, guest lecturer, Scientific Writing for Environmental, Agricultural, and Life Sciences, University of Arizona, Tucson, AZ.

October 7, 2015, Susanna Eden. New Water Harvesting Assessment Tool for the Desert Southwest, WaterSmart Innovations Conference and Exposition, Las Vegas, NV.

October 12, 2015, Sharon B. Megdal. Mechanisms for Transboundary Cooperation at the United-States Mexico Border, AGAM International Conference, Critical Issues in Water Policy and Technology in the 21st Century.

October 13, 2015, Sharon B. Megdal. Efforts to Close the Gap Between Water Supply and Demand in the Colorado River Basin, WATEC 2015, Session on Management of National Water Systems in Arid Regions, Tel Aviv, Israel.

October 13, 2015, Sharon B. Megdal. Management of National Water System in Arid Regions, the Pre-WATEC conference, Tel Aviv, Israel.

October 14, 2015, Claire Zucker. Opportunities for engineering to positively impact the environmental health of the region, guest lecturer, Introduction to Biosystems

Agricultural and Biosystems Engineering Seminar in Engineering Careers and Professionalism, University of Arizona, Tucson, AZ.

October 15, 2015, Susanna Eden. How Full is Our Water Glass? Lifelong learning in retirement at the highlands, Marana, AZ.

October 26, 2015, Claire Zucker. Career choices in water policy, Guest panel presentation, Water, Society, and Policy M.S. Program seminar, School of Natural Resources and the Environment, University of Arizona, Tucson, AZ.

October 29, 2015, Sharon B. Megdal. Issues and Opportunities in Demand-side Management, Western Water Conference, Salt Lake City, Utah.

November 2, 2015, Sharon B. Megdal. Forum with Israeli Dr. Miki Haran, Cronkite School of Journalism, Arizona State University, Phoenix, AZ.

November 5, 2015, Sharon B. Megdal. Drought, Shortage, and Closing the Gap in Water Supply and Demand in the Colorado River Basin and in Arizona, University of Arizona Federal Relations Office Briefing for Arizona-based congressional staff, WEST Center, Tucson, AZ.

November 5, 2015, Jean E. McLain. Human health and environmental risks of using recycled wastewater for irrigation of food crops, Arizona Registered Sanitarian Conference, Phoenix, AZ.

November 6, 2015, Sharon B. Megdal. Moderator, Sustainable Water for Southern Arizona:

Current Conditions and Future Prospects, Leo Rich Theater, Tucson, AZ.

November 10, 2015, Sharon B. Megdal. Drought, Shortage, and Closing the Gap Between Water Supply and Demand, Environmental Law Society, James E. Rogers College of Law, University of Arizona, Tucson AZ.

November 10, 2015, Sharon B. Megdal. Addressing Water Management Challenges in Tucson and Regionally, UA Campus Community Relations Committee, Tucson, AZ.

November 12, 2015. Kelly Mott Lacroix. The Good, The Bad and The Complicated - Water Management in Arizona. Master Watershed Steward Class, Payson, AZ.

November 15-18, 2015, Jean E. McLain. Soils as the New Frontier in Antibiotic and Antibiotic Resistance Discovery, 2015 ASA-CSSA-SSSA International Annual Meetings, Minneapolis, MN.

November 16, 2015, Sharon B. Megdal. Keeping Arizona's Water Glass Full, Arizona Town Hall, Authors' Panel, Arizona Town Hall, Mesa, AZ.

November 17, 2015, Jean E. McLain and M. Rothrock, Jr. Addressing the natural antibiotic resistome in soils, 2016 ASA-CSSA-SSSA International Annual Meetings, Minneapolis, MN.

November 17, 2015, Kelly Mott Lacroix. Stakeholder Engagement in Water Resource Management, Arizona, American Water Resources Association Annual Meeting, Denver, CO.

November 19, 2015, Kelly Mott Lacroix. Participatory Watershed Assessment and Planning for the Upper Gila River, Arizona, American Water Resources Association Annual Meeting, Denver, CO.

November 18, 2015, E. Garner, Jean E. McLain, M. Edwards, and A. Pruden. Comparison of antibiotic resistance and pathogen gene markers in reclaimed vs. potable water systems, 2015 Water Quality Technology Conference, American Water Works, Association, Salt Lake City, UT.

November 20, 2015, Sharon B. Megdal. Water Resource Planning and Opportunities, WEST Center Grand Opening Morning Program, Agua Nueva Water Reclamation Facility, Tucson, AZ.

November 25, 2015, Sharon B. Megdal. Drought, Shortage, and Closing the Projected Gap in Water Supply and Demand, Marana Chamber of Commerce, Marana, AZ.

December 1, 2015, Sharon B. Megdal. Sustainable Water Use in the Arid Southwest, Renewable Natural Resources Foundation Congress on Sustaining Western Water, RNRF, Washington, DC.

January 28, 2016, Sharon B. Megdal. Prospering with Limited Water Supplies: The Case of Israel. Operations and Management Workshop, Sponsored by *Irrigation Leader* Magazine, Phoenix, AZ.

February 8, 2016, Sharon B. Megdal. Reflections on NIWR Presidency 2014-15. Annual Meeting, National Institutes for Water Resources (NIWR), Washington, DC.

February 8, 2016, Sharon B. Megdal. UCOWR-NIWR partnership update. Annual Meeting, National Institutes for Water Resources (NIWR), Washington, DC.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	8	0	0	0	8
Masters	4	0	0	0	4
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	14	0	0	0	14

Notable Awards and Achievements

Northern Arizona University student Jonathan Credo (2015AZ544B - Characterization of Uranium and Arsenic in Unregulated Water Sources on the Navajo and Hope Reservations) received an Arizona Community Foundation Scholarship to continue work on water research for summer 2016.

Publications from Prior Years

1. 2014AZ530B ("Development of Antibiotic Resistance during Wastewater Treatment") - Articles in Refereed Scientific Journals - Franklin, A.M., D.S. Aga, E. Cytryn, L.M. Durso, J.E. McLain, A. Pruden, M.C. Roberts, M.J. Rothrock, Jr., D.D. Snow, J.E. Watson, and R.S. Dungan. 2016. Antibiotics in Agroecosystems: Introduction. Journal of Environmental Quality, 45: 377-393; DOI: 10.2134/jeq2016.01.0023.
2. 2014AZ530B ("Development of Antibiotic Resistance during Wastewater Treatment") - Articles in Refereed Scientific Journals - McLain, J.E., E. Cytryn, L. Durso, and S. Young. 2016. Culture-based methods for detection of antibiotic resistance in agroecosystems: advantages, challenges, and gaps in knowledge. Journal of Environmental Quality, 45: 432-440; DOI: 10.2134/jeq2015.06.0317.
3. 2014AZ530B ("Development of Antibiotic Resistance during Wastewater Treatment") - Articles in Refereed Scientific Journals - Williams-Nguyen, J., J.B. Sallach, S. Bartelt-Hunt, A.B. Boxall, L.M. Durso, J.E. McLain, R.S. Singer, D.D. Snow, and J.L. Zilles. 2016. Antibiotics and antibiotic resistance in agroecosystems: state of the science. Journal of Environmental Quality, 45: 394-406; DOI: 10.2134/jeq2015.07.0336.