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Clean Water, Clean Life: Promoting Healthier, Accessible Water in Rural Appalachia

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Abstract: In the rural Appalachian region of the United States, thousands of residents struggle with issues of water quality and accessibility. Vulnerabilities of poverty, isolation, and rough geographical terrain complicate life for Appalachians who need access to adequate water supply and septic systems. In 2013, an inter-professional team of nursing, architecture, engineering, and law enforcement faculty and students developed a water-focused collaboration with community members in southeastern Kentucky. Greater accessibility to clean drinking water is a critical need in the area. Collaborative community engagement yielded effective and sustainable interventions. Inter-professional teams completed N=30 comprehensive home assessments examining factors such as water source utilization, septic system management, health status, and disaster preparedness. While the majority of homes evaluated had functional water supply and septic systems, the team observed straight piping as a means of waste disposal for several homes. Homeowners who did not have a residential water supply identified common gathering places where they typically obtain drinking water. To expand environmental assessment, the team collected water samples at 16 different sites where residents obtain drinking water or use it for recreational purposes. Testing of collected samples revealed 15 of 16 sites contained fecal coliforms, *Escherichia coli*, or both. Because of the findings, the team and community key informants collaboratively developed interventions, such as relaying findings to community leaders, developing a WASH (Water, Sanitation, and Hygiene)-related education program, and improving access to clean, safe water through the design and construction of a water kiosk. Outcome of interventions included greater awareness and knowledge of WASH related topics, improved access to clean water sources, and sustainable solutions to enhance overall quality of life, health and well-being.

Keywords: *Appalachia, community-based inter-professional research, environment, health*

Local environment, the air we breathe, and the water we drink, can enhance or harm the health risk and disease burden of a community. Humans are in constant interaction with their physical and natural surroundings; therefore, the quality of environmental conditions can have a significant impact on public health status. According to Healthy People 2020 (2016), environmental quality is a leading health indicator and considered a national priority. Healthcare providers typically treat symptoms of gastrointestinal illnesses, but rarely assess for compromised environmental sources that contribute to bacterial exposure and contamination.

Water quality is a primary concern for many residents of rural isolated communities, particularly in Appalachia, where critical infrastructure for water utilities is minimal to non-existent. Piping municipal water to neighborhoods in remote mountain hollows is expensive due to difficult terrain or geographic distance between hollow communities. Impoverished residents may lack sufficient funds to maintain existing infrastructure or even install indoor plumbing. Residents who lack access to municipal water in their homes rely on alternative sources for water, such as wells, natural springs, or expensive bottled water from a remote convenience store. Another unfortunate

alternative is to drink sugary substitutes such as sodas or energy drinks, leading to further financial and medical consequences.

Several sampling events took place from 2012-2014 in the Red Bird River Watershed, including Clay, Leslie, and Bell County, KY. Samples from as many as 64% of testing sites exceeded the Environmental Protection Agency (EPA) threshold for *Escherichia coli* (*E.coli*), a contaminant known to cause mild to severe human illness (Red Bird River Watershed Plan [RBRWP] 2014). Microbial source tracking is necessary to determine actual causality; however, invasion of human waste into surface and/or groundwater is the presumed issue. Poor sanitation practices can, unfortunately, release contaminants into nearby watersheds that can lead to adverse health when humans contact affected streams. This makes the water unsafe for recreational contact like swimming/fishing; and especially for use as a potable water source.

E.coli contamination, primarily spread through human waste, is prevalent in rural Appalachia regions with inadequate sewage maintenance. Residents who live in densely populated areas have limited availability of property for installment of adequate septic systems and drainage beds. Therefore, straight piping sewage onto ground surface or into streams is a common means of waste disposal. Fecal pollution results in elevated *E. coli* levels in drinking water or recreational water sources (CDC 2015). Consuming *E. coli* bacteria can cause abdominal cramping, diarrhea, dehydration, and even death, if not treated (CDC 2015). Therefore, the cost to human health is high.

Sources of Drinking Water

According to the Centers for Disease Control (CDC), public water systems and private wells are two of the most common sources of drinking water in the United States. Public water systems supply over 286 million Americans with drinking water on a regular basis (CDC 2014). Consumed drinking water is from both surface and ground sources. Surface water consists of open-air sources, such as rivers and streams. Ground water includes sources that are primarily underground, and not open to the atmosphere (EPA 2015c). The Environmental Protection Agency (EPA) regulates public water systems with strict guidelines and testing (EPA 2015b). EPA guidelines, however, do not apply to private water systems, such as residential ground water wells that function as a primary drinking water supply. Homeowners are responsible for maintenance and testing of their private wells (CDC 2014).

Federal Guidelines

The federal government determines requirements for water quality, namely through the Clean Water Act of 1972, which established standards for quality, regulations for pollutants, instituted authority to set pollution standards and develop programs, and allowed grant funding for sewage treatment plant construction (EPA 2015e). States and other territories establish their specific policies, but they are subject to EPA approval. The EPA standards consist of four main parts: 1) designated uses of water; 2) criteria for protection; 3) anti-degradation requirements; and 4) general policies. Designated uses of water sources include wildlife, recreation, and drinking water (EPA 2015a).

Impact on the Ecosystem

The amount of pollutants in freshwater sources, including microorganisms, heavy metals, and other chemicals, has risen since the 1970s. Land development and other changes in land use have altered the flow of both surface and ground water. Water management is a cooperative effort, as everything occurring at one site in the system affects the environment downstream (World Health Organization 2016). Low levels of pH, high levels of fecal coliform, low dissolved oxygen, and high specific conductivity are indicators of poor water quality, which could directly affect aquatic life and ecology (Boettner et al. 2014).

Point and nonpoint sources comprise pollution. Point pollution comes from a single source, and includes industrial wastes, treatment plants, pipes, and drains. Nonpoint sources can be difficult to identify due to the resultant diffuse pollution. These sources include runoff from rain and agricultural use (EPA 2012). Criteria for protection include both numeric and narrative standards, ranging from allowable levels of pollutants to descriptions of ideal water sources.

Anti-degradation requirements help protect and improve upon the current state of a water source. General policies include both federal regulations and state-level guidelines (EPA 2015a). Sources of *E. coli* pollution include water treatment plants, septic systems, agricultural practices, upstream municipal sewer systems, and wildlife (Jenkins et al. 2005). Human activity is responsible for almost all sources of ground water contamination (EPA 2015d). Many states, however, do not have policies that consider sources of both human and wildlife contamination (Gostin et al. 2000). Interventions to aid in water quality improvement include the protection and treatment of water sources and maintenance of water distribution systems (Plummer and Long 2007).

Impact on Human Health

Consumption of contaminated water can lead to a wide variety of illnesses including cholera, hepatitis A, typhoid, and arsenic poisoning (Barbour et al. 2009) from bacterial and viral pathogens, pathogenic protozoa, and other water-borne pathogens (Legall 2005). Over 5 million people are estimated to die each year from water-borne disease resulting in diarrhea and fluid/electrolyte loss (Legall 2005). Evidence suggests diseases spread through increased exposure to human and animal waste near water sources (Sorenson, Morssink, and Campos 2011).

E. coli is a significant water quality indicator. The bacteria can survive in drinking water for 4-12 weeks depending on the environment (Edberg et al. 2000). In humans, *E. coli* infections can lead to colitis, renal disease, and death (Ram, Vajpayee, and Shanker 2008). Typically, symptoms appear within 2-4 days, but could still appear one week after exposure, with recovery usually occurring in 5-10 days (Connecticut Department of Public Health, n.d.). Potential sources of *E. coli* contamination include agricultural runoff, wildlife, waste treatment plants, and septic systems (Lewis 2016).

Access to Clean Water

VanDerslice (2011) investigated the relationship between water access and quality and the socioeconomic and demographic characteristics in the United States. He found that many low income and minority communities did not have access to piped water. It is difficult to determine if there is a statistically significant relationship between income and access to water because many water systems do not collect demographic information from customers (VanDerslice 2011). However, this would still not include those who rely on private systems for drinking water. While a 2007 survey estimated that 0.5-1% of U.S. households lacked access to piped water, in some low income and minority areas, entire communities did not have piped water. In California, counties with a high percentage of minorities had a greater percentage of drinking water violations, 42% compared to 16% (VanDerslice 2011).

Many people in rural communities rely on private wells and/or natural springs for drinking water supply. Periodic testing for contaminants should be standard practice; however, the EPA does not regulate private wells and natural springs. The responsibility for scheduled testing falls to the homeowners, which could be a costly deterrent for low-income residents. Many people in these areas lack the means for regular water testing and may be consuming unsafe water. Boiling does not remove all harmful substances from the water, and contaminants may remain present in wells for years without the owner's knowledge (Shiber 2005). An unfortunate result is that privately owned wells and natural springs can be common sources of gastrointestinal illness outbreaks in the United States (Raina et al. 1999).

McSpirit and Reid (2011) studied the use of bottled water in areas with poor water access and quality, such as Appalachia. Residents who perceived the quality of tap water as poor purchased more bottled water regardless of socioeconomic level, leading the researchers to conclude that while buying bottled water may be a financial hardship, many people considered it a necessity and factored it into monthly expenses. Thus, money earmarked for water may prevent people from buying other nutritious food. Residents' trust in their water treatment facility was associated with their decision to purchase bottled water. Those who trusted the facility were less likely to use bottled water, while those who did not have a high level of trust were more likely to purchase bottled water (McSpirit and Reid 2011).

Sanitation

Inadequate waste management is an additional contributor to poor water quality. Rural Appalachian areas lack access to waste water systems and septic tanks due to lack of adequate land space, steep rough terrain, and poor soil conditions. As a result, straight piping is common, which further deteriorates the water quality (Cook et al. 2015). Some states are trying to help residents eliminate the use of straight piping. North Carolina established a project that would provide financial assistance to help citizens install proper septic systems. Before initiating the program, the researchers collected data, demonstrating over 17% of the homes surveyed used straight piping to eliminate waste from the home. Initially, the program's goal was providing funding for 130 households to replace their straight piping, but follow-up data on subsequent homes is not available (Baldwin n.d.).

Eastern Kentucky Personal Responsibility in a Desirable Environment (PRIDE) is a program established in 1977 that focuses on environmental protection, as well as on community education and resources. PRIDE provides grants to citizens for a variety of environmental projects, including the installation of septic systems. Requirements include proof of income (must be under 55% of federal poverty guideline), deed of property ownership, and electric bill (Eastern Kentucky PRIDE 2016). Septic system installation can range from $6,000 to $15,000, depending on soil, topography, and other site conditions. Land with a significant slope and wet or wooded areas all increase the price of installation (Kentucky Septic Service 2015) making it financially impossible for some without the aid of grant programs.

The rural community in southeastern Kentucky expressed a clarion call for help to address the need for improving access to clean water. In response, a university based inter-professional team, with expertise in nursing, architecture, civil and environmental engineering, and law enforcement began a synergistic process of knowledge sharing and joint planning to identify and address issues impacting community health and disaster readiness. The university team listened to the needs of the community and incorporated community input throughout a collaborative engagement process to design and implement innovative solutions. The mantra, Clean Water/Clean Life, became a shared value. As a result, a vision for creating a healthier, equitable community has become a reality.

Methods

Community-Academic Partnership

The *Appalachia Community Health & Disaster Readiness Project*, funded in July 2013 by the U.S. Department of Health and Human Services, Health Resources and Services Administration (HRSA grant #UD7HP26205-01-00), is an inter-professional collaborative practice (IPCP) effort to identify, evaluate, and address the health, safety, and disaster readiness needs of rural Appalachian communities in southeastern Kentucky. The IPCP team included professionals from the disciplines of nursing, architecture, engineering, and law enforcement innovation associated with the University of Tennessee. Site coordinators from Red Bird Mission (RBM), a local faith-based organization, and the local emergency management service were included on the team as well.

Community Engagement

A novel process of community engagement was necessary to understand contextual issues surrounding water quality. The IPCP team used an integrated, social-ecological approach to develop a synergistic partnership with the community. An overarching goal of the IPCP team partnership with the community was to share knowledge of problems affecting the health and readiness of the community. The socio-ecological systems approach considers factors such as biological, social, and environmental determinants of health (Wilcox and Colwell 2005). Site coordinators at RBM and members of the local community first highlighted the urgency of getting access to clean water due to lack of piped water supply and potentially contaminated common water sources, such as wells or natural springs. Further assessments revealed factors contributing to disease, such as poor water quality caused by ground and soil contamination. Environmental factors leading to the root cause of illness was the necessary impetus to align culturally driven and appropriate interventions.

Engagement of stakeholders was crucial to understanding and improving health outcomes at the community level. In this model of interaction depicted in Figure 1, community was central. Community stakeholders and residents were experts in their own history, culture, community challenges and strengths; therefore, joint meetings and listening sessions provided an opportunity for the IPCP team to understand historical solutions to community problems attempted in the past, and to discuss priorities and collaboratively develop strategies to address pressing community issues. Site coordinators identified key stakeholders who had an interest and responsibility in addressing community concerns. IPCP team members joined representatives from Kentucky Waterways Alliance to participate in Red Bird River Watershed planning meetings. In addition, the team met with individual local leaders (County Judge Executive, County Attorney, Director of Emergency Management Services, County Directors of Water and Utilities for both Clay and Leslie Counties). Meetings with state and federal leaders (U.S. Forestry Service, Area Director of the U.S. Department of Agriculture [USDA] Office of Rural Development, and Director for Office of Rural Health) permitted discussion of concerns. Each encounter with stakeholders provided an opportunity to share knowledge, establish culturally driven goals, and determine available resources to assist with implementing active solutions.

Residents of the community were also prime stakeholders for water quality issues that were affecting their health, well-being, and disaster readiness. The IPCP team used their specialized knowledge and skill to engage with each other, as well as the community, to share knowledge and identify and solve critical problems that were compromising the health of the community. Community voice was vital throughout the process. Residents needed to know that the IPCP team listened and truly heard them, and appreciated health as a shared value. Essential priorities were to: 1) engage community stakeholders to determine needs; 2) build trust between academic-community partners; and 3) develop greater cultural awareness of communities in rural Appalachia.

Community-Based Assessments

Community-based assessments of community neighborhoods and critical infrastructure helped to identify target neighborhoods, individual



Figure 1. Inter-Professional Collaborative Practice (IPCP) Project Model for improving wellness and disaster readiness through community engagement and knowledge-sharing. Image copyright [2013] by M. McArthur, S. Speraw, and J. Darragh.

households, and community/public facilities that needed more focused evaluation or intervention. As a result, the team was able to prioritize critical needs and develop strategies for intervention to create sustainable solutions to the challenges facing the rural Appalachia community. Community-based assessments included *community health and disaster readiness needs assessments*, and specific environmental evaluation requiring *water sampling*, *water testing, and a water knowledge survey*.

Community Health and Disaster Readiness Needs Assessment. Upon approval of the Institutional Review Board at the University of Tennessee, the IPCP team evaluated structural soundness of homes, environmental safety, and vulnerability to health and security threats for individual community residents. Data collection included: 1) face-to-face interviews with individual residents, small family groups, or focus groups; 2) surveys using A *Health and Emergency Preparedness Assessment Survey* tool, an assessment tool adapted from the Center for Disease Control and Prevention (CDC) *Community Assessment for Public Health Emergency Response (CASPER) Toolkit* (2012); and 3) topographical, environmental, and architectural observations documented on an observation tool developed by the IPCP team.

In the spring and fall of 2014, community partners led the IPCP team to specific areas in the community to broaden cultural awareness of community need. Inter-professional teams of nursing and architecture students and faculty conducted 30 individual health, home, and environmental assessments. Survey data included demographic information, home ownership, number of people living in the home, sources of worry, presence of health conditions, type of home structure, and length of time in the home. Specific questions focused on resident access to water (source and amount consumed) and source of power, heat, and air. Assessment also included presence or absence of indoor toilets, septic infrastructure, and foundation and stability concerns around the home. Significant flooding in 2013 devastated the area; therefore, questions were intentionally designed to assess previous and current water/flood damage to the home, as well as the presence of mold.

Assessments revealed that community members who did not have access to water from a municipal water supply used other sources for drinking water, such as natural springs, wells, or simply a pipe extending from an embankment with flowing surface water. Residents expressed concerns about potential contamination of alternative water sources due to pollutants from mining practices, failing septic systems, and/or inappropriate practices of straight piping waste onto the ground or into nearby streams. Community members conveyed suspicions that the same impurities compromised public areas used for recreational purposes such as swimming, fishing, or performing local baptisms.

