Water Resources Research Center
Annual Technical Report
FY 2016

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 "tackle key water policy and management issues, empower informed decision-making, and enrich understanding through engagement, education, and applied research." It accomplishes its mission by assisting communities in water management and policy; educating teachers, students and the public about water; and conducting applied research on state and regional water issues. The WRRC is recognized statewide as a reliable source for water resources research and information transfer. Arizona's designated state water resources research institute established under the 1964 Federal Water Resources Research Act, the WRRC administers research grant programs and engages in information transfer activities that produce 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 assessment, and groundwater governance. Collaborations and cooperative arrangements are vital to the WRRC's research, education and outreach goals. Water, Environmental and Energy Solutions (WEES), a UA program funded by the university's Technology and Research Initiative Fund (TRIF), and Arizona Project WET (Water Education for Teachers) are key partners. The WRRC houses Arizona Project WET, a program initiated at the WRRC in 1991 that is now 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 supports water resources research in Arizona with small research grants through the WRRA, Section 104(b) research grant program. The call for proposals encourages Investigators at the three state universities in Arizona to apply for these grants. The WRRC typically selects two to four research projects for funding per year. Selected projects have addressed water research that contributes to resolving water resource issues across the state. 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 has been funded over the years, emphasizing the mandated program goals of improving water supply reliability and quality, exploring new ideas to address water problems, and expanding understanding of water and water-related phenomena. For the 2016-2017 cycle (March 1, 2016-February 28, 2017), the Technical Review Committee met on December 18, 2015 and evaluated the five proposals received. 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.

A reexamination of the WRRC's 104(b) grants program procedures, suggested by the technical review committee, led to refocusing the call for proposals. Graduate students were encouraged to apply for research project funding through a faculty member at their university. The focus on students was intended to broaden the range of proposals received and give students experience in applying for grant funding and in managing their own research. For the 2017-18 grant cycle, the WRRC selected two research projects for funding from the seven proposals received: • Impact of projected climate changes on mountain-block recharge processes, Principal Investigator: Thomas Meixner and Graduate Student: Ravindra Dwivedi, University of Arizona • Might recycled wastewater solve the rising problem of toxin-producing algae? Principal Investigator: Kevin Fitzsimmons and Graduate Student: Robert Lynch, University of Arizona. The proposed research was deemed by the Technical Review Committee to me the high standards for significance and technical merit used in previous proposal reviews.

Grants from the nationally competitive grants program (104(g)) awarded to Arizona investigators are administered by the WRRC, which is responsible for submitting the proposals from Arizona. No Arizona 104g projects were funded in 2016.

Sunlight-driven reactive oxygen species production for natural attenuation of wastewater trace organic compounds

Basic Information

Title:	Sunlight-driven reactive oxygen species production for natural attenuation of wastewater trace organic compounds
Project Number:	2016AZ552B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	Seventh
Research Category:	Water Quality
Focus Category:	Toxic Substances, Water Quality, Wastewater
Descriptors:	None
Principal Investigators:	Robert Arnold, David Matson Quanrud

Publications

1. Zhang, Tianqi., Long Cheng, L. Ma, F. Meng, Robert G. Arnold, A.E. Sáez, 2016, Modeling The Oxidation of Phenolic Compounds by Hydrogen Peroxide Photolysis, Chemosphere, 161, 349-357.
2. Cheng, Long., Tianqi Zhang, Hao Vo, D. Diaz, David Quanrud, Robert G. Arnold, A.E. Sáez, 2017, Effectiveness of Engineered and Natural Wastewater Treatment Processes for Water Reuse, Journal of Environmental Engineering, 143, 1-18.
3. Cheng, Long, 2017, Effectiveness of engineered and natural wastewater treatment processes for the removal of trace organics in water reuse, PhD Dissertation, Chemical and Environmental Engineering, College of Engineering, The University of Arizona, Tucson, Arizona.
4. Zhang, Tianqi, 2017, Modeling photolytic advanced oxidation processes for the removal of trace organic contaminants, PhD Dissertation, Chemical and Environmental Engineering, College of Engineering, The University of Arizona, Tucson, Arizona.
5. Vo, Hao, “Kinetic modeling of sunlight-assisted degradation of trace organic substances,” 253rd ACS National Meeting, San Francisco, California, April 2-6, 2017.

Problem and research objectives:

Wastewater reclamation and reuse have contributed to water resources planning in the Tucson area since 1984 (1). As competition grows for Colorado River water, the largest single water resource in the area, regional dependence on reclaimed water to satisfy water demand is likely to increase. Although the intended use of reclaimed water in the Tucson area is for landscape irrigation, it is probable that the public will embrace indirect potable use of reclaimed water in the not-too-distant future and City planning is based on that assumption. *De facto* potable reuse already occurs due to the impossibility of excluding wastewater effluent from entering local production wells as infiltrate from the Santa Cruz River. There remain, however, environmental and human health concerns that arise from the persistence of trace organic compounds (TOrCs) in treated wastewater. These include a variety of compounds that enter wastewater as a consequence of human use—phenolic compounds, phenoxy herbicides, pharmaceuticals and pharmaceutical by-products, endocrine disrupting compounds, and many others. These frequently survive conventional wastewater treatment processes (2-6). Some are toxic and tend to persist in receiving waters can produce negative biological effects among wildlife (5,7-9). Others are known or suspected carcinogens with attendant risk for those chronically exposed (10-13).

In the Tucson area, the vast majority of municipal wastewater treatment is provided at two facilities—the Agua Nueva Wastewater Reclamation Plant and the Tres Rios Wastewater Reclamation Plant. Effluent from those facilities is either reused for landscape irrigation or discharged to the Santa Cruz River, which flows north-northwest through the region. In the Tucson area, the Santa Cruz is effluent-dependent, so that no dilution of residual wastewater constituents occurs with distance traversed, and the trajectories of contaminant concentrations along the river offer clues regarding the fates of these chemicals in the environment. A number of important trace contaminants are gradually attenuated with distance while others tend to persist (3,4,9,14). Mechanisms responsible for attenuation are seldom known with certainty despite considerable interest (4).

Candidate transformation mechanisms for TOrCs in the aquatic environment include sediment adsorption, biotransformation, hydrolysis, and photolysis; the relative importance of these mechanisms depends on properties of compounds, geographic factors, and aquatic conditions (4,6,13-15). Numerous studies have shown that sunlight (photolysis) can play an important role in observed transformations—via direct and indirect photolysis (4,16-22). In direct photolysis, photon absorption is immediately responsible for compound transformation. That is, the energy of the photon is directly responsible for the conversion of the target compound to product(s). Indirect photolysis is slightly more involved. In this case, light energy activates an intermediate compound or compounds, sometimes referred to as "photosensitizers." The activated intermediate then either reacts with the target or with an additional intermediate such as molecular oxygen to produce a reactive intermediate that is capable of reacting with the target (23-25).

Compounds in effluent organic matter (EfOM) can play the role of photosensitizer, motivating the production of reactive oxygen species (ROS) such as singlet oxygen ($^1O_2$), hydroxyl radicals (HO•), superoxide anions ($O_2^{\bullet-}$), and hydrogen peroxide (H_2O_2) under solar-irradiation (26-30). Triplet excited states of EfOM ($^3EfOM^*$) are also candidate agents for reaction with TOrCs. Natural organic matter (NOM) plays a parallel set of roles (31-33). Compared to NOM, EfOM contains a higher concentration of hydrophilic organic matter. Hydrophilic organics have, in general, higher quantum yields for the production of $^1O_2$ and HO• by indirect photolysis but also provide a competitive sink for H_2O_2 and $O_2^{\bullet-}$ (26,28,34,35). Both EfOM and NOM absorb light

non-productively as well as playing the role of sensitizer, increasing the difficulty in modeling indirect photolytic systems in natural waters.

HO• has received more attention than other ROS due to its strength as an oxidant and ability to oxidize a great many organics. Furthermore, the light-dependent formation of HO• in the presence of EfOM is significantly greater than with NOM due to the potential contributions of nitrate photolysis and EfOM photosensitizer activity (27). Although $^1O_2$ generally plays a less important role in TOrC transformations than HO•, it enhances the photodecomposition of several important organic groups, including furans and phenols, in the aquatic environment (36).

Unlike ROS agents, excited triplet states, in this case EfOM*, can retard the phototransformation of contaminants such as phenols, anilines, pharmaceuticals, etc., by reacting with reaction intermediates to restore the parent compounds (37,38) and promoting redox transformations of TOrCs such as methyl and methoxy phenols (39,40), phenylurea herbicides (41), bisphenol A (42), heterocyclic groups (43), and others. Despite considerable focus on indirect photolysis of TOrCs involving ROS generated from EfOM, the photo-reactive behavior and mechanism of ROS agents in the transformation pathways of TOrCs is sufficiently complex as to resist complete understanding.

In this work, *p*-cresol was chosen as a model contaminant. It is a substituted phenolic compound that is commonly detected in the effluent of industrial wastewater and susceptible to photodegradation. Fufuryl alcohol, (FFA) a furan, was selected as a positive reference target, or probe, with which to quantify the concentration of singlet oxygen. Methylene blue (MB) is a common, well understood photosensitizer. Together, the MB sensitizer, singlet oxygen intermediate and FFA target comprise an ideal reactive system in which reaction mechanism and critical kinetic information are mostly known from previous work. The more representative system consisting of EfOM (containing photosensitizers) and *p*-cresol (or other) target can then be exposed to a degree from the ideal reaction system—to determine the importance of singlet oxygen to observed natural transformations for a range of TOrCs.

Research was focused on the following objectives:

- Establish the roles of singlet oxygen, excited triplet state (EfOM or MB), and hydroxyl radical in attenuating *p*-cresol and furfuryl alcohol in artificial sunlight (UVA-340).
- Construct and validate a mechanistic model. Simulate UVA-assisted indirect photolysis of furfuryl alcohol and *p*-cresol in the presence of methylene blue.
- Develop next experimental steps leading toward valid simulation of indirect photolysis of TOrCs involving reaction with singlet oxygen.

Methodology:

Chemicals used in the research were available commercial products and used as obtained, without further purification. Milli-Q water (resistivity ≥18.0 MΩ·cm) purified by Barnstead NANOpure II system was used in solution preparations. Compressed argon (Ar, ultrapure grade) used in degasification experiments was from the Cryogenics and Gas Facility, Tucson, Arizona. All glassware was prewashed with 2% soap solution first, then rinsed 3 to 5 times with Milli-Q water and baked overnight at 550 ^oC for later use. Quartz cuvettes (Perkin Elmer, Quartz SUPRASIL Macro) used to measure fluorescence and UV/Vis absorbance were pre-soaked in 3~5% nitric acid aqueous solutions before use.

Chlorinated, dechlorinated secondary effluent was collected at the outfall from the Tres Rios Wastewater Reclamation Facility (Tres Rios WRF Secondary Effluent) in Tucson, Arizona. In-plant treatment consisted of biological treatment for carbon stabilization and nutrient removal followed by chlorination/dechlorination. Nutrients were removed through sequential

anaerobic, aerobic and anoxic processes with recycle. Effluent was well buffered with pH ~7.8. After sampling, wastewater effluent was stored in the dark at 4 ^{o}C until used. The period of storage never exceeded 3 days. No loss of EfOM photosensitizer activity was observed during storage.