Water Sampling. An investigation of local water quality was necessary to evaluate environmental safety. Thus, a team member who is an environmental engineer with expertise in water quality, facilitated training on proper techniques to collect and store water samples. Training included information about the collection kits, proper fill levels for various containers, and paperwork to maintain chain of custody, as well as proper labelling of specimens. After receiving training, nursing students and faculty divided into three groups to collect water samples from specific locations residents identified as drinking water sources or recreational areas.

The team collected water samples according to proper procedures and guidelines. Sample collectors labeled, sealed and documented to assure chain of custody and promptly delivered them to University of Tennessee engineering faculty on the same day of collection. Water samples were tested for standard parameters including: pH, conductivity, sulfate (SO_4^{2-}), nitrate (NO_3^-), ammonium (NH_4^+), orthophosphate (PO_4^{3-}), chloride (Cl^-), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}). Bacterial tests included fecal coliform and *Escherichia coli*. Due to local mining practices, analyses also included testing for the presence of heavy metals, including aluminum (Al), copper (Cu), iron (Fe), manganese (Mn), silicon (Si), zinc (Zn), arsenic (As), and mercury (Hg).

Water Testing. At the University of Tennessee Water Quality Laboratory, samples were analyzed for pH and specific conductance (μS/cm) using

a ManTech™ autotitrator. Major base cations and trace metals (Ca^{2+}, Na^{+}, K^{+}, Mg^{2+}, Al, Cu, Fe, Mn, Si, Zn) were analyzed using a Thermo-Electron™ inductively coupled plasma optical emissions spectrometer (ICP-OES). Major anions (SO_4^{2-}, NO_3^{-}, Cl^{-}) and NH_4^{+} were measured using a Dionex™ ion chromatograph (IC). All laboratory test procedures were conducted in accordance with standard methods (Table 1). A separate set of grab samples were collected for As and Hg and sent to Test America, Inc. in Nashville, Tennessee, where standard EPA methods were used. Bacterial tests were conducted at the University of Tennessee using the IDEXX Colilert™ method.

State of Kentucky and EPA water quality standards were used to assess the water analysis results; they were the warm water aquatic habitat, primary contact recreational waters (fishing and swimming), and drinking water limits (Table 2). EPA (1986) criteria for fecal coliform were promulgated as 200/100ml, although *E.coli* has replaced most recreational standards used by state environmental regulatory agencies. A recent U.S. EPA rule on elevated specific conductance from coal mining activities has been proposed with a limit in the range of 300 to 500 µS/cm, as some evidence suggests levels exceeding this range may harm aquatic life.

Water Knowledge Survey. In addition to water testing, the IPCP team sought to understand the community's knowledge of WASH-related topics such as water collection, purification, storage, the protection of water from contamination to prevent water-borne disease, hygiene, hand-washing, and health benefits of water consumption. Community knowledge was assessed through baseline data surveying and focus group discussion. In collaboration with community leaders, the IPCP team developed a water knowledge survey to evaluate effectiveness of a clean water education program implemented in a variety of different venues throughout the community.

Results

Qualitative Insight

At the very first focus group session, community stakeholders expressed an urgent need to address the lack of clean water accessibility. Chronic poverty, isolation, historical neglect, and systemic vulnerability have impeded very basic needs, such as access to potable water. Piped water supply had been limited and inaccessible to hollow enclaves within the community. Sparse population density and rugged terrain make the cost of providing basic services prohibitive. Those who have no access to tap water in the home use local wells and springs, which are often contaminated because of inadequate human waste management throughout the county. Due to geography and poverty, raw sewage was often straight piped under foundations (contaminating ground water) and into waterways, contributing to widespread pollution. Yet, this was the only water available to local residents, since there is limited or no municipal supply to each individual home.

Discussions with local water district managers and community leaders confirmed that there were

Table 1. Analytical procedures performed for chemical analyses, and cited methodologies.

Analysis	Procedure	Equipment	Method
pH	Potentiometric	PC-Titration Plus™	USEPA Method 150.1
Conductivity	Potentiometric	PC-Titration Plus™	USEPA Method 120.1
Anions	Ion Chromatography	Dionex™ IC	AWWA Standard Method 4110 (Easton *et al.* 2005)
Cations, Metals	Inductively Coupled Plasma Spectrometry	Thermo-Elemental Ins Intrepid II™ ICP	USEPA Method 6010B & 6010C
Fecal coliform, *Escherichia coli*	Enzyme Substrate 24-hr presence/absence	Idexx Colilert Quanti-Tray	AWWA Method 9223B

Table 2. Summary of water quality standards for the state of Kentucky, Division of Water (KDOW) and the USEPA.

Parameter	Standard (Source)	Standard Type	KDOW Benchmark
Temperature	31.7°C (KDOW)	WAH*	
pH	>6.0 to <9.0 (KDOW)	WAH	
Dissolved Oxygen	≤4.0 mg/L (KDOW)	WAH	
Specific Conductance	<119 µS/cm (KDOW)	WAH	X
Sulfate	<19.5 mg/L (KDOW)	WAH	X
Nitrate-N	<0.16 mg/L (KDOW)	WAH	X
Total P	<0.02 mg/L (KDOW)	WAH	X
Alkalinity (as $CaCO_3$)	12-54 mg/L (KDOW)	WAH	X
Total Dissolved Solids	<500 mg/L (US EPA)	Drinking**	
Total Suspended Solids	No numeric standard		
Hardness (as $CaCO_3$)	No numeric standard		
Total Aluminum	0.05-0.20 mg/L (US EPA)	Drinking	
Total Calcium	0.005 mg/L (KDOW)	Drinking	
Total Cadmium	<0.0005 mg/L (KDOW)	Drinking	
Total Iron	<0.30 mg/L (KDOW & US EPA)	Drinking	
Total Magnesium	No numeric standard		
Total Manganese	<0.05 mg/L (US EPA)	Drinking	
Total Lead	<0.015 mg/L (US EPA)	Drinking	
Escherichia coli	<240 colonies per unit (KDOW)	Primary contact recreational waters	

* WAH = State of Kentucky, Division of Water, Water Quality Standards for the Designated Use: Warm Water Aquatic Habitat.
** Drinking = Drinking water regulations for either the USEPA National Secondary Drinking Water Regulations or the State of Kentucky (KDOW) Drinking Water Standards.

few plans to run either water lines or sewers to the remote hollows. Extensive and expensive barriers prevented access to city water, even in areas where city water lines are present. Municipal water lines exist along main roads, but the homeowners are responsible for a water meter fee in the realm of $600 and for paying for installation of water lines over 1000 feet away from the main roads, across bridges, streams, and rivers. The homeowners are also required to locate a contractor and pay for installation of the lines, fittings, and connection to the home. Families rarely have disposable income to afford this. Consequently, residents live with the financial and medical sequelae of drinking contaminated water, using water substitutes (such as soda or sweetened drinks), purchasing expensive bottled water, and living in close proximity to raw sewage. Socio-economic disparity, environmental contamination, inaccessible resources, and inequity are factors influencing health and quality of life for community residents.

Quantitative Measures

Survey Assessments. Descriptive data collected from the *Health and Emergency Preparedness Assessment Survey* tool with sample size (N=30) revealed 50% of residents had lived in their home more than 30 years. Thirty-six percent used wells as the primary source for drinking water and 57% used public municipal water. The remaining 7% used bottled water for drinking purposes. Over 50% of residents complained their water "tasted bad

like chlorine." Five out of eleven residents (45%) who used wells for drinking water revealed their well water had not been tested and certified as safe. Eighty-three percent of residents had a flushable working indoor toilet and 17% did not; therefore, use of an outdoor toilet was required. All residents who had indoor toilets indicated sewage disposals were via septic system. Flooding in spring 2013 caused damage to some septic systems that needed repair or replacement. The IPCP team directly observed straight piping into a local stream on two occasions, but residents did not self-report. During the data collection period, Red Bird Mission, Inc. generated a list of over 200 community residents needing septic tank installation or repair due to lack of or failing systems.

Water Testing. A total of 16 grab samples were collected on October 20, 2014 at locations numbered 1 through 18 (no samples were provided with numbers 10 and 12). This was a snap shot of sampling. There were no sampling criteria for a particular date to obtain information. The objective was to gather baseflow water quality information. All grab samples were collected in LDPE plastic bottles that had been triple rinsed in the lab with de-ionized water. All sample locations except Site 18 at Red Bird Mission were surface water. Site 18 at Red Bird Mission was the only drinking water sample. Figure 2 depicts water sample collection sites.

Table 3 summarizes results of chemical parameter analysis from the October 20, 2014 sampling efforts. Recreational water pH limits were exceeded at one site, Oneida junction, with a pH of 5.92 (range required is between 6 and 9). No other chemical parameter exceedances were identified. Nine sites had specific conductance that exceeded 300 µS/cm and of the nine, four of those exceeded 500 µS/cm. Two samples from the Chas Coal site were found to be 985 and 1072 µS/cm, which is considered very high for water approaching brackish conditions. Site 18 at the Red Bird Mission was 566 µS/cm, which was a drinking water source. The team recommended that this water be tested again. When conductivity is high, SO_4^{2-} concentrations may be elevated and the results indicate this may be the case because other contributing ions such as Ca^{2+} and Mg^{2+} were much lower comparatively. In addition to SO_4^{2-}, Na^+ and Cl^- were generally elevated. SO_4^{2-}, Na^+, and Cl^- have no EPA limits for recreational use.

Results of bacterial parameter analysis of October 20, 2014 sampling efforts are summarized in Table 4. Recreation limits were exceeded for *E. coli* at four sites based on a threshold of 126/100ml (geometric mean); they were Granny's Branch, Jacks Creek, Jesse's Fork, and Montana

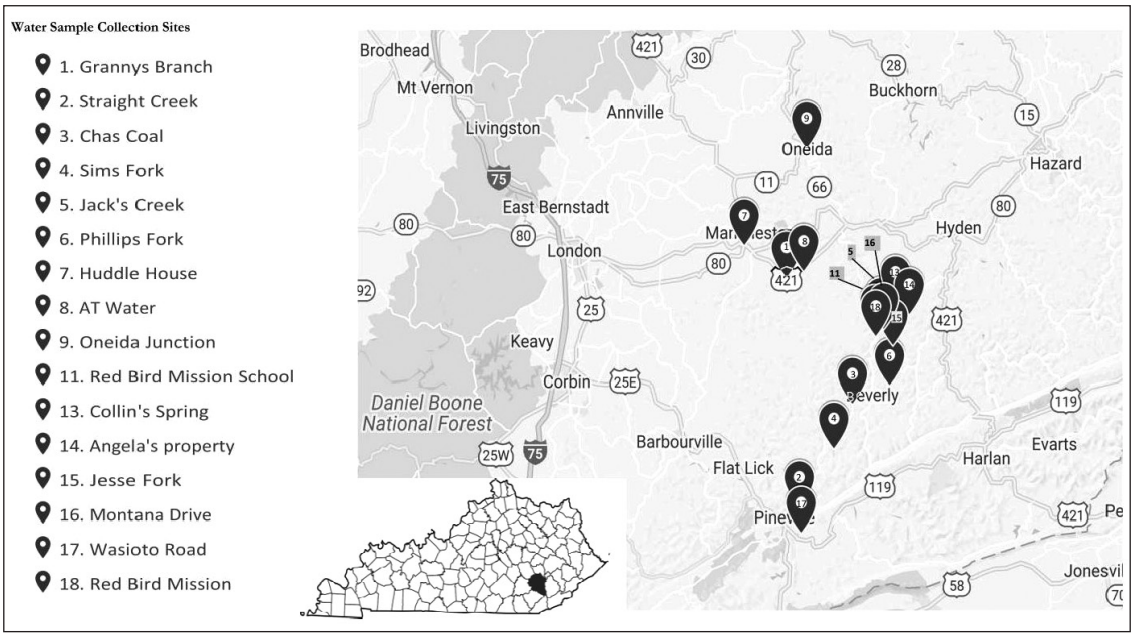


Figure 2. Water sample collection sites.

Table 3. Water quality analyses results from the surface waters in Clay County, Kentucky, and one drinking water sample at Red Bird Mission. Samples taken on October 20, 2014.

	Sample Locations (No samples at #10 & #12)																
Chemical Parameter	1. Granny's Branch	2. Straight Creek	3. Chas Coal (Sample 1)	3. Chas Coal (Sample 2)	4. Sims Fork	5. Jacks Creek	6. Phillips Fork	7. Manchester Huddle	8. AT Water	9. Oneida Junction	11. Red Bird School	13. Collin's Spring	14. Angela's Property	15. Jesse's Fork	16. Montana Drive	17. Wasioto Road	18. Red Bird Mission
pH	7.37	6.84	8.06	8.14	6.80	7.17	7.61	6.81	7.03	5.92	6.56	6.64	6.40	6.88	7.23	7.13	7.01
Conductivity	145	44	985	1072	172	310	772	-	271	380	490	49	115	344	307	24	566
Sulfate	16.8	8.4	257.7	447.3	40.5	92.0	292.8	207.5	14.8	153.4	180.2	10.1	15.2	98.2	85.5	6.2	158.8
Nitrate	3.1	2.0	17.7	17.8	2.3	4.8	*	3.4	*	5.9	*	*	*	2.4	2.2	*	2.5
Chloride	3.1	1.5	20.0	21.0	2.4	3.4	1.7	27.6	4.8	2.2	2.5	1.3	1.5	2.4	2.9	1.5	16.3
Ammonium	*	*	0.6	1.0	*	*	*	*	*	*	*	*	*	*	*	*	*
Phosphate	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Sodium	5.6	1.6	327.0	292.0	8.2	27.0	111.0	60.3	51.1	52.7	33.1	2.0	2.8	65.3	41.7	0.9	63.3
Potassium	3.0	1.8	11.8	11.5	2.2	3.9	6.4	9.2	2.7	4.9	2.4	1.1	2.9	4.2	3.4	1.6	6.4
Magnesium	6.5	2.6	11.9	-	11.3	18.8	39.3	47.9	9.3	16.7	24.6	2.8	8.8	10.5	10.0	1.9	33.4
Calcium	30.3	5.2	79.9	90.7	20.5	44.7	82.1	85.3	27.7	31.2	67.8	4.6	14.7	36.9	39.0	1.1	72.5
Silica	6.7	4.5	*	*	5.6	*	*	*	3.6	*	*	3.4	8.2	*	*	4.4	*
Aluminum	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Copper	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Iron	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Manganese	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Zinc	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Mercury +	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Arsenic +	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Note: + = parameters conducted by Test America; * = < instrument detection limit; - = abnormal instrument output.
Units: pH in standard pH units; conductivity in µS/cm; all other chemical parameters in mg/L.

Table 4. Water quality analyses (bacterial parameters) results from the surface waters in Clay County, Kentucky, and one drinking water sample at Red Bird Mission. Samples taken on October 20, 2014.

Bacterial Parameter	1. Granny's Branch	2. Straight Creek	3. Chas Coal (Sample 1)	3. Chas Coal (Sample 2)	4. Sims Fork	5. Jacks Creek	6. Phillips Fork	7. Manchester Huddle	8. AT Water	9. Oneida Junction	11. Red Bird School	13. Collin's Spring	14. Angela's Property	15. Jesse's Fork	16. Montana Drive	17. Wasioto Road	18. Red Bird Mission
	----------Sample Locations (No samples at #10 & #12)----------																
Fecal Coliform	+	894	805	x	241	+	395	219	116	6	805	601	326	660	+	109	0
Escherichia coli	308	60	109	x	4	136	3	3	0	0	98	7	2	149	263	5	0

+ = parameters above detection estimates; 0 = method detection limit; x = no sample.
Units: MPN (per 100 ml).

Drive. Note, the limit is for a geometric mean, and these values represent only one sample, so findings should be viewed as an indicator and potential location of concern only. EPA (1986) criteria for fecal coliform were promulgated as 200/100ml, although *E.coli* has replaced most recreational standards used by state environmental regulatory agencies. Nonetheless, 11 sites were found with fecal coliform levels above 200/100ml.

Water quality results were also compared with drinking water standards. No exceedances occurred with dissolved metals, e.g., Cu, Zn, As, and Hg. The only chemical parameter exceedance was at the Chas Coal site for NO_3^-, in which the limit is 10 mg/L for adults and 1 mg/L for infants. NO_3^- concentrations were found to be high from two samples taken at this site, consisting of 17.7 and 17.8 mg/l. These NO_3^- concentrations, together with ammonium found at this site, indicate a sewer problem that has the potential to cause local stream eutrophication within a receiving stream.

The EPA sets bacterial drinking water standards at zero for both fecal coliform and *E.coli* indicators. Fecal bacteria was detected at almost all sites, so it is best to note the few sites absent of counts. The Red Bird Mission site (Site #18) was the only site with an absence of both fecal coliform and *E.coli*. The AT Water (Site # 8) and Oneida junction (Site # 9) sites had fecal coliform, but no *E.coli*. Fecal pollution is a known problem for waterbodies in the Clay County area. The source of the fecal pollution is believed to be from failing septic tanks or "straight piping" sewage onto the surface or into a drainage. The other possible sources, such as cattle, were not present and levels exceeded natural background levels from wildlife.

Evidence into Action

Model of Inter-professional Practice

Innovation was the hallmark of this community-academic partnership. Foundational to the success of the project was community engagement and knowledge sharing. The project brought together disciplines that rarely work together in collaborative practice, and operated on an integrated socio-ecological model of community engagement, knowledge sharing, inter-professional practice, and joint planning between the IPCP and the

community. This framework replaces the disease, cure, intervention model common to healthcare, and fundamentally transforms clinical practice. This IPCP partnership, focusing on the community as client, brought community members and leaders together throughout all aspects of intervention development. University professionals valued local community members as experts in their own history, culture, community challenges, and strengths, and demonstrated that respect through joint meetings, listening sessions, and discussions about priorities and community needs. This in turn created increased community buy-in and sustainability to increase community health and improved quality of life. Figure 1 illustrates the movement and synergy of vertical and horizontal integration, combined with active, continuous community involvement and feedback.

The model represents: 1) socio-ecological systems influencing health for the area; 2) strategies for horizontally integrating nursing, architecture, civil and environmental engineering, and law enforcement disciplines to create an inter-professional team; 3) plan for engaging community members, local organizations, and government leaders; and 4) *process* of how knowledge sharing between both axes leads to community participation, planning, and inter-professional practice. Momentum created by vertical/horizontal synergy became the driving force for improving accessibility of clean water resources and providing education to promote better health outcomes.

Community-based Interventions

Water Kiosk. Triangulation of several data sources, including individual and focus group interviews, community assessments of critical infrastructure and individual households, and resultant findings from water sampling of local streams, natural springs, and well water, together confirmed the need for intervention to supply increased access to clean water to the area.

Years ago, a well-water kiosk was built by a local church. Two problems surfaced in that endeavor: due to heavy usage, the church could not afford expensive well water monitoring that the state required, and overuse drained the well. These barriers were insurmountable at the time, but the usage experience affirmed that residents would value and use clean water if it was available, and that the kiosk approach was welcome and acceptable in the community. An environmental engineer expert on the IPCP team, who had experience with implementation of water kiosks in developing countries, guided discussions with community partners and the local water district to gain approval for an alternative Water Supply Kiosk system. The intent was to tap into an existing county water line that was routinely monitored for purity and fluoride content.

In fall 2014, architectural experts on the IPCP team led an inter-professional academic course involving architecture, engineering, and nursing students to design a water kiosk structure. Student teams developed five unique kiosk designs, including input from the community and considering concerns such as health, security, location, accessibility, and incorporation of a community gathering space for events, such as a weekly farmer's market. Community members formatively reviewed designs with students. Selection of a final design was made with extensive community input. Students, faculty, and community partners built the water kiosk over a one-week period as an alternative spring break service learning activity in spring 2015. Figures 3 and 4 depict progression of the build and final rendering of the water kiosk structure.

Education. In conjunction with the water kiosk design/build, students and faculty from nursing and architecture worked in close collaboration with community members to develop materials and tools that encouraged use and highlighted the importance of water and sanitation. The IPCP team provided interactive, culturally and literacy appropriate education to target community groups within the school, senior center, and larger community. Assessment of WASH-related knowledge before, immediately after, and six months post-education revealed there was a 14% increase in overall knowledge of WASH-related principles retained at six months post education. Supplemental materials disseminated at larger community events and programs provided indirect education. The IPCP team, as listed in Table 5, provided direct education. A total of 1,020 community members were directly trained with the average household of n=4, resulting



Figure 3. Build progression on water kiosk; Red Bird Mission, Beverly, KY.



Figure 4. Final water kiosk photo; Red Bird Mission, Beverly, KY.

in an estimated 4,080 people served. At the conclusion of the project, the IPCP team provided community leaders resources and tools to achieve sustainability and to provide continuing outreach to more community members through an interactive presentation and evaluation of achievements.

Discussion

Ethical Significance

Ethical Principles. The American Nurses Association (2016) describes six ethical principles: Autonomy, Beneficence, Non-maleficence, Respect, Fidelity, and Justice. Autonomy encompasses respecting others' decisions, even if one does not agree. For this project, the researchers relied on the community for decisions and respected their feedback. By committing to better access to clean water, and thereby healthier lives, we participated in an act of beneficence because we sought to make positive changes in the community. Non-maleficence involves the intention to do no harm. In following other ethical principles, we demonstrated our desire not to harm the community

Table 5. Clean Water Education.

Venue Description	Event	Number of Persons Encountered
Older Adult Health Fair	Silver and Gold Fair	50
Community Hospital Health Event	Spring Fiesta	128
Community Partner Event	WASH Education at RBM School	116
Community Partner Event	Farmer's Market Education	20
Community Partner Event	Tri-County Health Fair	163
County Event	Creation Health Fair	50
Community Partner Event	Commodities Day	112
Community Partner Event	Christmas Box Distribution	133
County Event	Frakes Health Fair	184
County Event	Grow Appalachia Meeting	52
County Event	Clay Co. Community Prevention Council Meeting	12
Total	**11 Direct Education Events**	**1,020***

*People directly trained were 1,020 persons representing households of average N=4 persons, representing 4,080 persons.

or its members. Fidelity involves honesty and dedication (American Nurses Association 2016). The research team and kiosk design teams were open and honest with the community and were dedicated to developing interventions in the best interest of the region. We demonstrated justice by working with all members of the community who were agreeable to home assessments and water testing.

Ethical Concerns. There are many ethical concerns regarding access to clean water in rural Appalachian communities. A positive correlation exists between lack of access to clean water and low socio-economic status (VanDerslice 2011). The availability of federal funding could help alleviate some of this disparity. Indoor plumbing and septic system installation can be extremely costly and out of the reach of many families in rural Appalachia without this assistance. However, there are some region-specific challenges, namely the terrain and the isolation of some communities. Often sources of funding are available, but they cannot keep up with the need.

In our study sample, many of the participants who had private well water did not have it regularly tested or certified. This could be due to a variety of reasons, but citizens have to pay for the water testing if it is a private well. Often, people may not be aware of the process to have their wells tested nor have the financial means to test the water quality routinely.

The Clean Water/Clean Life project extended from needs identified by the community, and residents frequently provided feedback on interventions. This community focus helped establish trust and gave members some control over programs and education, leading to a successful project and culminating in widespread community education and the construction of the water kiosk. Community leaders now have resulting findings for dissemination to residents.

Implications for Ongoing Practice, Education, and Research

Practice. Few, if any, community-based projects have been developed by the type of inter-professional team demonstrated in this project. Members from each discipline were able to learn from and share with each other. This helped contribute to a better program, more effective

education, and beneficial interventions. The unique contributions of each field were invaluable. Not only was the overall project more successful, but specialists in each field learned a great deal from each other. Inter-professional communication and collaboration grew over time and was facilitated by courses, which brought students from the various disciplines together. The combination of inter-professional practice and community participation led to knowledge sharing and collaborative planning throughout the project.

Policy. Currently, residents are responsible for testing and certifying their private wells. Policies could be developed which would help encourage people to have their wells tested, as well as programs to provide assistance for testing and treatment, if needed. Water sources that were found to have contaminants above EPA guidelines should be clearly marked and residents should be notified of any changes in water quality. Straight piping is not well-measured in this area of Appalachia. There is a lack of data regarding the proportion of people who employ this method of waste disposal, which complicates enforcement of septic systems and community interventions.

Education. Community education is ongoing and resources were distributed to partners for continued education. Many of the tested water sources, though not used for drinking water, were frequently used for fishing, recreation, and baptisms. This presents a unique challenge because the site of baptisms may hold deep significance in the community, which is why consistent communication with, and input from, members is vital. Programs could also be developed with a focus on protecting the environment and sources of drinking water.

The IPCP team created a how-to manual titled, *Bringing a Water Kiosk to Your Community*, describing the holistic process of community engagement, assessment, intervention, evaluation, and empowerment. The how-to manual can help communities locally, nationally, and abroad to understand how to meet water accessibility needs in a culturally driven way.

Research. Numerous interventions arose from this project, namely educational programs and the water kiosk. Both have the potential of long-term positive effects on the health of the community. Population health measures could be followed in a longitudinal study to help determine the effectiveness of both the kiosk and community education. The water testing was one occurrence, and repeat testing is recommended. Follow-up should continue and residents with private wells should receive information and reminders for testing. Additionally, it would be beneficial long-term to determine the source of contamination and develop education for those both up and downstream of contamination points. Targeted education should focus on topics related to proper waste management and trash disposal.

Disaster preparedness was considered during the home assessments. However, education interventions were focused on WASH-related topics. Future interventions should focus on in-depth analysis of disaster preparedness and community education. The area under study was prone to flooding; particularly many residents had to shelter in place for several hours or days in the aftermath of the spring 2013 flood. Residents should receive education on how to adequately plan for times of disaster, and how they might accumulate disaster supplies, as well as where to go for assistance should disaster strike.

Conclusion

The importance of clean water is vital and access to water is a global priority. In the United States, there are still communities that lack access to clean water. The aim of this project was to work with a rural Appalachian community to understand community priorities and provide interventions. Community-based assessments and interventions such as educational programs and design/build of a water kiosk facilitated achievement of the overall project goals, which were: 1) to improve the health of this community by providing improved access to clean water; 2) to increase education about the importance of clean water; and 3) to serve as an exemplar of effective community-academic partnership and inter-professional practice for other areas in the region, nation, or abroad. Effective multi-sectoral partnerships and collaborations are required to address critical issues facing rural communities that often feel isolated and powerless.

Community-academic partnerships built upon a shared value of health, trust, and visionary

thinking can produce successful outcomes. In rural communities such as these, it is essential to have partners that residents trust. Bilateral trust and commitment facilitates a greater bond for successful change. Community empowerment is key to promoting long-term positive change and sustainability. The IPCP team provided educational tools and resources to community partners during an interactive presentation at the conclusion of the project. Sustainability of the project is ongoing as community partners continue to promote water kiosk utilization, and provide continued education through community programming. The impact of community-based intervention on population health outcomes requires longitudinal assessment over time. Funding long-term efforts becomes problematic when funding agency priorities inadequately align with community-based models of care. Strong innovative partnerships are critical in today's environment of limited funding and resources, especially to make an impact on health-related quality outcomes. This newly developed model of IPCP broadens the potential for future endeavors to include disciplines of public health, economics, law, policy, social work, and others whose expertise could help improve health and societal outcomes in the Appalachian region.

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Impact of Political Identity and Past Crisis Experience on Water Attitudes

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Abstract: With stories of regional diminishing water resources and tainted municipal water supplies consistently populating the news, a nationwide survey was conducted to gauge overall concern and attitudes toward water scarcity and water pollution, as well as scientists and scientific information regarding water crises. Of particular interest was the question of how political ideology and past experience with scarcity and/or pollution impact pro-water attitudes and intention to exhibit positive water behaviors. Multivariate analyses of data suggest that Liberals are more concerned about water scarcity and pollution and more likely to conserve and combat pollution than their Conservative counterparts. People who have experienced a past water crisis are also more concerned and act more favorably toward water than those without crises experience. The interaction between political ideology and water crises experience is such that Conservatives with experience display more water concern than do Conservatives without experience. Liberals, regardless of experience, exhibit water concern and favorable action. Results offer direction to policy makers, water resource managers, and strategic communicators regarding how constituent audiences can be segmented.

Keywords: *scarcity, pollution, conservation, social science, survey, strategic communication*

Issues involving water scarcity and water quality in the United States are widespread. The U.S. Drought Monitor (2016) classifies multiple regions in the United States as "Long-Term" drought areas, with areas in southern California and central parts of Alabama and Georgia currently suffering from extreme drought conditions. Additionally, lead contamination in the drinking water supply of Flint, Michigan, has propelled water quality into the national media forefront (Maher 2016), pushing the U.S. Congress to pass a resolution that will provide $170 million in aid to address water contamination in the city (DeBonis 2016). Likewise, authorities estimate that up to 40 percent of Western rivers are polluted (Finley 2016). While these issues provide exemplars as to how water scarcity and quality impact society, it should also be noted that these and other major events concerning water have created a foundation for social science research. Policy makers need greater knowledge of how the public views water issues in order to successfully approach communities with solutions to drought and contamination crises. To develop strategic messages that will change the public's attitudes and behaviors related to water issues, a clear understanding of the role that political ideology and water crisis experience play in water perceptions must be explored. Ultimately, an understanding of how individual traits can predict attitudes, behaviors, and possible reactions to water-positive messaging is crucial if the entities charged with overseeing U.S. water resources want to best develop public information messaging to protect the water supply.

Literature Review

There has been no shortage of research conducted across an array of academic disciplines focusing on how attitudes are formed and how they predict behavior (see Eagly and Chaiken 1993 for a comprehensive review). Any introductory text

in fields from rhetoric to social psychology will outline a variety of theories on how attitudes come into being, how they evolve (or not), and ultimately how they influence human behavior. Understanding the attitudes of constituent publics is especially important in designing strategic communication efforts aimed at diminishing crises as they develop or averting crisis altogether (see Dozier, Grunig, and Grunig 2013). To this end, successful campaigns to influence attitudes are advised to begin with focus groups, interviews, or surveys to determine the personal traits and characteristics that lie behind the attitudes (Rowe and Frewer 2000; Atkin and Freimuth 2001; Floress et al. 2015). Researchers have suggested an array of traits that may be tied to pro-environment attitudes and behavior change (Semenza et al. 2008; Quinn and Burbach 2010; Fielding et al. 2012; Warner et. al 2016). Among these, political ideology and past experience with the specific problem have emerged as two of the most studied of the possible predictors.

Political Ideology

The personal trait of ideology consistently impacts environmental attitudes. In their 2009 article titled "Political Ideology: Its Structure, Functions, and Elective Affinities," Jost, Federico, and Napier offer an in-depth look at how ideology is defined, how it is formed, and the ways in which it is expressed. Ultimately, and somewhat reluctantly, they state it is possible to categorize people into groups that can be labeled as Conservatives and Liberals, and that even those "who are relatively uninterested or uninformed about politics do exhibit at least some understanding of the core aspects of Liberal-Conservative differences" (316). The authors go a step farther to say that this divide occurs along the line of preference for change (Liberals) or stability (Conservatives). When measured as a predictor in research settings, political ideology has been investigated in studies on everything from soccer team preference (Hoberman 1984) to the downfall of the modern university (Debray 2006). Common practice for researchers investigating environmental issues has been to make a point of gathering data on political ideology when polling the public.

Overall, research suggests people view environmental issues broadly and climate change specifically through a political lens. A nationwide study showed that Democrats are more likely than Republicans to believe that climate change is real and to support action to mitigate its effects (McCright and Dunlap 2011). Other works suggest that individuals who identify as Liberal are more likely to engage in pro-attitudinal behavior in regards to environmental issues than their Conservative counterparts (Dunlap, Xiao, and McCright 2001; Jost, Nosek, and Gosling 2008; Hart and Nisbet 2011; Myers et al. 2013).

Research efforts to determine how ideology impacts environmental attitudes have not only shown the reliability of the finding that Conservatives seem less concerned with environmental issues, but have also demonstrated what may be driving the differences across political parties. When examining political ideology, researchers have found that Conservatives are more likely to question and lose trust in scientists than Liberals (Leiserowitz et al. 2013), while Democrats are the least likely group (compared to Republicans, Independents, other party affiliations, and those who have no party affiliation) to lose trust in scientists (Leiserowitz et al. 2013). Further, Democrats with more knowledge of science in general had increased concern for global warming compared to less knowledgeable Democrats, but Republicans did not report any increase in concern associated with science knowledge (Malka, Krosnik, and Langer 2009).

Personal Experience

In their 1991 book *Social Cognition,* Fiske and Taylor state that "direct experiences provide a great deal of information, so that attitudes that develop as a consequence may be better informed and more robust" (521). Given this assumption, when considering what personal traits may influence attitudes toward environmental issues, any experience a person possesses related to the topic area potentially becomes extremely impactful. While a broad array of work has looked at how experience influences attitudes generally (see Chaiken 1980), research has typically focused on global warming and climate change. Research pertaining to global warming attitudes has shown that people with direct experience with the topic have elevated assessments of the risks associated

with global warming compared to their less experienced counterparts (Akerlof et al. 2013). However, it should be noted that Akerlof et al. (2013) also found that more than a third of those surveyed responded "Don't Know" to the prompt "I have personally experienced the effects of global warming."