Light source. A sunlight simulator (Solarmeter® Model 5.0 UVA&B, digital UV meter) was used to conduct indoor, bench-scale experiments. The simulator generates 2.8 mWcm^{-2} at wavelengths from 300-400 nm. Light intensities were confirmed using an irradiance detector, Solarmeter ® model 5.0 UVA&B digital UV meter and UV Power Meter (Model C8026, Hamamatsu Photonics K.K.) and 254 nm sensor (Model H8025-254) to measure light intensities of UVA-340 and UVC-254, respectively. The manufacturer's emission spectrum for the light source is provided (Figure 1). The irradiance was approximately equivalent to that of natural sunlight in the same UVA range at 10 am in June and July and at noon in October in Tucson.

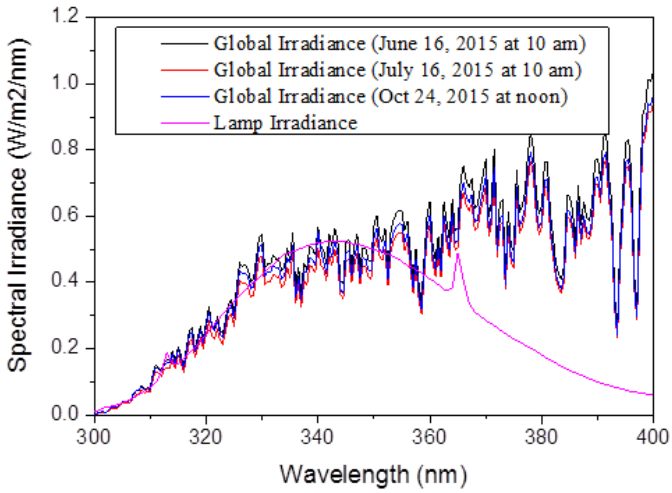

Figure 1. Comparison of wastewater spectral absorbance, spectral irradiance of UVA-340 fluorescent lamp (2.8 mW/cm^2) and the ground level global sunlight at the University of Arizona, Tucson, Arizona, obtained from SMARTS.

Reactor design. Batch reactors were clear glass, containing 600 mL of aqueous solution with a surface area of 0.0154 m^2. The liquid surface was 3 cm below the light source. Either Milli-Q water or wastewater effluent was spiked with target chemicals immediately prior to exposure to simulated sunlight. All experiments were performed at 23 ± 2 °C. Dark controls were maintained under the same conditions. Samples were withdrawn at 30-minute intervals, normally over a period of four hours.

Analytical. A Thermo Scientific Genesys 10S UV–Vis spectrophotometer was used to obtain the absorption spectra of test samples. The interval was set up at 0.5-nm increments. Methylene blue has an absorption spectrum from 200-800 nm. Furfuryl alcohol, *p*-cresol and wastewater effluent have absorption spectra from 200-350 nm. The scan range of the UV-vis spectrophotometer corresponded to those of the fluorescence excitation-emission matrix (EEM).

EEM measurements were used to characterize dissolved organic matter, including changes during treatments. 3-D fluorescence data were also employed in the quantitative analysis of target compounds when not precluded by medium-dependent interferences. The scan range and slit of the emission and excitation monochromators were 280 to 500 nm, 0.5 nm, 5 nm and 240 to 400 nm, 10 nm, 5 nm, respectively. Scan speed was set at 600 nm/min. Based on the work of Chen et al. (44), corrected fluorescence intensities obtained from EEM contours

were integrated using a trapezoidal rule in two different regions (upper peak and lower peak areas) as measures of total humic and fulvic material, respectively (Figure 2).

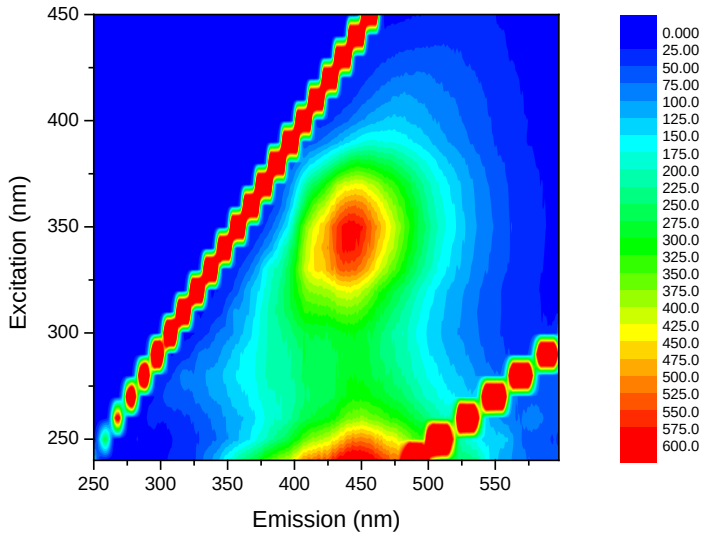

Figure 2. Fluorescence intensity integration regions following correction for internal light absorbance. The EEM contours represent EEM spectra for a Tres Rios WRF wastewater sample.

A Shimadzu TOC-VCSH Total Organic Carbon Analyzer was used to measure total organic carbon (TOC). Dissolved oxygen was measured using a Milwaukee MW600 LED Economy portable dissolved oxygen meter.

Furfuryl alcohol and *p*-cresol were measured using high performance liquid chromatography (HPLC), with a reverse-phase C-18 column (150 × 4.6mm Synergi, 4 micron). The composition of eluent H_2O (acidified to pH ≈ 3)/MeOH was 90/10 (v/v) for furfuryl alcohol at constant flow rate (0.8 mL/min), and 40/60 (v/v) for *p*-cresol at 0.7 mL/min. Concentrations of FFA and *p*-cresol were obtained by comparing integrated areas with those of standards.

Principal findings and significance:

Photolysis pathway of p-cresol. Preliminary experiments related to the mechanism of light-driven transformation of aqueous-phase *p*-cresol in wastewater effluent exposed to sunlight indicated that light, molecular oxygen and some material of wastewater origin are requisite to observed transformations (Figure 3a,b). When solutions were prepared in wastewater effluent in the presence of molecular oxygen and sunlight 20% of the 20 µM *p*-cresol initially present disappeared over the 4-hr experimental period. Absent light or molecular oxygen, or when effluent was replaced by Milli-Q water, *p*-cresol was stable over the same period. Results eliminate hydrolysis, volatilization and direct photolysis as major mechanisms for the disappearance of *p*-cresol in these experiments. Previous work indicates absorbance of sunlight by effluent organic matter initiates the production of ROS (26,39,45,46).

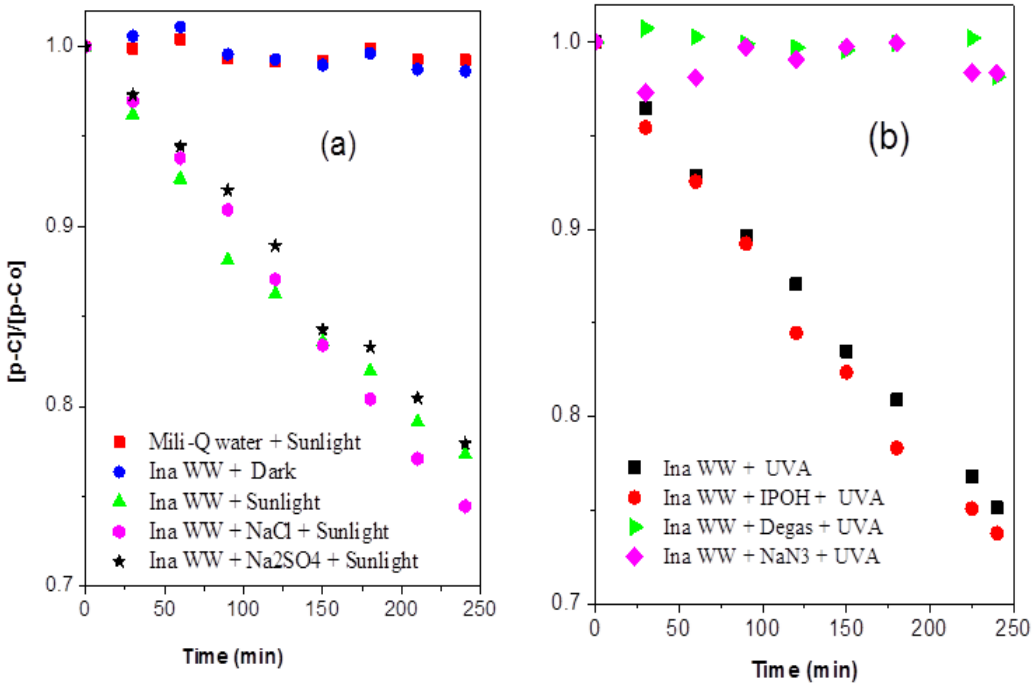

Figure 3. (a) Photo degradation of 50uM *p*-cresol in wastewater in dark control, in natural sunlight, Milli-Q water in sunlight and in wastewater supplemented with NaCl or Na_2SO_4. (b) Photo degradation of 50 µM *p*-cresol in wastewater effluent and effluent supplemented with NaN_3 or IPOH; wastewater without oxygen under UVA-340.

Deoxygenation experiments suggested that the formation of triplet states via sunlight irradiance of dissolved organic matter (33,41,42), although sometimes necessary, was not sufficient for the photo-degradation of *p*-cresol. The addition of 10 mM isopropanol (IPOH), a common scavenging agent for hydroxyl radicals, did not impede the transformation of *p*-cresol. The addition of 150 mg/L of NaCl or Na_2SO_4 to reactive mixtures containing *p*-cresol did not advance the reaction kinetics, suggesting that common inorganic radicals (e.g., ClO_2^*, Cl_2^*, SO_4^*) (47) were not responsible for the observed transformation. Finally, the addition of 10 mM sodium azide, which is known to scavenge singlet oxygen ($k_5 = 5 \times 10^8\ M^{-1}s^{-1}$) (48,49), was able to quench *p*-cresol transformation (Figure 3b). Taken together, results suggest that singlet oxygen in wastewater effluent was the primary reactant with *p*-cresol in UVA and natural light.

System simulation—model system consisting of methylene blue and furfuryl alcohol. A model system consisting of methylene blue (sensitizer), furfuryl alcohol (target) and UVA-340 lamp (artificial sunlight source) was used to expose the kinetics and mechanisms of photolytic reactions involving singlet oxygen. The supposed mechanism for transformations in the model system (Table 2) was assembled from a number of previous studies (17,48,50-54). Furfuryl alcohol, which does not participate in direct (UVA-340) photolysis, is a probe for singlet oxygen ($1.2 \times 10^8\ M^{-1}s^{-1}$) (55,56). Sodium azide is quencher for singlet oxygen, with a second-order reaction rate constant that has been variously reported as $4.5 \times 10^8\ M^{-1}s^{-1}$ (57), $4.0 \pm 0.6 \times 10^8\ M^{-1}s^{-1}$ (48), and $3.0 \pm 0.5 \times 10^8\ M^{-1}s^{-1}$ (58). The rate constant of sodium azide ion with singlet oxygen used here was $4.0 \times 10^8\ M^{-1}s^{-1}$ (17). Physical quenching was expressed as a first-order reaction with rate constant equal to $2.5 \times 10^5\ s^{-1}$ (59).