In light of the subtlety of observable manifestations of climate change, it stands to reason that respondents may have difficulty recalling specific experiences. It should be noted however that stimuli as subtle as slight variations in ambient temperatures can lead to public attitude shift concerning the existence of global warming, although the effect may be short-lived (Egan and Mullin 2012). The researchers here attribute the quick decay in attitude change related to the necessarily unstable phenomenon of temperature fluctuation. This idea that the issues of global warming and climate change are abstract, unstable and often seen as not requiring immediate contemplation or behavior change has gained traction through various studies (see Lorenzoni, Nicholson-Cole, and Whitmarsh 2007). More manifest, consistent, and longer-lasting climatic change impacts, such as extensive drought, may produce more robust attitude shifts (Egan and Mullin 2012; Huang and Lamm 2015), and behavior change should be more prominent among those who experience direct effects first hand (Lorenzoni, Nicholson-Cole, and Whitmarsh 2007).

Ultimately, pro-environmental attitudes and behaviors seem more directly influenced by a specific issue, such as drought, but impact is more indirect and less pronounced when generalized environmental issues served as the reference. Specific to overt water issues, research has shown that water crisis situations such as prolonged drought, directly influence water conscious attitudes and behaviors. Fielding et al. (2012), in their look into the determinants of household water use in drought-stricken regions of Australia, were able to link awareness of water crisis to adoption of conservation practices. Likewise, a Texas statewide study during the most severe single-season drought in the state's history found that perceptions of the drought's severity significantly impacted positive attitudes toward water conservation (Dascher, Kang, and Hustvedt 2014). Furthermore, the researchers obtained empirical evidence that pro-environmental behavior was directly influenced by the specific issue of "drought," but that the impact was more indirect and less pronounced when generalized "environmental issues" served as the reference. Again, this research lends additional support to the idea that personal experience with concrete and long-term consistent crises such as drought may lead to more pronounced and stable attitudes compared to the more fleeting attitudes associated with abstract phenomenon like global warming.

In sum, research uncovering how political ideology and water crisis experience influence attitudes toward climate change and global warming provide a foundation upon which to build more focused work on issues related to water. It should be noted, however, that fundamental differences between global warming/climate change and water crises make it difficult for strategic communicators or policy makers to predict public reaction to one based on the other. While the research literature suggests that Conservatives are less likely to have pro-environmental views, and those with direct experience with environmental issues are more prone to pro-environmental attitudes, there is scant data to show how political identity and experience separately and together impact water crisis attitudes broadly. The current research attempts to provide an outline of how personal traits align with water attitudes, specifically to fill this void in the literature.

Hypotheses

In the context of environmental issues, researchers have identified both political ideology and previous crisis experience as two personal traits that are particularly important in that both have been found to align with attitudes. Research has shown that the American public largely view environmental and scientific issues differently based on political identity (Dunlap, Xiao, and McCright 2001; Hart and Nisbet 2011; McCright and Dunlap 2011; Myers et al. 2013). Self-identified Democrats and Liberals express more pro-active attitudes toward environmental issues than self-identified Republicans and Conservatives (see Dunlap, Xiao, and McCright 2001). Based on

this information, the following hypothesis related to water consciousness, defined as the attitude that scarcity/pollution problems are important, worrisome, threatening, and that science surrounding the issues is valid (more detail in Method Section forthcoming), guided the research.

> H1: Political ideology influences perceptions of water issues such that Liberals demonstrate stronger water consciousness (defined as belief that scarcity/pollution issues are important problems, are worrisome, are threatening, and that science surrounding the issues is valid) attitudes and intended behavior change than do Conservatives.

Water crisis experience has also proven to influence attitudes related to environmental issues. In fact, it has been suggested that personal experience may influence attitudes to a greater extent than other attributes (Fiske and Taylor 1991). Though research suggests that attitudes associated with weather in particular are not stable due to the changing nature of the referent (temperatures for example), a long-term event such as a prolonged drought may be steady enough for more deeply rooted attitudes to form (Lorenzoni, Nicholson-Cole, and Whitmarsh 2007; Egan and Mullin 2012). Researchers have found that participants residing in close proximity to drought will form pro-water conservation attitudes, but little work has been done to see how global water issue experience may impact how people feel about water scarcity and pollution. As such, the following hypothesis is forwarded.

> H2: Personal experience with water scarcity or pollution influences perceptions of water issues such that those with experience demonstrate stronger water consciousness and intended behavior change than those with no experience.

Finally, little is known about how political ideology and personal experience with environmental crises interact. Past research findings suggest that group identification, such as political affiliation, more strongly influences attitudes toward global warming than does one's own personal experience with the issue (Akerlof et al. 2013). But this opinion contradicts that of social psychologists that state the most robust and unwavering attitudes develop from experience and not from other traits (Fiske and Taylor 1991). To determine how personal experience and political affiliation work together to influence water attitude, the following hypothesis is tested.

> H3: The interaction between political ideology and experience is such that Liberals, being inherently more water conscious, will be less impacted by experience with water issues than will be Conservatives, who will demonstrate a more pronounced level of water consciousness as a function of water issue experience.

Methods

Overview

Two brief reports regarding a water scarcity issue and a water pollution issue, professionally presented in a common news format, were shown to respondents. Respondents, after reading the reports, were surveyed and asked to indicate their attitudes toward the issues and how they might alter their future water behaviors as a result of reading the reports. Respondents also completed a series of items aimed at measuring political ideology and personal experience with water scarcity and pollution, among other traits. The items surveyed allowed for a statistical analysis of how measured individual traits and experiences may influence the reaction of persons to issues of water scarcity and pollution.

Procedure

Participants from across the U.S. were recruited using Amazon's Mechanical Turk (MTurk), an online opt-in platform that allows respondents to complete tasks for compensation. Past research has established that studies executed with MTurk respondents produce reliable and valid data (Mao et al. 2011; Mason and Suri 2011). U.S. members of Amazon's MTurk participant pool over the age of 18 were eligible to participate in the study. The study was created using Qualtrics software and was linked to MTurk using a unique web address.

MTurk directed U.S. participants to the Qualtrics online data gathering system, where they read a short synopsis of the study and agreed to participate. The 150-word stories were presented

in a format common to media news. Each participant saw one story on water scarcity and one on water pollution. The order of presentation was systematically varied so that half of the participants read the scarcity story first and the other half read the pollution story first. The stories were carefully crafted to not identify any real water event or to make it appear the story was taking place in any particular location. This kept the stories neutral and free from inherent biases that may result from referencing actual news or locations. All names and sources within the stories were fictional.

Participants completed the study either on a mobile device or using a desktop/laptop computer. Data were collected on July 8, 2016, from a total number of 498 participants. Each participant earned fifty cents upon completion. In order to prevent non-human 'bot' involvement, a random number generator was programmed into the end of the online participation experience (McCreadie et al. 2010). Participants were required to copy and paste the generated number into the data collection software in order to obtain the promised incentive.

Participants

Participant demographics were collected at the completion of the survey. A demographic analysis of the respondents revealed that 59% were male and 41% female. The average age of the participants was 35.8. Age intervals were created to provide testable age cohorts. Twenty-nine percent of participants were 18 to 28 years old, 43.8% were 29 to 39 years old, 14.1% were 40 to 50 years old, 10.7% were 51 to 60 years old, and 2.4% were 62 and older. In terms of political ideology, 21.2% reported as Conservative, 32.2% reported as Moderate, and 46.6% identified as Liberal. In terms of education, 8.4% attended high school, 29.9% attended some college, 44.4% received a college degree, and 17.3% received a post-graduate degree. Religion was also noted, with 22% identifying as Protestant, 16.9% as Roman Catholic, 8.5% as Hindu, 19.4% as Atheist, 21.6% as having no affiliation, and 11.6% as other. All demographics of participants were closely aligned with nationwide 2016 Census Bureau data suggesting that the study sample adequately mirrored that of the U.S. population.

Scarcity and pollution experience were considered separately, as a person could possibly have a background with one or the other, both, or neither. Participants were asked to respond to the statements "Water scarcity (pollution) has personally affected me" on seven-point scales of strongly disagree (1) to strongly agree (7).

Attitude and Behavior Measures

Following exposure to the rotated news stories, each participant completed a series of attitudinal and behavioral measures. The measures were specific to each story and were rotated to match the order of the news story consumption by the participant. Participants were asked to report their attitudes toward both water issues using scales with ratings for each item ranging from 0 (not at all) to 10 (extremely). Items were as follows: "How important is the report?" "How newsworthy is the report?" "Water scarcity/pollution makes me feel worried/negative/anxious/concerned." "The report made me feel threatened/unafraid/entertained/worried." "How severe is the threat of water scarcity/pollution?" "How sure are you that water scarcity/pollution is one of the most important problems facing the country?"

For the skepticism and behavior change items, participants responded using scales of 1 (Strongly Disagree) to 7 (Strongly Agree). Individual items were: "Researchers don't really know if there is a water scarcity/pollution crisis or not." "Average citizens can gauge the likelihood of a water scarcity/pollution crisis just as well as a scientist." "It is not possible for scientific data to demonstrate that water scarcity/pollution is a real threat." "Scientists often make claims that are not supported by reality." "Scientists often do not tell the whole story regarding the issues they study." The statements "I plan to be more conscientious about my water usage" and "I will make an effort to use less water/avoid water pollution in the future" were used to gauge intended behavior change.

Results

Data Reduction

Scale items were analyzed using factor analysis with an orthogonal rotation. Six factors emerged from the analysis. The first factor, labelled *importance*, showed high loadings for important issue (0.927) and newsworthy (0.927). *Importance*

had an eigenvalue of 1.27, accounted for 85.92% of the overall variance, and registered a Cronbach's α of 0.835. The second factor, labelled *worried*, showed high loadings for worried (0.951), negative (0.878), anxious (0.925), and concerned (0.922). *Worried* had an eigenvalue of 3.38, accounted for 84.53% of the variance, and registered a Cronbach's α of 0.818. The third factor, labelled *scared,* showed high loadings for scared (0.931), threatened (0.904), and worried (0.876). *Scared* had an eigenvalue of 2.10, accounted for 26.24% of the overall variance, and registered a Cronbach's α of 0.829. The fourth factor, labelled *threatening*, showed high loadings for severe (0.894) and important threat (0.894). *Threatening* had an eigenvalue of 1.60, accounted for 79.96% of the overall variance, and registered a Cronbach's α of 0.740. The fifth factor, labelled *skepticism*, showed high loadings for "Researchers don't really know if there is a water scarcity/pollution crisis or not" (0.787), "Average citizens can gauge the likelihood of a water scarcity/pollution crisis just as well as a scientist" (0.660), "It is not possible for scientific data to demonstrate that water scarcity/pollution is a real threat" (0.760), "Scientists often make claims that are not supported by reality" (0.838), and "Scientists often do not tell the whole story regarding the issues they study" (0.758). *Skepticism* had an eigenvalue of 2.91, accounted for 58.20% of the overall variance, and registered a Cronbach's α of 0.818.The sixth factor, labelled *behavior change*, showed high loadings for "I plan to be more conscientious about my water usage" (0.927), and "I will make an effort to use less water/avoid water pollution in the future" (0.927). *Behavior Change* had an eigenvalue of 1.72, accounted for 86.00% of the overall variance, and registered a Cronbach's α of 0.836.

Data Analysis

Preliminary Analyses. First, high and low water crisis experience groups were created via median splits. For water scarcity, the low experience group had 247 members and an average score of 1.61 (SD = 0.49) while the high experience group had 248 members and an average score of 4.73 (SD = 1.30). A t-test distinguished these two groups as statistically distinct from one another ($t(315.56) = 35.28$, $p < 0.001$). For water pollution, the low experience ($N = 232$, $M = 1.69$, $SD = 0.47$) and high experience ($N = 264$, $M = 4.59$, $SD = 1.22$) groups were also distinct ($t(346.46) = 35.88$, $p < 0.001$).

Initial data analysis considered participant gender, age, level of education, religion, political ideology, and past experience with both water scarcity and water pollution across the six water consciousness constructs (i.e., factors). All factors across item-type were subjected to parametric statistical analysis (Norman 2010). When combined through factorial design with the key variables of interest—political ideology and water issue experience—no consistent interactions or main effects emerged via ANOVA for gender, age, education, and/or religion. As such, and to produce more parsimonious tests of hypotheses, all four were dropped from future analyses.

Statistics of Hypotheses Testing. In testing of hypotheses, data were submitted to multifactor analyses of variance with post-hoc testing where appropriate. Fixed factors were political ideology (Liberal, Moderate, Conservative) and experience level (low, high), all within the scarcity and pollution contexts in isolation. As such, a 3 X 2 ANOVA was performed across all constructs. Statistics, including means, standard deviations, F values, estimates of effect size, and post hoc results, are all reported in Tables 1 through 3, for sake of efficiency.

Tests of Hypotheses. H1 posited that political ideology would influence water issue perceptions such that Liberals would report stronger water conscious attitudes and intended behavior change than would Conservatives. H1 was supported. Across both the scarcity and pollution scenarios respectively, Liberals were statistically more water positive in terms of pollution and conservation. Table 1 displays the sub group means, standard deviations, and reveals the results of ANOVA testing and appropriate post hoc tests as were needed. While political Moderates often aligned with one or the other politically extreme peer groups, Liberals saw water issues as more important, were more worried about water issues, were more scared after reading reports on water issues, felt more threatened by water issues, were less skeptical of the science related to water issues, and were more committed to changing their own

Table 1. Water consciousness across political ideology within issue.

Water Consciousness		Scarcity			Pollution		
		Liberal	Moderate	Conservative	Liberal	Moderate	Conservative
Importance	*Means*	8.29^{A}	7.70^{B}	6.97^{C}	8.31^{A}	7.78^{B}	7.28^{C}
	(SDs)	(1.59)	(1.90)	(2.57)	(1.67)	(1.76)	(2.57)
Worried	*Means*	7.23^{A}	6.55^{A}	6.04^{B}	7.56^{A}	7.06^{B}	6.31^{C}
	(SDs)	(2.02)	(2.32)	(2.89)	(1.94)	(2.08)	(2.79)
Scared	*Means*	5.93^{A}	5.41^{AB}	4.88^{B}	6.08^{A}	5.52^{A}	5.06^{B}
	(SDs)	(2.58)	(2.53)	(2.81)	(2.44)	(2.44)	(2.73)
Threatening	*Means*	7.34^{A}	6.96^{B}	6.09^{B}	7.37^{A}	6.94^{B}	6.15^{B}
	(SDs)	(2.07)	(2.12)	(2.56)	(2.04)	(2.00)	(2.58)
Skepticism	*Means*	2.66^{A}	3.15^{B}	3.58^{C}	2.54^{A}	3.06^{B}	3.42^{C}
	(SDs)	(1.18)	(1.14)	(1.20)	(1.14)	(1.11)	(1.26)
Behavior Change	*Means*	5.32^{A}	4.95^{A}	4.77^{B}	5.25^{A}	5.04^{B}	4.62^{B}
	(SDs)	(1.17)	(1.34)	(1.47)	(1.25)	(1.33)	(1.57)
Importance	*Stats*	$F(2, 474) = 13.06, \eta^2_p = 0.05$			$F(2, 477) = 9.05, \eta^2_p = 0.04$		
Worried	*Stats*	$F(2, 475) = 7.43, \eta^2_p = 0.03$			$F(2, 475) = 9.82, \eta^2_p = 0.04$		
Scared	*Stats*	$F(2, 475) = 3.97, \eta^2_p = 0.02$			$F(2, 476) = 4.11, \eta^2_p = 0.02$		
Threatening	*Stats*	$F(2, 476) = 8.65, \eta^2_p = 0.04$			$F(2, 477) = 9.68, \eta^2_p = 0.04$		
Skepticism	*Stats*	$F(2, 475) = 23.63, \eta^2_p = 0.09$			$F(2, 477) = 22.16, \eta^2_p = 0.09$		
Behavior Change	*Stats*	$F(2, 475) = 5.23, \eta^2_p = 0.02$			$F(2, 477) = 6.07, \eta^2_p = 0.03$		

Note: All horizontal means within scenario not sharing a superscript letter vary significantly ($p < 0.05$) by SNK post hoc tests. SD = standard deviation.

actions to help improve water problems than were their Conservative counterparts. These statistically robust differences did not deviate from this pattern on any single measure, and the pattern was consistent across both water scarcity and water pollution issues.

H2 forwarded that people who had experience with water scarcity or pollution would demonstrate stronger water consciousness and intended behavior change regarding water than those with no such experience. As can be seen in Table 2, this was almost universally the case, with experience having statistically significant influence across all measures save importance. A review of the associate means and ANOVA results shows that respondents who had indicated personal experience with either a water scarcity or water pollution situation were more worried about the prospect of water crises, were more scared after reading an article detailing potential water issues, saw the issues as more threatening, were less skeptical of scientific data regarding water issues, and were more likely to state they would alter their future behaviors to help avoid future water problems. Despite the consistent and statically significant differences between those with water issue experience and those without across the two scenarios, the lone measure where the groups did not differentiate themselves was on the importance they ascribed to water issues. Both groups saw water concerns as equally important, statistically.

H3 predicted that experience with water crises would be more impactful for Conservatives than it would be for Liberals. This expectation was based on the premise that Liberals are inherently more water conscious and therefore would have less latitude of change available compared to Conservatives, assumed to be less water conscious

Table 2. Water consciousness across crisis experience level within issue.

Water Consciousness		-------Scarcity-------		-------Pollution-------	
		Low	**High**	**Low**	**High**
Importance	*Means*	7.74^{A}	7.89^{A}	7.88^{A}	7.95^{A}
	(SDs)	(2.18)	(1.80)	(2.11)	(1.82)
Worried	*Means*	6.36^{A}	7.17^{B}	6.73^{A}	7.49^{B}
	(SDs)	(2.52)	(2.13)	(2.37)	(2.05)
Scared	*Means*	5.09^{A}	5.99^{B}	5.03^{A}	6.25^{B}
	(SDs)	(2.68)	(2.52)	(2.58)	(2.36)
Threatening	*Means*	6.36^{A}	7.55^{B}	6.38^{A}	7.50^{B}
	(SDs)	(2.35)	(1.97)	(2.37)	(1.89)
Skepticism	*Means*	2.70^{A}	3.33^{B}	2.65^{A}	3.12^{B}
	(SDs)	(1.09)	(1.27)	(1.08)	(1.27)
Behavior Change	*Means*	4.90^{A}	5.27^{B}	4.78^{A}	5.29^{B}
	(SDs)	(1.39)	(1.20)	(1.54)	(1.14)
Importance	*Stats*	$F(1, 474) = 3.52, \eta^2_p = 0.01$		$F(1, 477) = 1.41, \eta^2_p < 0.01$	
Worried	*Stats*	$F(1, 475) = 20.13, \eta^2_p = 0.04$		$F(1, 475) = 16.86, \eta^2_p = 0.03$	
Scared	*Stats*	$F(1, 475) = 13.20, \eta^2_p = 0.03$		$F(1, 476) = 32.96, \eta^2_p = 0.07$	
Threatening	*Stats*	$F(1, 476) = 43.60, \eta^2_p = 0.08$		$F(1, 477) = 38.60, \eta^2_p = 0.08$	
Skepticism	*Stats*	$F(1, 475) = 27.56, \eta^2_p = 0.06$		$F(1, 477) = 13.88, \eta^2_p = 0.03$	
Behavior Change	*Stats*	$F(1, 475) = 15.88, \eta^2_p = 0.03$		$F(1, 477) = 20.26, \eta^2_p = 0.04$	

Note: All horizontal means within scenario not sharing a superscript letter vary significantly ($p < 0.05$) by SNK post hoc tests. SD = standard deviation.

overall. H3 was supported. Across five of the six constructs on both scenarios, Conservatives saw the largest and most statistically significant increase in consciousness between those with low and high crisis experience, compared to their Liberal counterparts (see Table 3). A review of the means and test statistics show the average increase on the consciousness and behavior change scales, based on issue experience within the scarcity scenario, was 0.40 for Liberals and more than a full point higher at 1.43 for Conservatives. Similarly for the pollution scenario, the average increase on the consciousness and behavior change scales was 0.56 among Liberals and 1.52 among Conservatives. It should also be noted that the difference between low and high experienced Liberals was not statistically significant in the case of the construct *Importance* (for both water scarcity and pollution), *Worried* (for scarcity), *Behavior Change* (for scarcity), and *Scared (*for pollution*)*. On the other hand, the differences between low and high experienced Conservatives was significant across all measures other than *Scared* in the pollution scenario.

Despite the robust interaction of political identity and experience level overall, there was one measure where the data did not follow the established pattern. Experience level had little impact on Conservatives while it had significant impact on Liberals for the construct of Skepticism. A review of the means in Table 3 shows that Conservatives were more skeptical broadly, regardless of experience level with the water issues. Liberals with water issue experience, however, were more skeptical of the researchers and data associated with scarcity and pollution than were Liberals who had no experience with the issues. Generally speaking, across all the measures, even the most worried or scared Conservatives still did not reach the elevated levels of the least conscious Liberals.

Table 3. Interaction of political ideology and crisis experience level within issue on water consciousness.

Water Consciousness		----------Scarcity----------				----------Pollution----------			
		Liberal		Conservative		Liberal		Conservative	
		Low	High	Low	High	Low	High	Low	High
Importance	*Means*	8.36^{A}	8.22^{A}	6.44^{A}	7.64^{B}	8.22^{A}	8.39^{A}	6.90^{A}	7.65^{A}
	(SDs)	(1.61)	(1.57)	(2.96)	(1.70)	(1.74)	(1.65)	(2.91)	(2.10)
Worried	*Means*	7.05^{A}	7.42^{A}	5.27^{A}	7.06^{B}	7.26^{A}	7.84^{B}	5.55^{A}	7.10^{B}
	(SDs)	(2.07)	(1.98)	(3.11)	(2.17)	(1.97)	(1.89)	(3.05)	(2.22)
Scared	*Means*	5.58^{A}	6.33^{B}	4.27^{A}	5.66^{B}	5.71^{A}	6.47^{B}	4.02^{A}	6.15^{B}
	(SDs)	(2.67)	(2.45)	(2.90)	(2.47)	(2.49)	(2.36)	(2.78)	(2.20)
Threatening	*Means*	6.97^{A}	7.77^{B}	5.29^{A}	7.19^{B}	6.95^{A}	7.78^{B}	5.10^{A}	7.31^{B}
	(SDs)	(2.21)	(1.82)	(2.54)	(2.18)	(2.12)	(1.90)	(2.71)	(1.86)
Skepticism	*Means*	2.27^{A}	3.07^{B}	3.43^{A}	3.77^{A}	2.30^{A}	2.77^{B}	3.34^{A}	3.52^{A}
	(SDs)	(0.88)	(1.32)	(1.20)	(1.16)	(0.88)	(1.30)	(1.22)	(1.30)
Behavior Change	*Means*	5.23^{A}	5.43^{A}	4.38^{A}	5.26^{B}	5.00^{A}	5.48^{B}	4.17^{A}	5.13^{B}
	(SDs)	(1.15)	(1.19)	(1.65)	(1.01)	(1.39)	(1.08)	(1.81)	(1.06)
Importance	*StatsLib*	$F(1, 227) = 0.43, p = 0.51, \eta^2_p < 0.01$				$F(1, 228) = 0.56, p = 0.46, \eta^2_p < 0.01$			
	StatsCon	$F(1, 102) = 5.94, p = 0.02, \eta^2_p = 0.06$				$F(1, 102) = 2.25, p = 0.14, \eta^2_p < 0.02$			
Worried	*StatsLib*	$F(1, 228) = 1.87, p = 0.17, \eta^2_p < 0.01$				$F(1, 227) = 5.22, p = 0.02, \eta^2_p = 0.02$			
	StatsCon	$F(1, 102) = 10.85, p < 0.01, \eta^2_p = 0.10$				$F(1, 102) = 8.65, p < 0.01, \eta^2_p = 0.15$			
Scared	*StatsLib*	$F(1, 229) = 4.93, p = 0.03, \eta^2_p = 0.02$				$F(1, 227) = 5.59, p = 0.02, \eta^2_p = 0.02$			
	StatsCon	$F(1, 101) = 6.54, p = 0.01, \eta^2_p = 0.06$				$F(1, 102) = 18.46, p = 0.51, \eta^2_p < 0.01$			
Threatening	*StatsLib*	$F(1, 229) = 9.09, p < 0.01, \eta^2_p = 0.04$				$F(1, 228) = 9.76, p < 0.01, \eta^2_p = 0.04$			
	StatsCon	$F(1, 102) = 16.19, p < 0.01, \eta^2_p = 0.14$				$F(1, 102) = 23.13, p < 0.01, \eta^2_p = 0.19$			
Skepticism	*StatsLib*	$F(1, 229) = 29.32, p < 0.01, \eta^2_p = 0.11$				$F(1, 228) = 10.34, p < 0.01, \eta^2_p = 0.04$			
	StatsCon	$F(1, 102) = 2.04, p = 0.16, \eta^2_p = 0.02$				$F(1, 102) = 0.46, p = 0.50, \eta^2_p < 0.01$			
Behavior Change	*StatsLib*	$F(1, 229) = 1.72, p = 0.19, \eta^2_p < 0.01$				$F(1, 228) = 8.59, p < 0.01, \eta^2_p = 0.04$			
	StatsCon	$F(1, 102) = 9.83, p < 0.01, \eta^2_p = 0.09$				$F(1, 102) = 10.74, p < 0.01, \eta^2_p = 0.10$			

Note: All horizontal means within scenario not sharing a superscript letter vary significantly ($p < 0.05$) by SNK post hoc tests. SD = standard deviation.

Discussion

In a 2015 article published in the *Journal of Contemporary Water and Education*, Floress et al. call for more social science-based research by outlining that behavior choices are "predicated on a variety of social, psychological, institutional, and economic factors that need to be understood" (85). While these authors addressed watershed projects specifically, they speak to the importance of understanding how "attitudes, value orientation, perceptions of social capital, trust, risk, and awareness" (85) can influence perceptions and behavior change related to natural resources. To that end, the present study attempts to address the void by investigating how personal traits can predict water resource attitudes and behaviors.

The primary findings of this investigation show that personal traits have profound impacts

on how members of the public consider water issues and that these traits may impact behavioral changes related to use of the resource. In terms of enumerated hypotheses, the findings concerning the influence of political ideology on water attitudes and behavior are consistent with the greater body of research related to environmental issues in general. Hypothesis 1 predicted that Liberals would be more water conscious and more willing to make water positive behavioral changes compared to their Conservative counterparts. This expectation was confirmed across every measure employed and across both the scarcity and pollution scenarios. Liberals did in fact place more importance on water issues, were more worried, more scared, felt more threatened, were less skeptical of scientific data, and were more inclined to change their behaviors in a positive direction compared to Conservatives. Political Moderates oscillated between the two more extreme groups.

Findings here regarding the influence of political ideology thus align with past research focusing on the broader area of climate change and global warming (Dunlap, Xiao, and McCright 2001; Jost, Nosek, and Gosling 2008; Hart and Nisbet 2011; Myers et al. 2013). What is novel in the current study, however, is the discovery of this effect specific to water scarcity and pollution. The findings allow policy makers and strategic communicators to work within some level of certainty that the influence of ideology does in fact occur as would be expected, related to water. Ultimately, and practically, these data provide direction for any campaign effort aimed at addressing water issues. Because local population political identity can be ascertained by reviewing precinct voting records, any person or organization aiming to positively impact water issues should be able to predict support or resistance from constituent publics before formal efforts are launched. With the knowledge of public ideology in hand, messaging strategies can be adapted to target audiences.

Just as the current data offers little contradiction to previous work in political ideology, it is also supportive of foundational work in how previous experience impacts attitudes and expected behaviors. H2 stated that those persons with previous scarcity or pollution experience would be more water conscious and willing to support behavior change regarding water conservation than those without experience. Overall, data aligned with expectations. In the case of both water crisis scenarios, those who had personally experienced a water scarcity or water pollution situation did have more water-positive attitudes and willingness to change behavior. As stated previously, research has generally suggested that personal experience with an issue is more impactful than other less concrete associations (Fiske and Taylor 1991). And while researchers have looked at how experience with environmental issues such as climate change influences beliefs, it is suggested that general climate change indicators are subtle and less influential upon attitudes compared to more visible environmental issues such as drought (Lorenzoni, Nicholson-Cole, and Whitmarsh 2007; Egan and Mullin 2012). Data here do not compare the influence of global warming/climate change experience versus water issue experience on attitude, but it does show that experiences related to water are impactful. Additionally, results do not offer insight into how firmly attitudes are held or how slowly they decay relative to water experience, but there is clear evidence that having a water scarcity or water pollution incident in one's background is influential upon attitudes about water issues and conservation.

In terms of pragmatic value of the findings, knowing what experiences a person can reference should allow for better messaging, as with political ideology. Clearly those with water issue experience should be more receptive to pro-water messaging while those without experience will be more difficult to influence. But unlike with ideology, where some attempt to gauge Liberal or Conservative affiliation must be taken, water issue experience can be easily determined simply by taking into account local weather and water purity information. Whereas ideology can change from house to house on the same city block, experience with water issues should be global within a community. Obviously, it is possible that members of the public could have gained water issue experiences in other locales or could be oblivious to their own current surroundings, but policy makers and campaigners could readily ascertain a good sense of the majority population's experience and resulting attitudes.

Finally, the current study allows an opportunity to determine how political ideology and personal experience interact. Hypothesis 3 predicted that Liberals would be less impacted by experience as a result of a possessing a generalized higher level of water consciousness while Conservatives, who are less water conscious overall, would be more influenced by experience. Data analyses revealed just such an interaction where the mean score movement between low and high experienced respondents was much more pronounced among Conservatives than Liberals. A review of the effect size (partial eta squared) statistics in the testing of the first two hypotheses offers little to indicate which measure alone accounts for more influence. The key take away is that the influence of each is robust in and of itself but when considered simultaneously, a clear picture begins to form. Across the measures and issues, those Conservatives with issue experience possess attitudes and intentions that align them more closely to Liberals regardless of experience. The most pronounced exception to this finding centered on skepticism of the science associated with water issues. Conservatives, even those who had experiences with water scarcity or pollution, were skeptical of science behind either issue. Liberals, on the other hand, were less skeptical than Conservatives overall, but those Liberals with issue experience were even less skeptical than those Liberals without.

Practically, the interaction between political ideology and personal experience offers valuable insight into how to address water issues. In areas where the population has direct experience of either a water scarcity or water pollution issue, it could be expected that the public would be supportive via conservation or pollution prevention of messaging and campaign efforts regardless of the political ideology of individuals. In these locations, it may be possible to use broad-based efforts and not require audience segmentation. On the other hand, in areas where there may be a threat of water issues but none that have manifested themselves yet, Conservatives and Liberals can be expected to hold very different attitudes and have different behavior intentions related to water. In these markets, audience segmentation by ideology may be advisable. It should be noted, however, regardless of experience, it would seem that citing science and scientists in any water messaging may yield few positive results.

Limitations and Future Research

While the current study does offer some insight into how water attitudes and behaviors may be influenced by personal traits, it nonetheless has several limitations. This research does not address granular specificity in regards to issue experience and behavior change. Respondents were asked only if they had been personally affected by scarcity or pollution. What the study does establish is that experience is impactful, but experience with either issue can vary from direct economic or health impact to more abstract psychological impact. Future studies should be more specific in measuring experience and take a deeper look at the types of experience possible. Likewise, the behavior measures employed in the current study asked only if respondents planned to be more conscientious with water and use less water/be more aware of pollution in the future. Behavior change can include anything from investigating the issues more deeply to volunteering time to make positive contributions. A more detailed and nuanced gauge of behavior change intentions would lend depth to the findings. Finally, future researchers should investigate strategic messaging techniques and practices to determine how the traits and attitudes uncovered here may influence the impact of campaign efforts. Knowing that political ideology and personal experience shape attitudes and intentions provides a solid foundation, but ultimately the research goal should be to offer evidence of best practice message construction.

Conclusion

With water scarcity and water pollution garnering more attention in the U.S., there is little doubt there exists an increasing need to build support for water issues across a variety of constituent publics. The changes in human behavior that will be required to avert much larger crises hinge on the formation of water-positive attitudes. The current study lends insight to how water attitudes are currently forged and how personal traits may predict tendencies to

conserve water and be mindful of water quality. This nationwide survey suggests that Liberals and those with personal water issue experience are more water positive than are Conservatives and those without water issue experience. At the intersection of these variables lie Conservatives with no previous water issue experience, a group that may prove to be the most resistant to adopting a water positive stance. Ultimately, researchers and managers alike should be able to use the findings here as a springboard to conduct future investigations and build more support for water issues among the general public. In particular, this research sets the stage for municipal water boards and other managers to develop strategic messaging that can target consumers based on district voter registrations as well as water issue experience levels determined by recent local droughts or pollution.