Model system experiments were carried out with initial concentrations of MB ranging from 0.5 µM to 10 µM in Milli-Q water plus 20µM FFA under the UVA-340 light source to show that the triplet excited state of the MB sensitizer does not participate directly in the photo

degradation of FFA. Unlike Rose Bengal, another much-used photosensitizer (experiments not shown) the aqueous-phase concentration remained steady over the four-hour course of our experiments (Figure 4), reinforcing aspects of the mechanism proposed for MB-initiated photolysis reactions (Figure 5a,b).

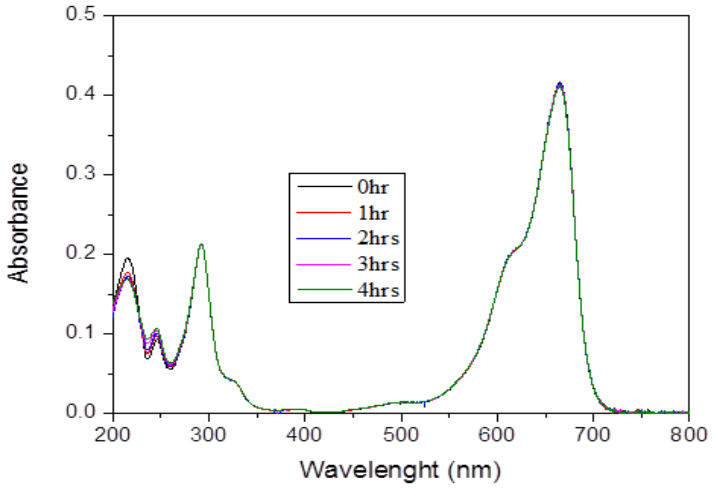

Figure 4. Time-dependent spectra for MB (5µM) spiked with FFA (20 µM) during four hours of irradiation under the UVA-340 light source.

There was no photo-attenuation of FFA in degassed solutions. In the presence of molecular oxygen at concentrations near saturation with air, the rate of FFA disappearance was about proportional to the concentration of MB and pseudo-first-order in FFA (Figure 5a). This is consistent with previous studies. It is apparent that FFA reacts exclusively with singlet oxygen, as opposed to excited states of MB (60,61). In these experiments, isopropanol did not affect the phototransformation of FFA (Figure 5a). Furthermore, the inhibition of FFA transformation rate was directly related to the concentration of sodium azide present (Figure 5b).

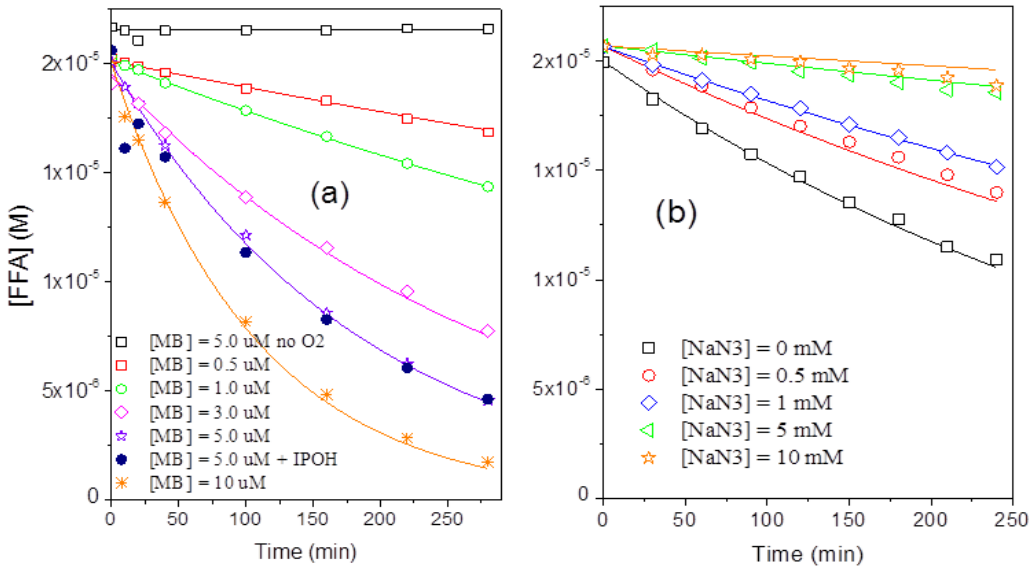

Figure 5. (a) – Experiment and simulation of FFA (20µM) degradation with 1-10 µM MB in Milli-Q water under UVA-340 irradiation. (b) FFA (20µM) degradation with MB (5 µM) spiked with 0-20 mM sodium azide ranging in Milli-Q water under UVA-340 irradiation. Solid lines represent simulation results.

Table 2. Kinetic and equilibrium parameters used to simulate the photo-degradation of FFA with MB as sensitizer in Milli-Q water. Sources of rate constants and quantum efficiency were as indicated.

Reaction		Parameter	References
(1)	$MB \rightarrow MB^* \rightarrow {}^3MB^*$	$[\Theta] = 0.63$ mol/Ein	This study
(2)	${}^3MB^* \rightarrow MB$	$k_1 = 10^4\ s^{-1}$	This study
(3)	${}^3MB^* + O_{2(aq)} \rightarrow {}^1O_2 + MB$	$k_2 = 10^9\ M^{-1}s^{-1}$	This study
(4)	${}^1O_2 + FFA \rightarrow$ product	$k_3 = 1.2 \times 10^8\ M^{-1}s^{-1}$	Reported (55,56)
(5)	${}^1O_2 \rightarrow O_{2(aq)}$	$k_4 = 2.5 \times 10^5\ s^{-1}$	Reported (28,62,63)
(6)	${}^1O_2 + N_3^- \rightarrow N_3^* + O_2$	$k_5 = 5 \times 10^8\ M^{-1}s^{-1}$	Reported (17)
(7)	$N_3^* \rightarrow N_3^-$	$k_6 = 10\ s^{-1}$	This study

(8)	$I_\lambda = \frac{A_r \lambda S_\lambda}{V_r N_a h c}$
(9)	$A_\lambda = \varepsilon_{\lambda-FFA}[FFA] + \varepsilon_{\lambda-MB}[MB] + \varepsilon_{\lambda-IS}[IS]$
(10)	$r_{MB} = \frac{d[MB]}{dt} = -\int_{\lambda_{300}}^{\lambda_{400}} \phi_{MB-\lambda} I_\lambda f_\lambda \left[1 - 10^{A_\lambda L}\right] d\lambda + k_1\left[{}^3MB^*\right] + k_2\left[{}^3MB^*\right]\left[O_{2(aq)}\right]$
(11)	$r_{{}^3MB^*} = \frac{d[{}^3MB^*]}{dt} = \int_{\lambda_{300}}^{\lambda_{400}} \phi_{MB-\lambda} I_\lambda f_\lambda \left[1 - 10^{A_\lambda l}\right] d\lambda - k_1\left[{}^3MB^*\right] - k_2\left[{}^3MB^*\right]\left[O_{2(aq)}\right]$
(12)	$r_{sO_2} = \frac{d[{}^1O_2]}{dt} = k_2\left[{}^3MB^*\right]\left[O_{2(aq)}\right] - k_3[FFA]\left[{}^1O_2\right] - k_4[N_3^-]\left[{}^1O_2\right] - k_5[{}^1O_2]$
(13)	$r_{FFA} = \frac{d[FFA]}{dt} = -k_3[FFA][{}^1O_2]$
(14)	$r_{N_3^-} = \frac{d[N_3^-]}{dt} = -k_4[N_3^-]\left[{}^1O_2\right] + k_6[N_3^*]$

Notes: I_λ is specific spectral intensity, S_λ is the spectral irradiance (W $m^{-2}nm^{-1}$), V_R is the reactor volume (m^3), A_r is the surface area of the reactor exposed to incident light (m^2), N_a is Avogadro's number (6.022×10^{23}), h is Planck's constant (6.626×10^{34} kg-$m^{-2}s^{-1}$) and c is the speed of light (299,762,458 ms^{-1}). ε ($M^{-1}cm^{-1}$) values are the wavelength-dependent molar extinction coefficients of target compounds; the wavelength dependence of absorbance by the MB sensitizer is as indicated (Figure 4). L is the path length for the light in the reactor (i.e., the depth of the reactor). It was assumed that light reaching the base of the reactor was not reflected. λ is wavelength of the UVA-340 lamp and ranged from 285 to 400 nm (Figure 1). (ϕ) (mol/Ein) for MB excitation was expressed as $\phi_{MB-\lambda}$. For this application, quantum yield was assumed to be independent of wavelength (64,65).

The reaction of FFA with singlet oxygen (Equation 4 in Table 2) and corresponding reaction rate (r_{FFA}) are as shown (Equation 13). To find the steady state concentration of singlet oxygen, a simplified mathematical model was introduced and solved using a stiff-ODE solver in MATLAB (ODE15s) as described by others (64,66). The data sets for Figures 6(a,b) were used to fit four model parameters—the quantum yield for MB photolysis, the rate constant for deactivation of $^3MB^*$ (k_1), the rate constant for reaction of MB with singlet oxygen (k_2), and the rate constant for deactivation of N_3^* (k_6).

The calibrated model was validated using data representing the trajectories of FFA concentrations in the presence of sodium azide. In all cases, agreement between data and simulation was excellent. Simulations of *p*-cresol transformations were also carried out, although it was necessary to distinguish individual rate constants for both the protonated (acid) and deprotonated (basic) forms. Again agreement between measured and predicted values was excellent (not shown).

Significance. Although the contribution of singlet oxygen to photolytic transformations of TOrCs in natural water and treated wastewater is widely acknowledged qualitatively, there have been relatively few attempts to develop quantitative kinetic models for such transformations, even under near-ideal conditions such as those in these experiments. The wide range of conditions under which agreement was obtained between observed and predicted values for FFA and *p*-cresol transformations suggests that the modeling techniques used here will be useful for a number of follow-on studies in more complex physical-chemical situations. The same techniques, for example, can be used to estimate rate constants for TOrC reactions with singlet oxygen in cases where accurate concentration profiles can be generated. And as kinetic models grow more sophisticated—incorporating the potential effects of wavelength-dependent quantum efficiencies and presence of multiple sensitizing agents in wastewater effluent, photolytic decompositions will be more reliably incorporated into fate analyses for emerging contaminants of importance to human and ecological health. Finally, mathematical representation of these transformations under conditions relevant to water and wastewater treatment will eventually support the rational design of treatment systems for reduction or elimination of exposures to specific TOrCs.

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Recycled water use for Agriculture: On-farm Demonstration and Evaluation

Basic Information

Title:	Recycled water use for Agriculture: On-farm Demonstration and Evaluation
Project Number:	2016AZ554B
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End Date:	2/28/2017
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Descriptors:	None
Principal Investigators:	Channah Rock, Natalie Brassill, Dametreea Carr

Publication

1. Dery, Jessica; Dametreea, Carr; Natalie, Brassill; Channah, Rock. Spring 2017, UA Partners with Ag Industry to Conserve, The Kachina News, AZ Water Association, pp. 38-39.

Problem and Research Objectives

Sustainable water management is imperative for the future of U.S. agriculture. Increasing demands on limited water supplies have added pressure for growers to identify long-range improvements in the sustainability of water supplies used for agricultural irrigation. The quest for sustainability has led to the development of technologies that decrease agricultural water use, including drip irrigation and the development of low water use crops. However, these technologies alone will not solve water supply issues of the future. Recycled water has the potential to meet increasing demands and provide a sustainable option for agricultural irrigation. Advances in wastewater treatment technologies have increased the quality of treated wastewater to near or above drinking water standards. Accordingly, confidence has increased as numerous municipalities have begun using recycled water for various end uses, including but not limited to, irrigation of municipal parklands, golf course irrigation, dust control, and (in some states), the irrigation of edible crops. Despite these widespread increases in recycled water usage, growers are reluctant to move towards its widespread use, due to a combination of unknown impacts on food safety, generally negative public perceptions, and misinformation.

Our multidisciplinary team has extensive research and extension experience in investigating irrigation water quality issues in the semiarid Southwestern U.S., working with biological and chemical contaminants of irrigation water and produce. The team scientists have also advanced current knowledge of the environmental fate and transport of constituents of concern in recycled water used for irrigation. Despite these advances, the use of recycled water and its impacts on the quality and safety of irrigated produce are poorly understood. This study is of vital importance to small-scale farmers, commercial growers, and irrigation districts, not just in Arizona, but in regions throughout the U.S., that depend on irrigated agriculture for food crop production. Ultimately, improved guidance for growers may increase usage of recycled water source, increasing water savings in a water-stressed world.

The primary objective of the project was to evaluate the potential impacts of recycled water on irrigated agriculture, including produce, through innovative stakeholder communication. The specific objectives of this proposal include the following;

Objective 1: Utilize stakeholder-based focus groups and advanced survey techniques to identify concerns related to recycled other nontraditional water irrigation for produce.

Objective 2: Using the collected information, develop a platform for microbial and chemical risk assessment tool for potential produce contamination.

Objective 3: Utilizing stakeholder commentary on the risk assessment, develop and promote a *Tool-kit* of water recycling and agriculture best management practices (BMPs) that will aid informed decision-making by growers and water managers.

Methodology

For this project two focus groups were convened; one was a citizen panel with representatives from the fields of science, economics, education, industry, regulation and Cooperative Extension. The second panel comprised agriculture professionals (growers, producers, food safety managers, and irrigation districts). Both groups were asked to evaluate issues and concerns related to perceptions of recycled water and other nontraditional water sources identified from the literature. They also considered the costs and benefits presented from the literature review related to public acceptance, health and safety concerns, and environmental considerations of the use of nontraditional water. The results of the focus groups were compiled, evaluated and synthesized into the foundation for the development of the ***Tool-kit***. The second panel of agricultural professionals also aided in identification of grower partners currently considering recycled water for irrigation in Arizona. Grower participation was targeted based on enthusiasm and agreed collaboration. Stakeholders learned about the program through flyers, word of mouth, and/or emails sent by University of Arizona Cooperative Extension. In addition, local Extension agents supported the program through newspaper, email, and flyers for

distribution at grower events.

Principal Findings and Significance

Over the course of the project, the research and extension team worked with industry to develop the two focus groups mentioned above. The focus groups met in February 2017 to coincide with the Southwest Ag Summit held annually in Yuma Arizona. During this meeting, 31 focus group members participated in active discussions of water resources, including water availability, water quality, non-traditional water sources, public health and safety, regulatory frameworks and public perception of crops grown with nontraditional water sources. A listing of the Southwest Extension focus group members and their affiliation is listed below (Table 1.)

Table 1. Southwest Extension Focus Group Members

Focus Group Member	Affiliation
Alex Muller, Food Safety Director	Pasquinelli Produce Co.
Anne Thebo, Ph.D. Graduate Student	External stakeholder/observer
Bahman Shiekh, Ph.D., PE, Consultant	Water Recycling, Reclamation, Reuse Consultant
Bob McClendon, Organic Grower	McClendon Farms
Brad Hill, Utilities Director	City of Flagstaff Water Utilities
Candace Hamana, Tribal Relations & Strategic Initiatives Analyst	Central Arizona Project
Cathy Carlson, Consultant	Carson FS Consulting LLC
Charles Sanchez, Ph.D. Soil Scientist	UA-Agronomist
Chris Udall, Executive Director	Agribusiness & Water Council of Arizona
Chuck Graf, Senior Hydrologist	ADEQ, Reclaimed Water Regulatory Agency
Claire Zugimyer, MS Ecologist	Sonoran Institute
Clinton Williams, Ph.D. Soil Scientist	USDA-ARS hydrologist

Donovan Neese, MBA Superintendent	Roosevelt Irrigation District Superintendent
Hank Giclas, Sr. VP	Western Growers
Jay Sughroue, Ph.D. CA/AZ Territory Manager	BioSafe Systems
Jean McLain, Ph.D. Associate Director	Water Resources Research Center
Jeremy Vanderzyl, Technical Services Manager	Duncan Family Farms
Jim Gorny, Ph. D. VP	Produce Marketing Association
Kurt Nolte, Ph.D. Plant Scientist	FDA, Yuma County Extension
Marc Verhougstrate, Ph.D. Assistant Professor	UA - Public Health
Mitch Basefsky, MA Communications Representative	Central Arizona Project
Paul Brierley, Executive Director	Yuma Center of Excellence for Desert Agriculture
Paul Brown, Ph.D. Associate Dean	UA Cooperative Extension
Paul Muthart, General Manager	Pasquinelli Produce Co.
Paula Rivadeneira, Ph.D. Assistant Specialist	UA - Food Safety
Rob Morrow, PE Senior Water Resources Engineer	RMC Water and Environment
Ron Fleming, President & CEO	Global Water Utilities
Steve Alameda, President	Topflavor Farms Yuma Fresh Vegetable Association
Teressa Lopez, Program Administrator	Arizona Department of Agriculture/AZLGMA
Tom Davis, President	Agribusiness Arizona, Yuma County Water Association
Vicki Scott, Director of Quality Assurance	Amigo Farms/Yuma Safe Produce Council

Additionally, to aid in tool-kit development, the research and extension team worked to develop a needs assessment survey for growers in the Southwest. The assessment was designed to help the extension team understand growers' existing 1) knowledge of

nontraditional irrigation water sources and on-farm water treatment technologies; 2) perceptions surrounding nontraditional waters; and 3) understanding of the laws associated with the use of these sources on food crops.

Figure 1. The South West Extension Team distributing the Needs Assessment Survey at the Southwest Agricultural Summit, Feb. 2017

Over the course of the project the research and extension team disseminated 390 needs assessment surveys in various formats including a large annual meeting of growers held in February in Yuma, Arizona in both 2016 an 2017, in addition to locally held listservs, industry groups, and with support from the Arizona Department of Agriculture. Surveys were disseminated both in paper format and online through a survey website called Qualtrics tailored to the Southwest region. The website is also mobile-friendly so the survey can be taken on smartphones and tablets in addition to computer and laptops. Based on the extension team's experience, growers often use mobile devices more frequently than computers, so making the survey mobile-friendly was important. A link to the needs assessment survey can be found here, https://umdsurvey.umd.edu/SE/?SID=SV_cI4BpYbxWPXQsGV.

In general, 41% (n=390) survey respondents felt that they were somewhat knowledgeable of nontraditional water sources (ie. reclaimed water/treated wastewater, return flows, brackish waters, etc). When asked if they would ever consider using water from a non-traditional source 66% responded in favor and 33% responded that they had not considered it as a source. When asked which activities would respondents be willing to use nontraditional water sources such as reclaimed water, responses were mixed with activities such as irrigation of forage crops, dust abatement, and irrigation of crops not eaten raw ranking relatively similar, with the irrigation of food crops ranking the lowest of all categories at 24%. When asked about concerns for use of alternative water sources for agriculture respondents ranked overall water quality as the largest concern, followed by reliability of treatment methods, human health risks, and consumer satisfaction. Water availability was also a concern voiced by a number of respondents in the open-ended comments. When asked what would alleviate concerns of the use of nontraditional water sources for agriculture, the sharing of water quality information and approval from a known/trusted source ranked highest among all responses at 51% and 52% respectively. Respondents also responded positively to the use of nontraditional water for agriculture if it was proven to have the same quality (or better) as water sources used currently across the State of Arizona. Additional comments collected indicted concerns of agriculture water users tied to water reliability as well as issues with increased salinity, Food and Drug Administration (FDA) Food Safety Modernization Act (FSMA) requirements and also the perception of the public to edible crops grown with nontraditional water sources. Because much of the agriculture grown in the State of Arizona is tied to market trends, pricing, consumer demands and buyer imposed specifications, the perception of the use of nontraditional water sources may largely be driven by perception rather than scientific assessment. This is a similar trend to the uses of recycled water for landscape irrigation as well as the movement towards advanced water purification of recycled municipal wastewater used for drinking also called potable reuse.

Lastly, as part of risk communication and the BMP tool-kit development, web-based interactive water information was also developed and includes topics such as

nontraditional water sources, water availability, water quality, food-safety, and BMPs. Feedback from stakeholders indicated that while factsheets and other print media can be helpful in conveying complex topics, information that can be shared through mobile platforms such as on-line tools, web-based grower Apps, and short videos is often the preferred method of communication. In order to aid in the information dissemination of this project, graduate student Dametreea Carr with support from the Yuma Center for Desert Agriculture media specialist Rosa Brevington, initiated a series of short instructional videos reviewing concepts of nontraditional water sources as well as risk assessment. The primary video can be found here; https://arizona.box.com/s/rhctktfkccn8h8jdhrstdmoz2bsmmdnc, and includes definitions of Arizona's current water supply, nontraditional water sources, water quality classifications, and considerations for risks in agriculture.

Figures 2-3. Water Reuse in Ag Instructional Video

Overall, as the Arizona agriculture industry begins to face challenges with competing demands for water, multiple sectors must determine the most economical path forward with consumer perceptions in mind. Tools such as those presented above as well as feed-back from both consumers and industry is critical for a successful path towards the use of nontraditional water sources in Arizona agriculture.

Information Transfer Program Introduction

In 2016, the University of Arizona WRRC’s Information Transfer program included two newsletters: a weekly email digest and a quarterly newsletter. The quarterly newsletter was published in both digital and printed form until January 2017, when the print version was discontinued. The annual Arroyo publication, which each year covers a different single topic of concern to the water community in Arizona, continued to be provided in both print and digital form.

The WRRC's Information Transfer program signature events were hosted, including an annual conference and a series of Brown Bag seminars, along with other special events. The fourth edition of the Arizona Water Map was created through an expert stakeholder process for release in spring 2017. In addition, the WRRC inaugurated a redesigned website, which was regularly updated with news, events, publications, and program updates. An innovative public water awareness campaign was completed and WRRC research and engagement programs were supported with IT and graphics expertise. Outreach on social media grew in its role of keeping the water community informed in a timely manner on various items of interest.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2016AZ557B
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Principal Investigators:	Sharon B. Megdal, Susanna Eden, Jean E.T. McLain

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The WRRC's information Transfer Program has consistently conveyed water resources information to a range of audiences through established programs and new initiatives. These include the Annual Conference and a Brown Bag seminar series, electronic and print publications, a reimagined and renewed website, and an updated Arizona Water Map poster. In addition, the Information Transfer Program assisted research and engagement projects in their communications and development of outreach products. The WRRC in collaboration with a team from the University of Arizona College of Agriculture and Life Sciences and Arizona Public Media completed a multi-faceted project, called "Beyond the Mirage", using video, the internet, social media, broadcast television, and face-to-face interactions to raise water consciousness in Arizona and throughout the country. Work carried out during the reporting period is described below.