One example of how the findings might direct efforts centers on the data suggesting that experience with a water crisis partially negates the negative impact of Conservative political ideology. Regions that have experienced water scarcity, for example, may require only a single water conservation messaging strategy—Conservatives and Liberals alike have shown positive water attitudes when crisis experience is high. Messages should be more tailored along the lines of ideology, however, if a municipality is planning proactively, and hoping to influence a population before any water crisis experience has developed. In particular, message designers, considering the skeptical nature of Conservatives toward water science and scientists, would likely find more success by using a non-scientist spokesperson in any messaging. Care must be taken not to step outside of the research scenario employed, as a broad test of messaging techniques was not conducted here. Nonetheless, this study illustrates that efforts to impact water usage habits as well as pollution concerns stand a much better chance of positively affecting behaviors and attitudes when the political ideology and experience levels of a target audience are taken into account.

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Survey of Rainwater Catchment Use and Practices on Hawaii Island

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Abstract: The harvesting of rainwater for domestic use on Hawaii Island is widespread, particularly in areas not served by municipal water. Rainwater catchment is currently unregulated in Hawaii with the responsibility of installing and maintaining appropriate systems on owners and users. Well-designed and maintained rainwater catchment systems are more likely to provide water free of pathogens than poorly designed or maintained systems. We conducted outreach to rural Hawaii Island communities on rainwater catchment best practices and explored household uses and practices associated with these systems via survey of 110 individuals. Nearly 90% (N=96) of all survey respondents used harvested rainwater as a potable water source or for bathing, and we estimate only 66% of those systems may reasonably be expected to produce safe drinking water. Reported testing frequency of captured rainwater falls below recommended levels and varies significantly with rainwater use and system adequacy. Outreach was effective in changing perceptions on rainwater catchment as evidenced by individuals' reported beliefs before and after engagement. The majority (N=75) of all survey respondents reported they will change how they maintain their catchment systems, and over 50% (N=61) reported they will change their catchment system elements, as a result of outreach. We conclude there is a demonstrated need for ongoing, professional, evidence-based outreach programs to serve rainwater catchment system users in Hawaii.

Keywords: *Zika virus, dengue virus, rat lungworm disease, rainwater harvesting, Sea Grant*

The Island of Hawaii, the largest and most southerly island in the Hawaiian archipelago, is characterized by diverse communities including rural and remote communities not served by municipal water. These communities rely on private or shared wells, water trucked to cisterns, or rainwater catchment for their water needs. Rainwater catchment is the harvest of falling rain, often shed from rooftops, which can be stored in barrels, tanks, cisterns, ponds, or other repositories for household, agricultural, or commercial use. An ancient practice (Pandey et al. 2003), particularly in arid regions (AbdelKhaleq and Alhaj 2007), rainwater harvesting is used worldwide in rural areas without centralized water systems (Pacey and Cullis 1986), including islands, to augment domestic water supply (Han and Ki 2010; Quigley et al. 2016). Rainwater harvesting has also been identified as a technology that communities across the globe may increasingly rely upon to adapt to climate change (Pandey et al. 2003). With proper design, maintenance, and water treatment, a rainwater catchment system can provide water that is free of contamination, soft, clear, odorless, and suitable for drinking and other daily needs (Cunliffe 1998; Macomber 2010). However, improperly designed or maintained rainwater catchment systems may pose a health risk, for example via the introduction of waterborne illness that can be exacerbated in persons with compromised immunity (Pathak and Heijnen 2005; Ahmed et al. 2011).

Up to 60,000 people in the state of Hawaii were estimated to be dependent on rainwater catchment as their primary domestic water source in 2010, with the majority of obligate rainwater catchment users residing on the Island of Hawaii (Macomber 2010). Hawaii Island's population increased

25% between 2000 and 2010, with the greatest increases in districts heavily dependent upon private rainwater catchment systems to supply their daily water needs (Western Rural Development Center 2010; Department of Business, Economic Development and Tourism 2012). The availability of municipal water service has not increased commensurately with the increase in population size over this period (Department of Water Supply, County of Hawaii 2010).

Waterborne and vector-borne illness may be transmitted to users from rainwater catchment systems that lack appropriate system elements and maintenance or from insufficient treatment of stored water (Koplan et al. 1978; Lye 1987; Yaziz et al. 1989; Crabtree et al. 1996; Pathak and Heijnen 2005; Ahmed et al. 2011). For example, rainwater catchment tanks lacking covers or with damaged or poorly sealed covers can provide breeding opportunities for mosquitos known to be disease vectors. During the 2015-2016 dengue virus outbreak on Hawaii Island, which sickened hundreds, The Hawaii State Department of Health identified "uncovered catchment systems…" as a potential source for dengue virus infected mosquitos (Hawaii State Department of Health 2016) and suggested "…essential actions to control mosquito breeding in rainwater catchment systems" (Hawaii State Department of Health 2015). Other vector-borne diseases transmitted by mosquitos, such as the globally emerging Zika virus, are of concern in areas where mosquitos may breed, including mosquito-accessible rainwater catchment systems. Microbial contamination of roof-harvested rainwater that is insufficiently disinfected may also pose a health risk due to bacterial or protozoal pathogens, the latter including *Giardia spp.* and *Cryptosporidium spp*. (Crabtree et al. 1996; Fewtrell and Kay 2007; Ahmed et al. 2010). Additionally, an invasive semi-slug found in Hawaii, *Parmarion cf. martensi*, which has a propensity to climb up and into water tanks, is a host of the parasitic nematode responsible for infecting humans with rat lungworm disease (Hollingsworth et al. 2007).

Rainwater harvesting is not regulated by the federal government in the United States; it is up to individual states to regulate the collection and use of rainwater (Loper 2015). Rainwater catchment systems on individual homes serving less than 20 individuals are not regulated by the Hawaii State Department of Health. Consequently, it is important for owners and end-users of these systems to understand how to use rainwater catchment systems in a safe and appropriate manner. It is therefore critical that stakeholders who harvest rainwater in Hawaii understand the associated potential negative impacts on human health and employ best practices to mitigate these impacts. Development and delivery of effective outreach on rainwater catchment, in Hawaii and worldwide, will be increasingly needed as reliance on these systems increases due to climate change (Pandey et al. 2003). Here, we share information on a professional outreach project that aimed to: educate and empower rural Hawaii Island communities reliant on rainwater catchment to make informed decisions related to their catchment practices; and better understand rainwater catchment use and practices on Hawaii Island to inform future outreach needs.

Methods

In March and August 2015, we conducted 11 rainwater catchment workshops on Hawaii Island. Workshops were conducted in six of the nine island county council districts in the following census designated places: Ocean View, Naalehu, Volcano, Pahoa, Keeau, Hilo, Honokaa, Kealakekua, and Kona, encompassing a wide geographic area. Workshops were scheduled for 2.5 hours in length in the early evening weekdays or Saturday mornings to facilitate public attendance. Workshops were conducted in venues selected to be of convenience to community members such as community centers, civic centers, public schools, and county government buildings. Workshop components were developed to provide and deliver evidence-based outreach on rainwater catchment in multiple modalities and included an oral presentation accompanied by projected visual content. Written material was also made available to participants at no charge in the form of seven unique thematic "Rainwater Catchment Solutions" brochures (College of Tropical Agriculture & Human Resources, CTAHR 2009) and the 51-page publication, "Guidelines on Rainwater

Catchment Systems for Hawai'i" (Macomber 2010). Workshop participation was free of charge and complimentary PathoScreen™ using the WhirlPak® Fecal Bacteria Water Test Kits were distributed at the end of workshops to increase awareness of and facilitate testing of rainwater catchment system water. Learning outcomes were also identified to evaluate outreach effectiveness as follows. Upon completion of a workshop, participants are able to: indicate the need for testing water in a catchment system; identify what to test for, and how and when, to test water in a catchment system; and recall what rat lungworm disease is and how it is transmitted.

We invited participants to complete a one-page, voluntary paper survey at the conclusion of the workshops addressing rainwater catchment systems, maintenance practices, and water use. Workshop participation and provision of published outreach materials were not tied to survey participation. Participants were instructed that they could elect not to participate in the survey and were free to decline to answer one or more survey questions. No individually identifying information was collected or maintained with survey responses and selected survey data presented here are in aggregate. Participants were informed that the survey was intended to gain insight on future outreach that might benefit communities in the state of Hawaii. A survey response rate was calculated by dividing the total number of completed surveys by the total number of workshop attendees and multiplied by 100. As survey participants were allowed to skip questions, we considered a survey complete if it was actively handed in at the completion of a workshop with one or more questions answered. To further explore nonresponse bias, item nonresponse rate at the question level was also calculated. Item nonresponse rate was calculated by dividing the total number of blank responses per question by the total number of surveys handed in and multiplied by 100.

The survey included specific questions on the uses of captured rainwater, rainwater catchment system components and treatments, and the frequency of testing of captured rainwater. The survey was not developed to explore specific water tests employed by workshop participants, but to gain insight on the perceptions of rainwater catchment system owners and users regarding water testing in general. While more detailed information on water testing is desirable, survey length and content were crafted to optimize participation and response rate. The survey also included a retrospective pretest section that specifically addressed the learning outcomes described above.

The survey retrospective pretest section, also known as a "post then pre*"* design (Rockwell and Kohn 1989; Davis 2003), allowed us to investigate participants' perceptions of their rainwater catchment knowledge after (post) and before (pre) workshops using a single survey per participant at the end the workshop. Post then pre survey design asks participants to reflect upon their pre workshop knowledge after they have reported their post workshop knowledge. A post then pre design is appropriate when seeking to reduce the burden on participants of taking two surveys, when time with participants is limited, and to reduce response shift bias (Rockwell and Kohn 1989; Davis 2003; Hill and Betz 2005). The post then pre section documented the change in participants' beliefs after participation in the workshop regarding the specific learning outcomes described above. This section also included two questions aimed at detecting future changes in behavior as result of workshop participation for which a pre response was not requested. This section of the survey is included in Table 4.

To quantify changes in perception before and after workshop outreach, responses to the post then pre survey section were scored numerically: a negative one (-1) for each *Disagree* answer, a zero (0) for each *Don't Know* answer, and a positive one (+1) for each *Agree* answer. For each participant response, the change in score was calculated (Δ score = post score - pre score). The possible range of change in score values per question was -2 to +2; the larger the number, the greater perceived knowledge gain. For example, if a respondent checked *Disagree* (-1) for a statement pre workshop and *Agree* (+1) for the same statement post workshop, the change in score is +2, the greatest possible gain in perceived knowledge. The average change in score for each question for all respondents pooled was calculated to provide a quantitative measure of perceived knowledge

change for the learning outcome addressed by each question. The change in score values also provided an indirect measure of outreach effectiveness.

To qualitatively estimate the potential adequacy of rainwater catchment systems currently in use by survey participants, we evaluated the system components and treatments reported by each participant. We defined potential adequacy as any combination of system elements and treatments in place that might reasonably be expected to provide safe potable water, inclusive of the removal of disease causing organisms, as described by Macomber (2010). For a system to be deemed potentially adequate we required, at minimum, either 1) an ultraviolet (UV) light disinfectant component coupled with fine physical filtration or 2) the use of chlorine as a disinfectant coupled with fine physical filtration. Estimates of potential adequacy did not include parameters of system maintenance that can affect water quality, such as frequency or level of chlorine treatment or routine cleaning of UV bulbs, nor did it factor in the presence or absence of a water tank cover. Thus, potential adequacy *is not* an estimate of active systems that have been confirmed to be producing a safe water supply; rather it reflects an estimation of systems that have the potential to do so with appropriate maintenance, assuming respondents' systems were representative of existing systems on Hawaii Island.

Statistical analysis was conducted where noted in the text when sample sizes and assumptions allowed using Fisher's exact test.

Results

Rainwater Catchment Water Uses

Of a total of one hundred thirty-eight (N=138) workshop participants, 110 participants completed surveys for a survey response rate of 80%. One hundred eight (N=108) of the 110 respondents provided information on their uses of rainwater catchment water in response to the survey question: "What do you use your rainwater catchment system water for?" (Table 1). The nonresponse rate for this question was 1.8%; two survey participants declined to answer this question. Nearly one-half (48%; N=52) of those providing information on uses of their rainwater catchment system used harvested water as a potable source. Eighty-nine percent (N=96) of survey respondents answering this question reported using rainwater catchment for drinking water *or* bathing water. Other uses of rainwater catchment that were identified by a majority of participants were agriculture and gardening, and other household uses. Just over 40% of those answering this question used harvested rainwater for pets or livestock. All survey responses identifying uses of rainwater catchment are presented in Table 1.

Table 1. Reported uses of rainwater catchment water on Hawaii Island in 2015. The number of survey responses and percent of survey respondents by use in response to the rainwater catchment survey question, "What do you use your rainwater catchment system water for?"

Reported use of rainwater catchment water	# Survey responses	% Survey respondents
Drinking water	52	48
Bathing water	92	85
Other household supply	92	85
Irrigation/gardening	81	75
Pets or livestock	45	42
Other	10	9
I do not have a catchment system	11	10

Please note individual respondents (N=108) could identify multiple uses. Percent of survey respondents' values do not include those who declined to respond to this question.

Rainwater Catchment System Components or Treatments

Of persons participating in the survey that owned or used a rainwater catchment system and provided a response to the survey question: "Do you have and/or use any of the following with your rainwater catchment system?" (N=89), the most common components or treatments used were: fine filtration (61%), chlorine bleach (52%), tank covers (52%), and UV light "filter" (49%) (Table 2). Rainwater catchment tank covers were not reported to be in widespread use, with just over one-half of those surveyed (52%) indicating they used a cover on their water tanks. Of those reporting use of a tank cover, most used a soft rather than hard cover (38 of 46). The nonresponse rate for this question was 19% inclusive of 11 survey participants who indicated they did not have a rainwater catchment system; if these 11 records are excluded, the nonresponse rate for this question was 9%. All survey responses identifying rainwater catchment system components and treatments are provided in Table 2.

Of all respondents who owned or used a rainwater catchment system (N=99), we estimate 66% (N=65) had rainwater catchment systems in place and used treatments that were potentially adequate, i.e. could reasonably be expected to result in safe potable water with appropriate maintenance. The 66% estimate of potentially adequate systems includes ten systems reported in use for which no data on components or treatments were provided; these ten systems were not considered potentially adequate in calculations.

Rainwater Catchment System Water Testing

Overall, 56% (54 of 96) of those providing information on their rainwater catchment testing

Table 2. Reported rainwater catchment system components and treatments on Hawaii Island in 2015. The number of survey responses and percent of survey respondents by component or treatment in response to the rainwater catchment survey question, "Do you have and/or use any of the following with your rainwater catchment system?"

Reported rainwater catchment system components and treatments	# Survey responses	% Survey respondents
Ceramic filter	2	2
Ultraviolet (UV) light filter	44	49
Chlorine bleach	46	52
Activated carbon	32	36
Reverse osmosis	5	6
Distillation	0	0
Boiling water	7	8
Solar disinfection	0	0
Hard tank cover	8	9
Soft tank cover	38	43
Sediment (coarse) filters	33	37
Ozonation	1	1
Fine filters	54	61
Other	4	4

Please note individual respondents (N=89) could identify multiple components or treatments. Percent of survey respondents' values do not include those who declined to respond to this question.

frequency in response to the survey question "Please indicate if and/or when you last tested the water in your rainwater catchment system" reported never testing the water in their rainwater catchment system (N=43) or did not know or remember when they had last tested the water in their catchment system (N=11). Forty-four percent (42 of 96) reported some history of testing the water in their catchment system. One-third of those responding to this question reported they had tested their captured rainwater within the last year and an additional 10% reported testing harvested rainwater over one year ago. The nonresponse rate for this question was 13% inclusive of 11 survey participants who indicated they did not have a rainwater catchment system; if these 11 records are excluded, the nonresponse rate for this question was 3%. All survey responses on rainwater catchment system water testing frequency are provided in Table 3.

Of the subset of survey respondents that used rainwater catchment for drinking water or bathing water (N=96), over one-half (53%, N=51) had never tested the water in their system or did not know/remember if or when they had last tested their catchment water and 44% had some testing history (N=42) (Figure 1A). However, those who drank their rainwater catchment water were significantly more likely to have tested their water within six months as compared to non-drinkers and this was also significant for testing within the last year ($p < 0.005$ for both, Fisher's exact test). Those who drank or bathed in their rainwater catchment water were also significantly more likely to have tested their water within six months as compared to non-drinkers or bathers and this was also significant for testing within the last year ($p < 0.05$ for both, Fisher's exact test).

Those with rainwater catchment systems qualitatively characterized as potentially adequate, i.e. systems reasonably expected to result in safe potable water as a result of appropriate components and treatments, were also significantly more likely to have tested their water within six months as compared to those with potentially inadequate systems (this was also significant for testing within the last year, $p < 0.05$ for both, Fisher's exact test) (Figure 1B).