Annual Conference

The 2016 Annual Conference, titled, #AZwaterfuture: Tech, Talk, and Tradeoffs, which took place on March 21st at the UA Student Union Memorial Center in Tucson, focused on innovative ideas and approaches in the realms of technology, communication, and policy. Approximately 275 people attended from 23 communities throughout Arizona and six other states. They were treated to talks and panel discussions from a full roster of 28 experts and innovators from water technology, communication, education, policy, and management fields. Farmers shared experiences with irrigated and dryland farming, and keynote speakers were Anne Castle, Former Assistant Secretary for Water and Science, US Department of the Interior, and Lisa Beutler of MWH Global, a nationally known expert on collaborative resolution of water problems. At lunch, Hunter Moore, Arizona Governor Doug Ducey's Natural Resources Policy Advisor, described the Governor's Water Initiative. A poster session after lunch provided an opportunity for conferences goers learn about ongoing research and programs. Three students were awarded cash prizes for their posters. NETAFIM, one of the many conference sponsors, provided funding for the student awards. External sponsors included Arizona Public Service, Arizona Water Company, BKW Farms, EPCOR, Central Arizona Project, KXCI Community Radio, Montgomery & Associates, NETAFIM, Salt River Project, Southern Arizona Water Users Association, U.S. Bureau of Reclamation, Water Asset Management, and WestLand Resources. A post-conference reception featured interactive digital media, with stations set up to monitor the conference's Twitter conversation, introduce the new University of Arizona Water Network, and engage participants in exploring the "Beyond the Mirage" web experience.

Planning for the 2017 Annual Conference began in the summer of 2016. The conference, "Irrigated Agriculture in Arizona: A Fresh Perspective," was scheduled to take place on Tuesday, March 28, at the UA Student Union Memorial Center. A committee of advisors was assembled with knowledge and expertise in Arizona's irrigated agriculture to help develop the program. Meetings in person and by telephone established the title, themes and a roster of potential speakers, who were invited to present on specific topics. Preparation for the conference was nearing completion by the end of the reporting period.

Brown Bag Seminars

During the reporting period, the WRRC presented 20 Brown Bag seminars by speakers who covered a range of water resource-related topics chosen to be interesting to a broad spectrum of audiences. Average in-person attendance was 23 and an average of 13 attended through Go-To-Webinar. In-person audiences were made up of about half from the UA Campus and half from the wider community. Go-To-Webinar recordings of most of the Brown Bag seminars can be viewed by going to the WRRC website. Slide presentations from the seminars are also accessible from the website.

Brown Bag seminars from the reporting period are listed below:

1. March 8, 2016, George Frisvold, Professor and Extension Specialist, Department of Agricultural & Resource Economics, University of Arizona, “Economic Aspects of the Yuma Case Study”
2. March 10, 2016, Sharon B. Megdal, Director, Water Resources Research Center, College of Agriculture and Life Sciences, University of Arizona; and Ken Seasholes, Manager, Resource Planning and Analysis, Central Arizona Project, “Water Banking and Arizona’s Framework for Groundwater Recharge and Recovery”
3. March 29, 2016, Charles Bayless, retired Utility Executive and former President and Provost of the West Virginia University Institute of Technology, “Perspectives of an Electric Utility Executive on the Water-Energy-Climate Nexus”
4. April 5, 2016, Eve Halper, Natural Resources Specialist, Bureau of Reclamation; and Kathy Chavez, Water Policy Manager, Pima County; with Brian O'Neill, Master's Student University of Arizona, “Water Supply/Demand Imbalance in the Face of Climate Change – How will we prepare?”
5. April 12, 2016, Jeremy Weiss, Climate and Geospatial Extension Scientist, School of Natural Resources and the Environment, University of Arizona, “DroughtView – Combining On-the-Ground Know-How with Remotely Sensed Data to Assess Drought Impacts”
6. April 20, 2016, Shane Snyder, Professor and Co-Director, Chemical and Environmental Engineering, Arizona Laboratory for Emerging Contaminants, Water & Energy Sustainable Technology Center, University of Arizona, “Ensuring the Safety of Recycled Water”
7. May 20, 2016, Cody Sheehy, “Beyond the Mirage” Screening
8. September 2, 2016, Grant Weinkam, Research Analyst, Water Resources Research Center, University of Arizona, “Safe and Sustainable Wastewater Treatment and Reuse: In Theory and Reality”
9. September 21, 2016, Laurel Lacher, PhD, RG, Principal, Lacher Hydrological Consulting, “Groundwater Modeling to Support Water Resources Planning in Clarkdale, Arizona”

10. September 23, 2016, Sam Fernald, Professor and Director, New Mexico Water Resources Research Institute, “Development of a Dynamic Statewide Water Budget for Improved Water Planning in New Mexico”
11. October 6, 2016, Chris Magirl, PhD. Studies Chief, U.S. Geological Survey, “Dam removal and river restoration of the Elwha River, Washington: Lessons Learned five years into the Project”
12. October 14, 2016, Adriana Palma Nava, Institute of Engineering, Universidad Nacional Autónoma de México (UNAM), “Principles in Sustainable Groundwater Management Policy”
13. October 21, 2016, Beth Kleiman and Surabhi Karambelkar, "The Water-Energy Nexus Dimension of the Central Arizona Project System Use Agreement” and “When the Turbines Stop Turning: Examining the Impacts of Drought on Power Production at Hoover Dam and Its Consequences for Entities in Arizona”
14. October 26, 2016, Jeff Biggs, Administrator, Strategic Initiatives Division, Tucson Water, and Michael Hwang, West Regional Technology Leader for Membranes, CH2M, “Potable Reuse for Inland Applications: Pilot Testing Results, Tucson AZ”
15. October 31, 2016, Dr. Kevin Lansey, Professor and Head, Department of Civil Engineering and Engineering Mechanics, University of Arizona, and Hwee Hwang, PhD Candidate, Department of Civil Engineering and Engineering Mechanics, University of Arizona, “Arizona Value Integrated Food-Energy-Water (ARVIN-FEW)”
16. November 10, 2016, Jacob Petersen-Perlman, Research Assistant, Water Resources Research Center, University of Arizona, “Assessing Water Security at Global and Local Scales”
17. November 29, 2016, Jeff McCormick, Town Manager, Town of Pima (Graham County), “Low impact design in context of water resources”
18. December 5, 2016, Victor R. Baker, Regents’ Professor of Hydrology and Atmospheric Sciences, Geosciences, and Planetary Sciences, University of Arizona, “Scientific Thinking to Remedy “Black Swans,” “Wicked Problems,” and Assorted Science/ Policy Failures”
19. January 19, 2017, Tim Thomure, Director, Tucson Water, “Agua Dulce”
20. February 24, 2017, Grant Davis, General Manager, Sonoma County Water Agency, “Implementing California’s Sustainable Groundwater Management Act and Other Innovative Water Solutions”

Co-Sponsored Outreach Events

October 14, 2016, the WRRC joined Department of Chemical and Environmental Engineering, Udall Center for Studies in Public Policy, Consortium for Arizona-Mexico Arid Environments, School of Geography and Development, and UNAM Center for Mexican Studies (UA) in co-hosting a lecture by Dr. Fernando González Villarreal, Institute of Engineering, Universidad Nacional Autónoma de México (UNAM). Dr. Villarreal's seminar, “Water Management in

Mexico: Status and Challenges", provided an overview and insights into water management in Mexico.

The WRRC Co-Hosted Special Seminar with the James E. Rogers College of Law, by Michael E. Webber, Ph.D., author of the book "Thirst for Power: Energy, Water, and Human Survival." In his seminar, which took place at the law college on November 15, 2016, Dr. Webber explained how energy and water supplies are linked and how problems in either can be crippling for the other.

On February 10, 2017, the WRRC held its annual Chocolate Fest. This year the theme was Picturing Chocolate and Water and it featured a presentation on nature photography by Greg Griffin, "Best in Show" winner in the WRRC Photo Contest. The 13th Annual WRRC Chocolate Fest offered chocolate and other treats to WRRC friends and colleagues and showcased the WRRC photo contest winners.

Publications

The **Weekly Wave** is an e-news digest sent to subscribers regularly each week during the academic year and every two weeks during the summer. Each edition includes updated WRRC and water community events, news, media appearances, announcements, and social media interaction opportunities. During the reporting period, the distribution lists grew by more than 200 recipients to approximately 2,200. Growth in Weekly Wave readership brought increased website traffic, event attendance, and dissemination of WRRC news through other outlets. Beginning with the first Weekly Wave of 2016, the redesigned format has provided better mobile compatibility.

The **Arizona Water Resource** (AWR), the WRRC's quarterly newsletter continued to be printed and distributed by mail and electronically in 2016. Mail subscriptions held steady at around 1,800, while the number of electronic subscribers increase slightly to more than 1,900. The January 2017 issue was the first to be distributed entirely digitally. Previous AWRs alerted print subscribers to the change and provided a choice of easy methods for subscribing to the digital version. A four-page insert, "2015 Highlights", summarizing the WRRC's 2015 activities and accomplishments was included in the Summer 2016 AWR. Graduate Outreach Assistants Marie-Blanche Roudaut and R. Andres Sanchez contributed significantly to developing articles for the AWR and the AWR provided an opportunity to shine a spotlight on some of the WRRC's exceptional students. In addition, several articles were invited from external authors, including stories following up presentations made at the 2016 Annual Conference, #azwaterfuture: Tech, Talk, and Tradeoffs. Lisa Beutler, Public Affairs Specialist at MWH Global wrote "What to Do about Wicked Water Problems", Amy L. McCoy, AMP Insights LLC working with the WRRC's Kelly Mott Lacroix wrote "Tradeoffs Reexamined: Moving Beyond Water Scar[ed]city toward Conscious Choices about Our Water Future," and Hunter Moore, Natural Resources Policy Advisor to Arizona Governor Doug Ducey contributed "Governor's Water Initiative Takes on

State's Water Planning Challenges." Guest views on reusing reclaimed water and the El Nino-Southern Oscillation were supplied respectively by Chuck Graf, Arizona Department of Environmental Quality, and Mike Crimmins, Department of Soil, Water and Environmental Science, College of Agriculture and Life Sciences. Greg Hess, R.G., Clear Creek Associates, also provided a Guest View, "How Much Groundwater is Down There, as part of the Winter 2017 AWR, which focused on groundwater, the invisible resource. In the same issue, Zachary P. Sugg, Ph.D., Visiting Assistant Professor, Southwest Studies, Colorado College wrote on "Whither Critical Area and Sub-AMA Groundwater Management In Arizona?" and Kerry Schwartz, Arizona Project WET, tackled the topic of "Making Groundwater Visible." In addition to brief news articles and items on new resources, each issue of AWR carried the regular Public Policy Review column by WRRC Director Sharon B. Megdal.

The ***Arroyo***, WRRC's annual publication that presents a single topic of timely interest to Arizona in clear and concise language for the interested public, was published in the spring of 2016. This 16-page publication discussed the various issues relating to potable reuse of water. It covered the reasons that reuse is being considered an important water source, treatment methodologies, regulations, and challenges to reuse such as contaminants, waste handling, operator training, and public acceptance. Drafted by Nejlah Hummer, the 2015 Montgomery & Associates Summer Writing Intern at the WRRC, the 2016 Arroyo was reviewed both internally and externally by experts in the field. Reviewers included Guy Carpenter, Carrolo Engineers; Karen Dotson, BKW Farms; Chuck Graf, Arizona Department of Environmental Quality; Brad Hill, City of Flagstaff; Jean McLain, University of Arizona; Arthur Nunez, City of Scottsdale; Channah Rock, University of Arizona; and Timothy Thomure and Wallace Wilson, City of Tucson.

Work began on the 2017 *Arroyo* after the selection of the 2016 Montgomery & Associates intern, Noah Silber-Coats, in Spring 2016. Silber-Coats is a Ph.D. student in Geography with a background investigating the development of hydropower projects in Mexico. He did the original research and drafted the *Arroyo* on Arizona's water banking, recharge, and recovery. Scheduled for publication in Spring 2017, the *Arroyo* was sent in draft form to a roster of expert reviewers in February. Printing and mailing is being sponsored by the Central Arizona Project.

Arizona Water Map

A stakeholder-driven process informed the development of the new Arizona Water Map from brainstorming to final reviews, ensuring that this fourth version of the Water Map accurately reflects the current state of water resources in Arizona. Four WRRC personnel completed research and tasks at varying stages of map development and relied upon the volunteer hours of dozens of supporters. An Arizona Water Map Technical Advisory Committee (TAC) was convened on the basis of GIS expertise, experience with Arizona water resources data, and involvement in previous Arizona Water Map development. The TAC included representatives from the Arizona Department of Environmental Quality, Arizona Department of Water Resources, Central Arizona Project, Salt River Project, U.S. Bureau of Reclamation, University

of Arizona, and Water Infrastructure Finance Authority of Arizona. The TAC provided vital guidance and expertise, which was taken by WRRC staff to create the map poster. In addition to data updates, notable changes included a stronger emphasis on water supply and demand among different water using sectors and regions and on groundwater usage. The map also highlights population density and shows sites of recharge and subsidence. The new natural terrain background uses Esri's multi-directional hillshade, which computes hillshade from six different directions (as opposed to one direction in a default hillshade). The logos of sponsors and partners who contributed to map development are displayed at the bottom of the map and include the Arizona Department of Water Resources, Arizona Municipal Water Users Association, Arizona Public Service, Arizona Project WET, Arizona Cooperative Extension, Central Arizona Project, EPCOR Water, Jacobs Engineering, Salt River Project, Sonoran Institute, The Nature Conservancy, U.S. Bureau of Reclamation, University of Arizona Research, Discovery & Innovation, and Water Resources Research Act §104(b) program.

Website and Electronic Communications

The new WRRC website, developed in collaboration with the UA College of Agriculture and Life Sciences information technology team, was launched on November 15 with an entirely new look and improved functionality. Its structure allows program leaders to update information and provide news on their own programs, which was intended to produce a more dynamic site. It continued to feature news, events, and programs, as well as publications and other resources. The site still provided access to a searchable video gallery (wrrc.arizona.edu/video-gallery) and Brown Bag webinar recordings. It also linked with the University of Arizona Libraries' Campus Repository, where 384 digitized archival copies of past WRRC publications are available.

Communications efforts at the WRRC expanded in 2016. In addition to the Weekly Wave, Constant Contact emails advertise events, publications, and other items of interest to our growing lists of recipients. Such items provide posts to keep an active presence 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 in 2016, adding one new follower a day in the last three months of the year, and the WRRC Facebook page surpassed 280 likes. Externally, the WRRC has been featured over 29 times across a variety of news and media outlets.

Program Collaborations

The WRRC extends its research, outreach, and education role through its collaborations. Collaborative activities with the Water, Environmental and Energy Solutions (WEES) initiative have included co-sponsoring lecturers and other events, disseminating information to the more than 300 UA investigators involved in water-related research, and working on a website to replace the WRRC's Desert Landscaping CD. In 2016 the WRRC Director served as one of two co-Director of WEES and in July 2016 became the WEES Director. Collaborations with the WRRC-based Arizona Project WET (Water Education for Teachers) have expanded the reach

and effectiveness of outreach and education projects of both partners, and this collaborative relationship continued through the project year. A comprehensive water education program with growing relationships with school districts and communities throughout the state, Arizona Project WET provides programs, workshops, mentoring, and partnership activities for teachers, students, and community members.

Ongoing programs of research and outreach continued and were expanded. The Transboundary Aquifer Assessment Program (TAAP) in Arizona focuses on two U.S.-Mexico shared aquifers for studies by researchers on both sides of the border to increase the information available for groundwater management. The goal of Water Research and Planning Innovations for Dryland Systems (Water RAPIDS) is to help balance water demand for human uses with the water demands of ecosystems. In 2016, the Water RAPIDS program included four projects. Understanding Environmental Flow Needs in Water Scarce Regions built on the information in its geospatial database to create a methodological guidebook for assisting resources managers in planning for stream maintenance and restoration in the deserts of the U.S. and Mexico. Watershed Planning in the Upper Gila Watershed has been exploring effective mechanisms for engaging agricultural sector stakeholders in discussions of water supply and demand and developing a guide for landowners on the Upper Gila River that answers questions about allowable uses of riverfront property. Recommendations for Water Resources Management in Cobre Valley engaged community members in conversations about their water resources toward managing their water future. Outreach is a major function of WRRC research projects, and although they are almost entirely funded from non-program sources, their outreach receives some support from the Information Transfer Program.

Beyond the Mirage

In 2014, the WRRC began collaborations on a multi-faceted project to raise awareness and knowledge about water issues in Arizona and the Southwest. The project's core is an interactive, guided but self-directed learning experience drawing on hundreds of video clips. Clips are presented in a smart web environment, and users can choose among them according to their interests. Users are then able to create their own documentaries, which can easily be shared on social media. The WRRC, working with Cody Sheehy and a team from the College of Agriculture and Life Sciences, successfully completed the "Beyond the Mirage" web experience (beyondthemirage.org) and launched it at events in Phoenix and Tucson, including the WRRC 2016 Annual Conference in March.

The "Beyond the Mirage" documentary was completed in March and two free "sold out" documentary screenings were held prior to its premiere broadcast by project partner Arizona Public Media on AZPM PBS 6, Friday, April 15 at 9:00 pm. Each screening was followed by a panel discussion moderated by AZPM's Loraine Rivera. Following the AZPM broadcast, a scientist panel was recorded for premiere airing, consisting of UA Professor Robert Glennon and Sharon B. Megdal, along with Sheehy and moderator Loraine Rivera. KAET (PBS) in Phoenix

aired the documentary on its main station 8.1 HD on May 16th at 9PM. AZPM secured national distribution through American Public Television and in mid-October, “Beyond the Mirage: The Future of Water in the West” was shown in 33 states or approximately 80 stations nationwide. Live streaming of the documentary, which had to wait until after nationwide airing through the national PBS network, was scheduled for availability as of April 2017. DVDs have been available for purchase since Spring 2016.

Arizona Project WET engaged teachers and schools in the Phoenix area to use “Beyond the Mirage” video content and website as a teaching tool during a special event on Earth Day, April 22. The Stack Sharing Festival resulted in 273 stacks created by the middle school students. In early May, these stacks were judged and voted on by users of the “Beyond the Mirage” site, parents, teachers and students. “Oscar” awards were presented to the three winners at the Water Investigations STEM Symposia in mid-May.

Multiple screenings of the “Beyond the Mirage” documentary for specific audiences have taken place since it was first shown and requests for screenings and presentations continue to come in.

Other Activities

In addition to all of the above, WRRC personnel were called upon regularly to give lectures and make presentations to diverse audiences across Arizona. They have collaborated with local, state, regional, and federal agencies and organizations, as a resource for general information and as partners on specific projects. WRRC personnel participated on community and regional boards and commissions, and served on state and local task forces and study committees. The WRRC facility is open to the public and has provided information on water related topics to the public and a space for water-related meetings. WRRC personnel also have responded to inquiries from the public on issues of concern.

Presentations

Presentations for Information Transfer on 104b projects

Project Number: 2016AZ552B

Title: Sunlight driven reactive oxygen species production for natural attenuation of wastewater trace organic compounds

Vo, Hao, “Kinetic modeling of sunlight-assisted degradation of trace organic substances,” 253rd ACS National Meeting, San Francisco, California, April 2-6, 2017.

Presentations by WRRC Personnel

March 2, 2016, Ashley Hullinger, Bailey Kennett. Watershed Planning in the Upper Gila. Briefing, Farm, Home, and Ranch Day with Arizona Cooperative Extension - EAC campus, Thatcher, AZ.

March 4, 2016, Ashley Hullinger. Water 101. Class, Osher Lifelong Learning Institute (OLLI) Green Valley, AZ.

March 10, 2016, Sharon B. Megdal and Ken Seasholes. Water Banking and Arizona's Framework for Groundwater Recharge and Recovery. Speaker, Water Resources Research Center Brown Bag Seminar, Tucson, AZ.

March 15, 2016, Sharon B. Megdal. No One is Immune: Social Justice, Climate, & Health Symposium. Panelist, Final panel on research and policy, College of Public Health, University of Arizona, Tucson, AZ.

March 18, 2016, Jean E. McLain. Public health and environmental safety of recycled municipal wastewater: current research. Osher Lifelong Learning Institute (OLLI), Green Valley, AZ.

March 21, 2016, Nate Delano, Kelly Mott Lacroix. WRRC Arizona Water Map. Presentation, WRRC Annual Conference, Tucson, AZ.

March 21, 2016, Sharon B. Megdal. #AZwaterfuture: Tech, Talk, and Tradeoffs. Conference Moderator, Panel Moderator, Water Resources Research Center Annual Conference, Tucson, AZ.

March 22, 2016, Kelly Mott Lacroix. Riparian and Aquatic Ecosystems - Why change can be good. Class. Globe, AZ

March 22, 2016, Ashley Hullinger. Beyond the Mirage. Booth, Miami, AZ.

March 23, 2016, Sharon B. Megdal. Keeping Arizona’s Water Glass Full. Panelist. Arizona Town Hall Tucson Community Outreach Program, Tucson, AZ.

March 23, 2016, Ashley Hullinger. Beyond the Mirage. Booth, Miami, AZ.

March 24, 2016, Susanna Eden, Cody Sheehy. Beyond the Mirage: Introduction and Discussion. Class, OLLI-University of Arizona, Tucson, AZ.

March 25, 2016, Jean E. McLain. Antibiotics in agroecosystems: state of the science. Webinar. National Antibiotic Resistance in Animal Agriculture. Presented by the Livestock and Poultry Environmental Learning Center.

March 28, 2016, Jean E. McLain. Water Recycling 101: What Every Arizonan Should Know. Keynote Speaker, College of Agriculture and Life Sciences Spring Luncheon, University of Arizona, Tucson, AZ.

April 2, 2016, Sharon B. Megdal. The Future of Hydrologic Education. Panelist. Hydrology: The Next 50 Years, Tucson, AZ.

April 4, 2016, Sharon B. Megdal. Beyond the Mirage: The Future of Water in the West. Panelist. Panel discussion aired as part of 90-minute Beyond the Mirage documentary, filmed at KUAT, PBS 6, Tucson, AZ.

April 6, 2016, Kelly Mott Lacroix. Moderator, Healthy Rivers Panel, Arizona Forward luncheon, Arizona Inn, Tucson, AZ.

April 12, 2016, Kelly Mott Lacroix. The Good, The Bad and The Complicated - Water Management in Arizona. Guest Lecture. Globe, AZ.

April 15, 2016, Sharon B. Megdal. Beyond the Mirage: The Future of Water in the West. Featured in-film expert. Premiered KUAT, PBS 6, Tucson, AZ.