Insufficient sample sizes prevented statistical analysis of variation in rainwater catchment parameters with geographic (workshop community) location.

Learning Outcomes and Outreach Efficacy

Survey participants' perceptions on rainwater catchment and associated learning outcomes after (post) as well as before (pre) workshop participation are summarized in Table 4. Across all learning outcomes there is a trend toward agreement with the survey question statements from pre to post workshop. The greatest area of

Table 3. Reported rainwater catchment water testing frequency on Hawaii Island in 2015. The number of survey responses and percent of survey respondents by frequency in response to the rainwater catchment survey question, "Please indicate if and/or when you last tested the water in your rainwater catchment system."

Reported rainwater catchment system water testing frequency	# Survey responses	% Survey respondents
Never	43	45
Last 6 months	24	25
6 months to 1 year ago	8	8
Over 1 year ago	10	10
Don't know/remember	11	11
Total	96	99

Please note that the number of individuals responding to this question was ninety-six (N=96). Percent of survey respondents' values do not include those who declined to respond to this question and are rounded to the nearest integer.

perceived knowledge pre workshop related to the statement, "Water in a rainwater catchment system should be tested regularly" with 65% of those answering this survey question agreeing with this statement; post workshop agreement rose to 98%.

With regard to the survey statements, "I know *what* to test for in my catchment system;" "I know *how* to test the water in my catchment system;" and "I know *when* to test the water in my catchment system," 73%, 75%, and 80%, respectively, of those responding to these statements pre workshop answered either *Disagree* or *Don't Know.* Post workshop, the percentage of those responding *Disagree* or *Don't Know* to these statements

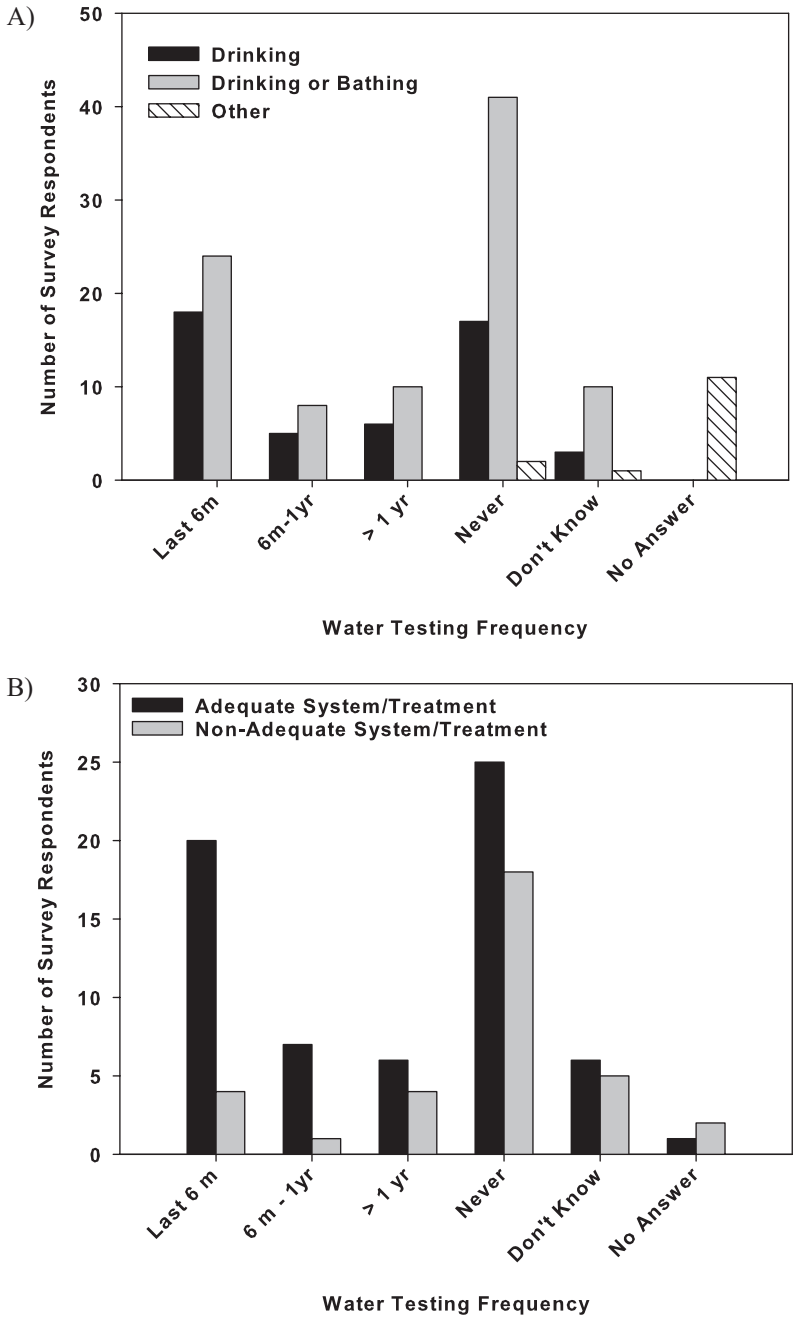


Figure 1. Rainwater catchment water testing frequency, Hawaii Island, 2015 by A) use of rainwater catchment water, and B) potential adequacy of rainwater catchment system components or treatments reasonably expected to result in safe potable water.

decreased to 8% (I know *what* to test for in my catchment system), 2% (I know *how* to test to test the water in my catchment system), and 12% (I know *when* to test the water in my catchment system). Before workshop participation, 46% of those answering the survey question statement, "I know what rat lungworm disease is and how it is transmitted" agreed with this statement; post workshop this value increased to 91%.

After workshop participation, 67% (N = 61) of the 91 participants who provided an answer to the survey question, "I will change my catchment system elements as a result of this workshop" *Agreed* with the foregoing statement. With regard to the statement, "I will change how I maintain my catchment system as a result of this workshop," 81% (N = 93) of participants who provided an answer to this survey question *Agreed* with this statement.

When perceived knowledge gains are quantified via numerical scoring of responses, the greatest perceived gains in knowledge were in understanding *when* to test the water in a rainwater catchment system, followed by *what* to test for in a catchment system, followed by *how* to test the water in a rainwater catchment system (Table 5). A positive

Table 4. Perceptions of participants before and after attending a public workshop on rainwater catchment best practices on Hawaii Island in 2015 from a retrospective pretest survey. This table provides survey questions in the retrospective pretest, associated learning outcomes, question sample size (N), question nonresponse rate, and number of responses by category (Disagree, Don't Know, or Agree).

Survey Question (*Learning Outcome)	N	Question Nonresponse Rate (%)	Before Workshop (Pre)			After Workshop (Post)		
			Disagree	Don't Know	Agree	Disagree	Don't Know	Agree
Water in a rainwater catchment system should be tested regularly.*	99	10	4	31	64	0	2	97
I know *what* to test for in my catchment system.*	98	11	13	59	26	0	8	90
I know *how* to test the water in my catchment system.*	99	10	13	61	25	0	2	87
I know *when* to test the water in my catchment system.*	98	11	16	62	20	1	11	86
I understand what Rat Lungworm disease is and how it is transmitted.*	97	12	11	41	45	1	8	88
I will change my catchment system elements as a result of this workshop.	91	17	N/A†	N/A†	N/A†	8	22	61
I will change how I maintain my catchment system as a result of this workshop.	93	15	N/A†	N/A†	N/A†	6	12	75

†These two survey questions did not include a *Before Workshop (Pre)* component for respondents to answer.

perceived gain in knowledge was also achieved in an increased understanding of what rat lungworm disease is and how it is transmitted. Pre workshop, the majority of survey respondents (65%) already agreed with the statement, "Water in a rainwater catchment system should be tested regularly," and the smallest realized gain in perceived knowledge was in this area (Table 5).

Discussion

Rainwater Catchment Water Uses

Though residential rainwater catchment is assumed to be an important water source for those in areas not served by municipal water on Hawaii Island, to our knowledge this is the first published information on the private use of captured rainwater in Hawaii. Our results support the conclusion that a majority of rainwater catchment users on Hawaii Island rely on their harvested water for uses that may, absent appropriate rainwater catchment system components and practices, expose them to health concerns related to water quality. Not surprisingly, uses of particular concern are drinking and bathing. That nearly one-half of those providing information report using their harvested rainwater as a potable water source illustrates application of best practices in the capture and treatment of stored water cannot be over-emphasized. Of additional concern is the majority use of harvested rainwater as bathing water. Bathing is a potential route of exposure to waterborne pathogens, even absent intentional ingestion of bathing water. Incidental ingestion, for example via the mouth or nose during bathing, could result in exposure to insufficiently disinfected rainwater catchment water.

The question nonresponse rate for information on uses of rainwater catchment was the lowest in our survey at 1.8%, suggesting minimal item nonresponse bias on this topic. Our overall survey response rate of 80% is high, increasing confidence in our results. Our calculation of survey response rate did not factor number of questions answered in determining a completed survey (as respondents were allowed to skip questions), complicating comparisons to survey response rates that include such a factor. For comparison, if we define a completed survey as one on which 80% of questions are answered in our calculation of response rate, our survey response rate is 61%, potentially increasing survey nonresponse bias.

Worldwide, in areas that lack municipal water

Table 5. Quantified perceptions of participants before and after attending a public workshop on rainwater catchment best practices on Hawaii Island in 2015 from a retrospective pretest survey. Responses were assigned numerical scores: a negative one (-1) for each *Disagree* answer, a zero (0) for each *Don't Know* answer, and a positive one (+1) for each *Agree* answer. For each respondent who answered both before (pre) and after (post) for a given question, a change in score was calculated (Δ score = post score - pre score). The mean for all scores per question for all respondents pooled was calculated to provide quantitative insight on perceived knowledge gained and evaluate learning outcomes. This table provides survey questions in the retrospective pretest/learning outcomes, question sample size (N), mean score pre outreach, mean score post outreach, and mean Δ score.

Survey Question (Learning outcome)	N	Mean Score Before (pre)	Mean Score After (post)	Mean Score Δ
Water in a rainwater catchment system should be tested regularly.	99	0.61	0.98	+0.37
I know *what* to test for in my catchment system.	98	0.14	0.92	+0.78
I know *how* to test the water in my catchment system.	99	0.12	0.88	+0.76
I know *when* to test the water in my catchment system.	98	0.04	0.87	+0.83
I understand what Rat Lungworm disease is and how it is transmitted.	97	0.35	0.90	+0.55

but are developed for residential or agricultural use, reliance on rainwater harvesting is likely to increase. Climate change has also been proposed as a worldwide driver of increased use of rainwater harvesting (Pandey et al. 2003). In some areas, alternative sources of freshwater do not exist or are financially out of reach to individuals. For example, water well drilling is relatively expensive if wells must be drilled through rocky substrate, such as oceanic island volcanic rock. Even where municipal water is available, establishing a water line connection and meter may be prohibitively expensive, as may be trucking in fresh water. Thus, many households are financially or functionally obligate rainwater catchment system users. Given the documented uses of captured rainwater for diverse household needs, including potable water, rainwater catchment system elements, maintenance, and associated water treatment practices may directly impact human health in rural Hawaii Island communities and elsewhere.

Rainwater Catchment System Components or Treatments

A wide range of rainwater catchment system components and treatments are in use on Hawaii Island with varying expected efficacy with regard to providing a safe and reliable water supply. The frequency of use by survey respondents of fine filtration (61%), chlorine bleach (52%), and a UV light component (49%) in the treatment of stored rainwater is encouraging, as these components, when used in proper combination and maintained appropriately, can increase the likelihood of a safe and sustainable water supply. However, to maximize the probability of achieving a safe, reliable water supply, such components and treatments must be employed according to the best available science. For example, the concentration and frequency with which stored water is treated with chlorine affects the reliability of disinfection, but also alters the taste and odor of water complicating treatment (Flanagan et al. 2013). Further, chlorine alone is not adequate to produce safe drinking water due to its limited efficacy on *Giardia spp.* or *Cryptosporidium Spp.* cysts (Korich et al. 1990; McAnulty 1994). Ultraviolet light treatment and appropriate filtration, when combined, have been demonstrated to effectively remove pathogens from water when used and maintained correctly (National Sanitation Foundation 2016). However, UV light component users may be unaware that glass-like quartz UV bulb sleeves must be routinely cleaned to allow light to penetrate and effectively disinfect the passing water stream and that the turbidity of treated water can impact effectiveness (Macomber 2010 provides a summary of water treatment systems). Additionally, some UV light component users are unaware that a UV light filtration unit must run continuously, rather than intermittently with water demand, to ensure a safe water supply (Macomber, unpublished data). Professional outreach is needed to assist rainwater catchment system users in establishing and maintaining systems that increase the probability of generating a safe and sustainable water supply.

The lack of use of rainwater catchment water tank covers by about one-half of those surveyed identifies an area of opportunity with regard to improving the quality of stored rainwater, i.e. through increased tank cover use. The predominant use of soft rather than hard covers likely reflects economic drivers inclusive of the ability to fashion soft covers for standard as well as non-standard (e.g. above-ground swimming pool) water tanks. While soft tank covers are generally less expensive and can be adapted to fit a wide range of tank types, achieving a consistent seal between the tank rim and cover can be challenging. In addition to the utility of tank covers in reducing detritus entering stored water supplies, uncovered rainwater catchment tanks, or those with compromised or poorly fitting covers, may play a significant role in the establishment and propagation of mosquito-borne disease. Rainwater catchment tanks on Hawaii Island were directly implicated in a dengue virus outbreak in 2015-2016 and the control of mosquito breeding in such tanks identified as essential by the Hawaii State Department of Health (2015; 2016). While at press time, the U.S. Centers for Disease Control and Prevention (CDC) have reported no locally acquired cases of the Zika virus in the State of Hawaii (CDC 2016a), the mosquito species that transmit dengue fever, *Aedes aegypti* and *Aedes albopictus*, are the same as those that transmit the Zika virus (CDC 2016b). Local mosquito-borne Zika transmission has occurred in the U.S. Territories of Puerto Rico and the U.S.

Virgin Islands (CDC 2016a), areas where rainwater harvesting is common. Rainwater catchment tanks accessible to other animals may also pose a human health risk via microbial contamination of water via feces, urine, or when animals enter and die inside water tanks (Macomber 2010).

The parasitic nematode that causes angiostrongyliasis, commonly known as rat lungworm disease (Chen 1935), is also of concern to rainwater catchment system users. A species of invasive semi-slug now established in Hawaii is a known intermediate host of rat lungworm disease and has been proposed as a vector for rat lungworm transmission to humans (Hollingsworth et al. 2007). This species of semi-slug, *P. martensi,* has been observed in and near water tanks (Hollingsworth et al. 2007). Increasing the use of properly fitted tank covers on rainwater harvesting tanks is a straightforward action that has the potential to reduce community exposure to waterborne and vector-borne diseases in Hawaii and other areas where rainwater catchment is used.

Our evaluation of rainwater catchment systems indicates that while the majority of systems reported (66%) may potentially be expected to result in a safe water supply *assuming they are maintained according to recognized best practices,* over one-third (34%) of systems are of questionable efficacy and safety. Almost certainly, not all systems are maintained in an optimized fashion and thus our estimate of adequacy is liberal. Estimates of adequacy neither account for the use or non-use of rainwater catchment tank covers, nor the condition or application of tank covers in use, increasing the potential error of these estimates. The 9% question nonresponse rate for information on rainwater system components and treatments for those who have or use rainwater catchment suggests some sensitivity to this topic by respondents. Further, workshop attendance may reflect a non-random sample of rainwater catchment system owners and users. Attendance may favor those of sufficient socio-economic means to attend and those for whom cultural norms allow for broad gender and age-class participation in such forums. Additionally, attendance may be positively biased toward those who speak or understand the English language used to deliver workshops and on surveys. Nearly one in five (19%) Hawaii County residents speak a language other than English at home and of these 60% speak a Pacific Island language (Department of Business, Economic Development and Tourism 2015). Acknowledging the unknown quantification of identified and unidentified biases and associated ramifications, we present these outcomes as a "best case scenario" with the actual percentage of rainwater catchment systems that may pose a human health risk likely greater than the 34% estimated.

Rainwater Catchment System Water Testing

The quality of harvested rainwater may vary considerably with capture circumstances and location, system components, physical or chemical water treatments, tank/cistern composition and condition, pathogen exposure, and other variables. Testing of captured and stored rainwater can provide information on water quality and potential risks to human health while informing appropriate treatments. Though water testing was reported by less than 50% of respondents, before outreach most (67%) agreed with the statement, "Water in a rainwater catchment system should be tested regularly." Thus, workshop attendance was likely stimulated in part by a general knowledge that harvested rainwater should be tested coupled with a lack of specific knowledge on the "what," "how," and "when" of appropriate water testing.