April 15, 2016, Sharon B. Megdal. Beyond the Mirage: The Future of Water in the West. Post-film panelist. Premiered KUAT, PBS 6, Tucson, AZ.

April 20, 2016, Sharon B. Megdal. Panelist. CAP Board Member panel, Southern Arizona Leadership Council Membership Meeting.

April 23, 2016, Ashley Hullinger. Beyond the Mirage. Booth. Miami, AZ.

April 25, 2016, Kelly Mott Lacroix. The Language of Water and Water-User Perspectives. Presentation. Tucson, AZ.

April 27, 2016, Sharon B. Megdal. Groundwater Withdrawals and Resiliency. Speaker. NGWA Panel, Denver, CO.

April 28, 2016, Jean E. McLain. Emcee. University of Arizona Women in Science and Engineering, 2016 Science and Engineering Excellence Banquet, University of Arizona, Tucson, AZ.

April 28, 2016, Sharon B. Megdal. Speaker/Workshop Steering Committee. Policy, Governance, and Engagement, Groundwater Visibility Initiative Workshop, cosponsored by the National Groundwater Association and the American Water Resources Association, Denver, CO.

May 6, 2016, Kelly Mott Lacroix. Desert Flows Database. Presentation, Flagstaff, AZ.

May 10, 2016, Sharon B. Megdal. The Central Arizona Groundwater Replenishment District and Related Issues. Speaker, Tucson Regional Water Coalition, Tucson, AZ.

May 11, 2016, Sharon B. Megdal. Connecting Israeli Water Management and Technological Innovations to Arizona. Panel member and moderator, AzWater Association 89th Annual Conference, Glendale, AZ.

May 12, 2016, Jean E. McLain. Moderator. Track 5: Research Session, Arizona Water Association 89th Annual Conference, Glendale, AZ.

May 16, 2016, Ashley Hullinger. Flagstaff Conserve2Enhance. Panel/Presentation, Flagstaff Water Commission Meeting, Flagstaff, AZ.

June 12, 2016, Sharon B. Megdal. Renewing Our Commitment to Water Stewardship. Keynote Speaker. Leadership America. Scottsdale, AZ.

June 15, 2016, Sharon B. Megdal. Working together to address Arizona water resource challenges. Speaker. Yuma Center of Excellence for Desert Agriculture, Yuma, AZ.

June 15, 2016, Jean E. McLain. Recycled municipal wastewater and antibiotic resistance: is there a connection? National webinar. Presented to Water Reuse Community of Practice, Arcadis, Inc.

June 21, 2016, Sharon B. Megdal. Meeting Water Management Objectives through Water Storage and Recovery in Arizona, USA. Speaker/Moderator. International Symposium on Managed Aquifer Recharge (ISMAR9), Mexico City, Mexico.

June 22, 2016, Jean E. McLain. Antibiotic resistance in surface water and groundwater. Briefing. Presidential Advisory Council on Combating Antibiotic Resistance, Public Meeting #3, Washington, DC.

June 30, 2016, Sharon B. Megdal. Groundwater Governance in the USA, with a focus on Arizona Agriculture. Speaker. Toward Sustainable Groundwater in Agriculture - An International Conference Linking Science and Policy, San Francisco, CA.

July 25, 2016 Jean E. McLain. Recycled municipal wastewater and antibiotic resistance: is there a connection? Arizona WateReuse 2016 Symposium, Flagstaff, AZ.

August 10, 2016, Ashley Hullinger. Presentation. Beyond the Mirage screening, GWP Monthly Meeting, Safford, AZ.

August 11, 2016, Jean E. McLain and C. Rock. Source Tracking of Water Contaminants. Presentation. University of Arizona Water In-Service Training Conference, Phoenix, AZ.

August 22, 2016, Jean E. McLain. Metagenomic survey of antibiotic resistance genes in four paired reclaimed and potable water distribution systems. Presentation. 252nd American Chemical Society National Meeting, Philadelphia, PA.

August 31, 2016, Jean E. McLain. How to construct an effective presentation. Lecture. ENVS696: Topics in Soil, Water and Environmental Class, University of Arizona, Tucson, AZ.

September 2, 2016, Grant Weinkam. Safe and Sustainable Wastewater Treatment and Reuse: In Theory and Reality. Presentation. WRRC Brown Bag Seminar, Tucson, AZ.

September 6, 2016, Sharon B. Megdal. “Arizona Water”. Lecture. MNE 422m, Engineering Sustainable Development class, University of Arizona, Tucson, AZ.

September 8, 2016, Sharon B. Megdal. “Arizona Water”. Lecture. ARC561a, Water Efficiency in the Built Environment class, University of Arizona, Tucson, AZ.

September 12, 2016, Sharon B. Megdal, Andrea Gerlak and Ethan Vimont. A Survey of Groundwater Governance and Management Strategies, Challenges, and Opportunities Connected to Water Quality: Preliminary Results. Presentation. Groundwater Protection Council Annual Forum, State Water Sustainability Planning: The Groundwater Connection, Orlando, FL.

September 12, 2016, Jean E. McLain. The critical importance of study design for projects assessing wastewater impacts on resistance. Panelist. 31st Annual WateReuse Symposium, Tampa, FL.

September 13, 2016, Sharon B. Megdal. Using Recharge and Recovery to Meet Water Management Objectives in Arizona. Presentation. Groundwater Protection Council Annual Forum, State Water Sustainability Planning: The Groundwater Connection, Orlando, FL.

September 13, 2016, Jean E. McLain. Session Moderator. Co-Managing Water Quality, 32nd Annual WateReuse Symposium, Tampa, FL.

September 15, 2016, Susanna Eden. Session Moderator. Energy and Water, Arizona Hydrological Society Symposium, Tucson, AZ.

September 16, 2016, Susanna Eden. Are We Ready for Potable Reuse - Issues and Answers. Presentation. Arizona Hydrological Society Symposium, Tucson, AZ.

September 28, 2016, Ashley Hullinger, Bailey Kennett, Grant Weinkam. Workshop participants. Santa Cruz Water Budget and Planning Workshop, Tubac, AZ.

September 28, 2016, Ashley Hullinger, Bailey Kennett, Grant Weinkam. Santa Cruz River Water Budget. Presentation, Tubac, AZ.

October 7, 2016, Sharon B. Megdal. Working together to address Arizona water resource challenges. Presentation. La Posada at Park Centre, Green Valley, AZ.

October 7, 2016, Jean E. McLain and K. Fitzsimmons. Sustainable Seafood Development in Burma. Presentation. 2016 International Burma Studies Conference, Dekalb, IL.

October 7, 2016, Claire L. Zucker, University of Arizona – Where's the Water? Presentation. Environmental Planning Advisory Committee, held at Pima Association of Governments, Tucson, AZ.

October 8, 2016, Ashley Hullinger. Beyond the Mirage. Presentation, Beyond the Mirage Screening, Albuquerque, NM.

October 11, 2016, Jean E. McLain. Recycled municipal wastewater and antibiotic resistance: is there a connection? Featured Speaker. Statewide Water Quality Management Working Group Meeting, Arizona Department of Environmental Quality, Phoenix, AZ.

October 12, 2016, Ashley Hullinger, Bailey Kennett, Grant Weinkam. Beyond the Mirage: Community Discussion. Presentation. Gila Watershed Partnership Monthly Meeting, Safford, AZ.

October 18, 2016, Sharon B. Megdal. U.S. Climate Change Policies. Keynote Presentation. Conference on El mundo después de París: construyendo el futuro, University of Sonora, Hermosillo, Sonora, Mexico.

October 18, 2016, Sharon B. Megdal. Panelist. Water Management and Changing Climate, Conference on El mundo después de París: construyendo el futuro, University of Sonora, Hermosillo, Sonora, Mexico.

October 19, 2016, Ashley Hullinger, Bailey Kennett, Grant Weinkam. Celebrating our Legacy: The Shared History of Cobre Valley in Digital Form. Presentation, Miami, AZ.

October 19, 2016, Ashley Hullinger, Bailey Kennett, Grant Weinkam. Historical Timeline of Water Resources in the Cobre Valley. Presentation. History of Water Resources in the Cobre Valley, Globe, AZ.

October 19, 2016, Susanna Eden. Water Harvesting Assessment Toolbox for the Desert Southwest. Webinar. Desert Landscape Conservation Cooperative Webinar Series.

October 20, 2016, Sharon B. Megdal. Water and the West. Speaker. Living Building Challenge: the Sonoran Collaborative, Tempe, AZ.

October 24, 2016, Sharon B. Megdal. Water Challenges and Solutions in the West. Webinar on Water is for Fighting Over, and other myths about water in the west, hosted by Security and Sustainability Forum and Island Press.

October 25, 2016, Claire Zucker. Sustainability - How are we doing? Lecture. Planning/Geography Course #501.

October 27, 2016, Ashley Hullinger, Elia Tapia. The Desert Flows Database. Poster Presentation, Joint Landscape Conservation Cooperatives - SW Climate Science Center Steering Committee Meeting, Asilomar, CA.

October 27, 2016, Sharon B. Megdal. Addressing Changes in Regional Groundwater Resources: Lessons from the High Plains Aquifer. Keynote Speaker. Groundwater Governance and Management, American Geophysical Institute's 2016 Critical Issues Forum, hosted by the Colorado School of Mines Payne Institute for Earth Resources, Golden, CO.

November 3, 2016, Sharon B. Megdal. Bringing Clarity to a Murky Regulatory Environment on Water. Presentation. Arizona Farm Bureau Annual Meeting, Litchfield Park, AZ.

November 5, 2016, Ashley Hullinger, Grant Weinkam. UA WRRC and the Water RAPIDS program. Tabling Event, Big Green Event, Marana, AZ.

November 5, 2016, Ashley Hullinger, Grant Weinkam. Beyond the Mirage showing and discussion. Presentation. Big Green Event, Marana, AZ.

November 6, 2016, Jean E. McLain. Tour of Biosphere2. Organizer and Lead. 2016 ASA-CSSA-SSSA International Annual Meetings, Phoenix, AZ.

November 9, 2016, Sharon B. Megdal. Desalination in Israel. Presentation. Desalination Committee, Governor's Water Augmentation Council, Phoenix, AZ.

November 9, 2016, Jean E. McLain, A. Pruden, and D.M. Edwards. Antibiotic Resistance of Indicator Bacteria Isolated from Recycled vs. Potable Water Systems. Presentation. 2016 ASA-CSSA-SSSA Annual International Meetings, Phoenix, AZ.

November 14, 2016, Sharon B. Megdal. Regional Approaches to Improving Integrated Surface Water and Groundwater Management. Presentation. AWRA 2016 Annual Conference, Orlando, FL.

November 14, 2016, Ashley Hullinger. Key Ingredients for Building Better Watershed Partnerships. Presentation. AWRA 2016 Annual Conference, Orlando, FL.

November 16, 2016, Ashley Hullinger. Water Banking in Arizona. Presentation. AWRA 2016 Annual Conference, Orlando, FL.

November 23, 2016, Sharon B. Megdal. Panel Moderator and Panelist. High Level Panel: Basin Commissioners and Basin Representatives; Water Security and Sustainable Development for our Common Future,Stakeholder Insights Panel on the Lower Jordan River, EcoPeace Middle East Annual Conference, Dead Sea, Jordan.

November 29, 2016, Sharon B. Megdal. Groundwater Invisibility and Decentralized Governance: The role of science in informing groundwater policy. Keynote Speaker, Session on "Groundwater – How can we manage the commons under uncertainty?" of the Science-Technology Forum of the Budapest Water Summit, Budapest, Hungary.

November 29, 2016, Jacob Petersen-Perlman. Linking Water, Security, and Peace in the Middle East. Brown Bag Lecture. Royal D. Alworth, Jr. Institute for International Studies, University of Minnesota Duluth, Duluth, MN.

December 2, 2016, Sharon B. Megdal. Connecting Israeli Water Management and Technological Innovations to U.S. Water Management. Speaker. JNF Program, Israel H2O, A tour of Israel's Water Solutions, Ramot, Israel.

December 7, 2016, Susanna Eden, Groundwater, Climate, and Stakeholder Engagement (GCASE), Webinar. Desert Landscape Conservation Cooperative Webinar Series.

December 13, 2016, Sharon B. Megdal. Current State and Regional Water Issues. Speaker. Tucson Regional Water Coalition, Tucson, AZ.

January 17, 2017, Grant Weinkam. Introduction to "A Guide for Landowners on the Upper Gila River". Presentation. Rancher Roundup Event with University of Arizona Cooperative Extension, Safford, AZ.

January 23, 2017, Grant Weinkam. Contamination and Remediation: Past, Present, and Future of Soil and Water Pollution in the United States. Presentation. USDA Arid Lands Agricultural Research Center, Maricopa, AZ.

January 24, 2017, Jacob Petersen-Perlman. Hydropolitical Resilience in Transboundary River Basins. Presentation. ENR2 S49, Tucson, AZ.

January 27, 2017, Jean McLain. The realities of recycled water. Is it safe and sustainable? Is it drinkable? Lecture. ENVS596B, Arizona Water Policy class, Tucson, AZ.

February 1, 2017, Jean McLain. How to construct an effective presentation: it's not as hard as you think. Lecture. NVS696a: Topics in Soil, Water and Environmental Science class, University of Arizona, Tucson, AZ.

February 1, 2017, Sharon Megdal. The WRRC and water issues in our region. Presentation. Pima County Development Services Brown Bag, Tucson, AZ.

February 5, 2017, Sharon Megdal. Beyond the Mirage and its Connection to Water Management in Israel. Presentation. Temple Emanu-El Adult Education Academy, Tucson, AZ.

February 15, 2017, Jean McLain, C.M. Rock, and G. Lopez. ddPCR droplet generator, thermocycler, and plate reader. Presentation. Water, Environment, and Energy Solutions Funding for Research and Equipment Meeting, University of Arizona, Tucson, Arizona.

February 15, 2017, Sharon Megdal. Water, Environmental, and Energy Solutions Program (WEES) Funding and Equipment Opportunities. Presentation and moderator.WEES Funding for Research and Equipment Meeting, University of Arizona, Tucson, AZ.

February 15, 2017, Sharon Megdal. The WRRC and water issues in our region. Presentation. Undergraduate Biology Research Program, University of Arizona, Tucson, AZ.

February 17, 2017, Sharon Megdal. The Role of Recharge in Meeting Water Policy Objectives in Arizona USA. Briefing for water officials from Sonora, Mexico, delivered via Go-to-Meeting.

February 24, 2017, Grant Weinkam. Water Quality and Contamination Issues in Human and Environmental Systems. Presentation. Osher Lifelong Learning Institute (OLLI), Green Valley, AZ.

February 28, 2017, Sharon Megdal. Update on NIWR-UCOWR Partnership. Presentation. NIWR Annual Meeting, Washington, DC.

February 28, 2017, Sharon Megdal. Engaging in global water policy dialogues. Presentation. NIWR Annual Meeting, Washington, DC.

February 28, 2017, Sharon Megdal. Briefings. Arizona's federal elected officials and/or staff, 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	11	0	0	0	11
Masters	1	0	0	0	1
Ph.D.	8	0	0	0	8
Post-Doc.	0	0	0	0	0
Total	20	0	0	0	20

Notable Awards and Achievements

Data generated from the 104b Project, Development of Antibiotic Resistance during Wastewater Treatment , contributed to a follow-up funding proposal to the National Science Foundation, “Collaborative Research: Relative Abundance and Diversity of Antibiotic Resistance Genes and Pathogens in Reclaimed Versus Potable Water Distribution Systems”, with PI Amy Pruden from Virginia Tech University, and co-PIs Marc Edwards (Va Tech), David Engelthaler (T-Gen North), and Jean McLain (University of Arizona). The total of the grant is $315,000, and the project period is 8/1/2014 to 7/31/2017. The NSF proposal examines the development of antibiotic resistance in bacteria traveling through water distribution systems. All water samples collected are fully analyzed for microbial diversity, resistance genes, resistant bacteria, and a wide range in bacterial nutrients, including organic carbon. Our justification for characterizing carbon is based on the 104b work, which indicated a trend for increased antibiotic resistance in bacteria exposed long-term to organic carbon compounds.

Itzel Marquez Hernandez (PhD student in CHEE), received a University of Arizona Graduate and Professional Student Council Research Grant ($1,000) in April 2017 to support continuing work related to project 2016AZ552B, Sunlight driven reactive oxygen species production for natural attenuation of wastewater trace organic compounds.

The Beyond the Mirage team from the University of Arizona was acknowledged with the Environmental Education/Communication Award at the Arizona Forward 36th Annual Environmental Excellence Awards dinner, for its work educating and empowering users to act as informed citizens on complex water issues facing our state. This prestigious event recognizes outstanding contributions to the physical environment of local communities. Beyond the Mirage received the top prize in its category, the Crescordia Award. Beyond the Mirage combines user-guided exploration and creativity with true expertise in water issues of Arizona, making education of this topic accessible to Arizonans of all ages.

Publications from Prior Years

1. 2011AZ436B ("Hydrology Versus Ecology: The Effectiveness of Constructed Wetlands for Wastewater Treatment in a Semi-arid Climate") - Articles in Refereed Scientific Journals - Weller, N.A., D.L Childers, L. Turnbull, and R. Upham, 2016. Aridland constructed treatment wetlands I: Macrophyte productivity, community composition, and nitrogen uptake. Ecol. Engineering 97:649-657.
2. 2011AZ436B ("Hydrology Versus Ecology: The Effectiveness of Constructed Wetlands for Wastewater Treatment in a Semi-arid Climate") - Articles in Refereed Scientific Journals - Sanchez, C.A., D.L Childers, L. Turnbull, R. Upham, and N.A. Weller, 2016. Aridland constructed treatment wetlands II: Macrophyte-driven control of the wetland water budget makes the system more efficient than expected. Ecol. Engineering 97:658-665.
3. 2011AZ436B ("Hydrology Versus Ecology: The Effectiveness of Constructed Wetlands for Wastewater Treatment in a Semi-arid Climate") - Articles in Refereed Scientific Journals - Bois, P., D.L. Childers, T. Corlouer, A. Massicot, and C.A. Sanchez, 2017. Confirming a plant-mediated “biological tide” in an aridland constructed treatment wetland. Ecosphere. 8(3):1-16.
4. 2011AZ436B ("Hydrology Versus Ecology: The Effectiveness of Constructed Wetlands for Wastewater Treatment in a Semi-arid Climate") - Dissertations - Ramos, J. 2017. Methane and nitrous oxide fluxes from water, plants, and soils of a constructed treatment wetland in Phoenix AZ. Ph.D. Dissertation, Arizona State University.
5. 2011AZ450B ("Iodinated Disinfection By-product Formation from Water Reuse Practices") - Other Publications - Durazo, A and S. A. Snyder (2014) An Examination of the Presence, Formation, and Transformation of Volatile Halogenated Organic Species in Wastewater Extracts Using GC-ICP-MS, Application Note, April 17, 2014, 5991-4398EN, Agilent Technologies, Inc.
6. 2013AZ517B ("Extraction Methods for Engineered Nanoparticles From Aqueous Environmental Samples") - Articles in Refereed Scientific Journals - Yang, Y., Reed, R., Schoepf, J., Hristovski, K., Herckes, P., Westerhoff, P. “Prospecting nanomaterials in aqueous environments by cloud-point extraction coupled with transmission electron microscopy ”, Science of the Total Environment, 584-585:515-522 (2017)
7. 2013AZ517B ("Extraction Methods for Engineered Nanoparticles From Aqueous Environmental Samples") - Articles in Refereed Scientific Journals - Zhang, T., L. Cheng, L. Ma, F. Meng, R.G. Arnold, A.E. Sáez, Modeling The Oxidation of Phenolic Compounds by Hydrogen Peroxide Photolysis, Chemosphere, 161, 349-357 (2016).
8. 2013AZ516B ("Sequential advanced oxidation and soil-aquifer treatment for management of trace organics in treated wastewater") - Articles in Refereed Scientific Journals - Cheng, L., T. Zhang, H. Vo, D. Diaz, D. Quanrud, R.G. Arnold, A.E. Sáez, Effectiveness of Engineered and Natural Wastewater Treatment Processes for Water Reuse, Journal of Environmental Engineering, 143, 1-18 (2017).
9. 2013AZ516B ("Sequential advanced oxidation and soil-aquifer treatment for management of trace organics in treated wastewater") - Dissertations - Long Cheng, Effectiveness of engineered and natural wastewater treatment processes for the removal of trace organics in water reuse, PhD Dissertation, Chemical Engineering, The University of Arizona, May 2017.
10. 2013AZ516B ("Sequential advanced oxidation and soil-aquifer treatment for management of trace organics in treated wastewater") - Dissertations - Tianqi Zhang, Modeling photolytic advanced oxidation processes for the removal of trace organic contaminants, PhD Dissertation, Chemical Engineering, The University of Arizona, May 2017.
11. 2010AZ395B ("Bioremediation of Uranium Plumes with Nano-Scale Zero Valent Iron") - Articles in Refereed Scientific Journals - Luna-Velasco A, Sierra-Alvarez R, Castro B, Field JA. 2010. Removal of nitrate and hexavalent uranium from groundwater by sequential treatment in bioreactors packed with elemental sulfur and zero-valent iron. Biotechnol Bioeng 107:933-942

12. 2012AZ476B ("Fate of Emerging Nanoparticle Contaminants during Aquifer Recharge with Treated Wastewater") - Dissertations - Zeng Chao. 2016. Fate and toxicity of III-V materials in the presence of inorganic oxide nanoparticles. PhD Dissertation, Department of Chemical and Environmental Engineering, University of Arizona, Tucson, AZ.
13. 2010AZ395B ("Bioremediation of Uranium Plumes with Nano-Scale Zero Valent Iron") - Dissertations - Tapia Rodriguez, Aida. 2011. Anaerobic Bioremediation of Hexavalent Uranium in Groundwater. PhD Dissertation. Department of Chemical and Environmental Engineering, University of Arizona, Tucson, AZ. 273. http://hdl.handle.net/10150/202754
14. 2014AZ529B ("Improving Integrated Surface Water and Groundwater Management in the United States: Case Studies of Innovative Groundwater Governance Approaches") - Articles in Refereed Scientific Journals - Megdal, S.B., Gerlak, A.K., Huang, L.-Y., Delano, N., Varady, G., and Petersen-Perlman, J.D. (2017) Innovative Approaches to Collaborative Groundwater Governance in the United States: Case Studies from Three High-growth Regions in the Sun Belt, Environmental Management 59 (5), pp. 718-735. DOI: 10.1007/s00267-017-0830-7. http://link.springer.com/article/10.1007/s00267-017-0830-7.