Harvested rainwater testing frequency reported here falls well below recommended levels. Optimal water testing frequency is dependent on individual circumstances, such as storage tank condition, suspected contamination, increased water turbidity or changes in water color or taste, frequency of disinfection, presence of lead pipes, and on Hawaii Island, acid rain due to volcanic emissions, among other variables (Macomber 2010). On Hawaii Island periodic testing of harvested rainwater is recommended at six month intervals or whenever there is a change in a system or system's water such as: a change in water odor or color; after installation of a new treatment system; or after decontamination or other treatments of an existing system (Macomber, personal communication). Specific water quality tests that may be appropriate for rainwater catchment systems are detailed in Macomber (2010); increased use of the appropriate water quality tests for individual concerns and

circumstances would likely increase access to safe drinking water in rural Hawaii Island communities.

Though reported water testing frequency reported here does not meet recommended levels overall, our results suggest those who rely on harvested rainwater for potable or bathing needs have a higher frequency of water testing. Therefore, those who use their harvested rainwater in ways that may pose a relatively greater health risk may also have a greater awareness of these risks and increased commitment to water quality testing. That those with rainwater catchment systems characterized as potentially adequate had also tested their water more recently than those with potentially inadequate systems may reflect socioeconomic status. The low question nonresponse rate of 3% for information on water testing frequency supports these conclusions, though biases associated with workshop attendance remain undefined. Regardless, those in communities who may be most vulnerable or underserved may also be at greater health risk as a result of compromised water quality from inadequate rainwater catchment systems and insufficient water testing.

Learning Outcomes and Outreach Efficacy

Professional community outreach was effective in changing perceptions on rainwater catchment practices in rural Hawaii Island communities. Outreach efficacy is further supported by the majority of respondents reporting they would change their behavior related to rainwater catchment system practices, components, and treatments as a result of workshop outreach.

Achievement of learning outcomes is indirectly evidenced via the positive trend in mean numerical scores on the post then pre survey section (Table 5). The positive shift calculated for all responses indicates gains in perceived knowledge for all learning outcomes. Comparing changes in scores for the various learning outcomes reveals most respondents understood they should test the water in a rainwater catchment system, but did not have the knowledge base to do so prior to outreach engagement. Question nonresponse rates for the post then pre survey section were the highest in our survey, ranging from 10% to 17% (Table 4). Higher nonresponse rates may reflect sensitivity to question content, added complexity of the post then pre survey section, or other factors that may introduce bias. Nonetheless, community outreach on specific aspects of harvested rainwater testing is clearly a service area that could be fruitfully expanded on Hawaii Island and other rural areas that rely upon rainwater catchment.

A positive perceived gain in knowledge was also associated with the learning outcome associated with rat lungworm disease. Given the complex etiology of this disease, this positive gain is noteworthy and demonstrates outreach effectiveness. Similar outreach is likely to be critical in responding to emerging diseases in the state of Hawaii including those historically (e.g. dengue virus), and potentially (e.g. Zika virus) associated with rainwater catchment. Given that the design, maintenance, and water treatment of systems harvesting rainwater directly determine the quality of water available for use, the adoption of best practices by owners and users will increase access to safe and sustainable drinking water in Hawaii Island communities.

Conclusions/Findings

- Rainwater catchment is relied upon in rural Hawaii Island communities for potable or bathing water.
- Less than one-half of rainwater catchment system users reported testing captured rainwater regularly and about 66% are estimated to have rainwater catchment systems that may reasonably be expected to produce safe drinking water.
- Reported testing frequency of captured and stored rainwater falls below recommended levels and varies significantly with the use of captured rainwater and system adequacy.
- Community outreach was effective in changing perceptions regarding rainwater catchment practices in rural Hawaii Island communities.
- There is a demonstrated need for ongoing, professional, evidence-based outreach to serve rainwater catchment system users in Hawaii.
- Research aimed at identifying and understanding the barriers to achieving well-designed and maintained residential rainwater catchment systems on Hawaii Island is recommended.

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Land Use Modification and Changing Redox Conditions Releases Selenium and Sulfur from Historic Marsh Sediments

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Abstract: San Diego Creek Watershed forms the southern end of the Coastal Plain that covers much of Los Angeles County and Orange County, California. Prior to 1900, the central part of the watershed was marshland, and the edges of the watershed were used for grazing sheep and cattle. After 1900, cattle and sheep grazing were displaced by irrigated agriculture. Drainage ditches and channels were constructed to drain the marshes to "reclaim" the land for agriculture. Today, the drainage ditches and channels still exist in the watershed, which has undergone massive urban growth. Shallow groundwater discharges into these channels and ditches, which then flows as surface water, into Upper Newport Bay a thriving ecological habitat. Surface flows in these channels usually exceed the United States Environmental Protection Agency (EPA) aquatic water quality criterion for selenium (Se) of 3.1 µg/L (lotic) for protection of aquatic life. Selenium in surface flows is caused by groundwater inflows. The highest concentrations of Se in shallow groundwater in the watershed coincide with the marshland area that was displaced by agriculture. Concentrations of Se in shallow groundwater beneath the former marsh area often exceed 25 µg/L and are as high as 478 µg/L. In areas where marshes were absent, concentrations of Se in groundwater are usually less than 25 µg/L. In the marsh, Se accumulated due to chemically reducing conditions in the organic-rich marshland soils that caused it to precipitate as elemental Se(0) and metal selenides, Se(-II). We hypothesize that the elevated concentrations of Se in groundwater where the marshes once existed are a direct result of the destruction of the marsh. Today, oxidizing groundwater flows through the soils where the marshes once existed, remobilizing Se as selenate, a water soluble and oxidized form of Se(+VI) that is highly mobile in aquifer systems.

Keywords: *gaining stream, perennial stream, storm drain, seepage, watershed, bioaccumulation*

This paper documents the sources, fluxes, and spatial distribution of selenium in the surface water and shallow groundwater of the San Diego Creek Watershed, south-central Orange County, California. Boundaries of the study area include the Santa Ana Mountains to the north, the San Joaquin Hills to the southeast, and Upper Newport Bay to the south (Figure 1). Total land area in the study region is approximately 200 square miles.

The San Diego Creek Watershed forms the southern end of the Coastal Plain that covers much of Los Angeles County and Orange County, California. The aquifer beneath the watershed is composed of thick sequences of alluvial, fluvial, and marine sediments of Cretaceous to Quaternary age (Herndon and Reilly 1989).

Tectonic uplift and cycles of subsidence in the basin and corresponding changes in sea level have created many depositional environments over time. The deeper (older) sediments in the basin were deposited in a marine environment. As the coastal landmass was uplifted, the depositional environment changed to a nearshore, lagoonal environment. The lagoonal environment was later displaced by an alluvial fan and marshland

environment, which persisted until the historic period of agricultural development in the region (Camp Dresser & McKee, Inc. 1985). The central part of the basin was marshland as recently as 1900, and the edges of the basin were used for grazing sheep and cattle (Figure 1). The marsh was known to the locals of the time as the "Swamp of the Frogs Marsh". After 1900, cattle and sheep grazing were displaced by irrigated agriculture. Drainage ditches and channels were constructed to drain the marshes and reclaim the land for agriculture. Today, the ditches and channels still exist in the San Diego Creek Watershed, which has since undergone massive urban growth.

Problem Statement

Selenium is one of several elements and minerals that are needed in the diets of humans and many animals. Trace amounts of selenium contained in vegetables, other forms of vegetation, and water typically satisfy dietary requirements in humans and animals. However, selenium can become toxic at elevated concentrations in vegetation or water.

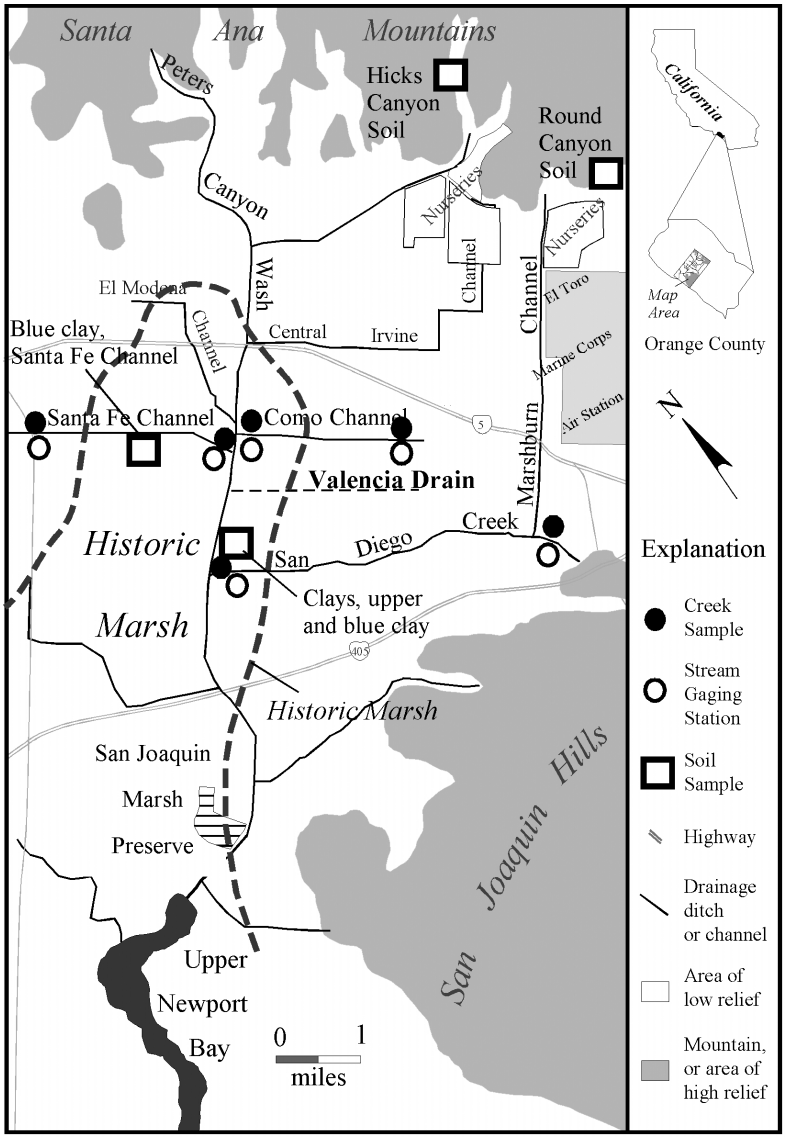


Figure 1. Study area location map covering a subregion of San Diego Creek Watershed, showing location of the historic marsh region in San Diego Creek Watershed, upstream and downstream sampling and gage stations on San Diego Creek, Como Channel, and Santa Fe Channel, and soil sampling locations. Dashed line is historic marsh boundary.

Selenium can also be a harmful element in aquatic habitats, even when concentrations are much lower than drinking water standards for humans and animals. In 1983, waterfowl deformities at Kesterson Reservoir, California were causally linked to selenium found in irrigation drainage systems. This discovery focused attention on selenium as a harmful toxin (Engberg et al. 1995). Plants absorb selenium through their roots. Insects and other organisms eat these plants, and predatory birds eat the insects and other organisms, causing bioaccumulation of selenium in the food chain (Lemly and Smith 1987; Lawrence Berkeley National Laboratory 1998). Fish and other aquatic organisms are also exposed to bioaccumulation of selenium.

In 1987 and again in 1999, the EPA recommended a 96-hour, 5 µg/L chronic water quality criterion for selenium concentration in surface water (EPA 2016). Drinking water for human consumption has a much higher Maximum Contaminant Limit in the United States of 50 µg/L. Although site specific criteria have been recommended for the San Diego Creek Watershed based on extensive studies (Nitrogen and Selenium Management Program Working Group 2009), in 2016 the national EPA revised its criterion to include new guidelines that recommend water quality limits of 1.5 µg/L (lentic) and 3.1 µg/L (lotic) over 30 days for surface water (EPA 2016). These criteria are combined with tissue concentration guidelines that together protect beneficial uses, including wildlife and aquatic life (EPA 2016). The existing water quality data indicate that shallow groundwater in the San Diego Creek Watershed often exceeds 20 µg/L selenium, reaching concentrations as high as 478 µg/L (Silverado 1997; Hibbs and Lee 2000). Thus, there was a need to determine if selenium-laden groundwater seeps into surface water in the watershed, placing aquatic organisms and waterfowl at risk.

Purpose of Investigation

The purpose of this study is two-fold: 1.) to characterize the interrelationships between surface water and shallow groundwater in the San Diego Creek Watershed; and 2.) to determine the sources and concentrations of selenium in surface water and groundwater in the watershed. With an understanding of the relationships between shallow groundwater and surface water in the study area, it is possible to determine the amount of groundwater that seeps into surface channels, becoming part of the surface flow. Similarly, by assessing water quality in the shallow aquifer, it is possible to determine if selenium in groundwater contributes to pollutant loading of surface water in the watershed.

A reconnaissance level investigation was conducted from 1999 to 2001, leading to a hypothesis of a source of selenium in the watershed (Hibbs and Lee 2000) known as the "Swamp of the Frogs Marsh Hypothesis." Additional investigations were conducted from 2004 to 2012 to test the hypothesis of the selenium source. The results developed from 2004 to 2012 have not been published except in contract reports (Hibbs et al. 2008). This manuscript is organized to review findings from the earlier reconnaissance study, and to present new information evaluating the earlier hypothesis based on extensive post-audit data sets. New information is developed using environmental isotopes and selenium speciation analysis of water and soils that were not available in the reconnaissance study completed by Hibbs and Lee (2000).

Methods

Field Methods

A variety of methods were used to collect the samples from the diverse number of sites investigated. These included surface water and groundwater samples and streambed and land surface sediment samples. Most field water samples were collected via grab sampling in polyethylene and glass bottles. Some samples were collected using a peristaltic pump with polyethylene tubing. Sample bottles and tubing were soaked and triple-rinsed in deionized water and inspected prior to field usage. Additionally, all bottles (and tubing at sites where the pump was used) were triple-rinsed with the water being sampled in the field prior to filling.

Samples collected for anion analysis and selenium speciation were filtered and kept refrigerated below a temperature of 4˚C. Samples

analyzed for dissolved selenium were filtered and acidified to less than pH 2 with nitric acid (HNO_3) then kept refrigerated (< 4˚C). For stable isotopes of sulfur in sulfate, unpreserved sample was collected in a 250-mL polyethylene bottle filled to the rim to ensure no headspace remained in the bottle. Samples were stored on ice until returned to the laboratory. All sites had conductivity, temperature, dissolved oxygen, and pH measured in the field using portable meters. Meters were calibrated according to manufacturer's guidelines.

Surface water sampling included grab sampling and width/depth integrated sampling, depending on judgements based on conditions observed in the field. Monitoring well sampling was done with battery operated purge pumps. Before sampling groundwater from monitoring wells, the wells were purged two or three well volumes until index parameters stabilized. Surface water discharge measurements were made using Marsh-McBirney Model 2000 portable flowmeters and top-setting wading rods. A straight stream reach with a relatively symmetrical channel cross section and shallow depth of flow was chosen. Stream gaging followed USGS procedures (Buchanan and Somers 1969; Turnipseed and Sauer 2010).

Sediment samples were collected using stainless steel hand augers or stainless steel shovels or spades. Auger samples were collected, properly identified (depth and location information), and sealed in glass jars. After the soil sample was collected and preserved in an ice chest and later in a refrigerator for shipment to the laboratory for chemical analysis, a portion of the soil sample that had been separated from the main sample was examined at the recovery site for color, field grain size characteristics (qualitative such as silty-sand, clayey-sand, silt), organic matter, odor (organic matter, hydrogen sulfide), and cohesiveness.

Laboratory Methods

Anion analysis was conducted by ion chromatography in the Hydrogeology Laboratory at California State University-Los Angeles. Selenium analysis was performed in reconnaissance data sets (collected between 1999 and 2001) using inductively coupled plasma – optical emission spectrometry (ICP-OES) by Associated Laboratories of Orange, California. The detection limit (DL) for selenium by this method was usually 4 µg/L. In subsequent studies, analysis of total dissolved selenium and selenium speciation was conducted by hydride generation atomic absorption (HG-AA) following the method described by Zhang et al. (1999) at the University of California-Riverside, with DL below 1 µg/L. For isotope ratios of sulfur in dissolved sulfate, sulfur was precipitated by adding BaCl at pH of 2 and then combusted at 1030°C with O_2 and V_2O_5 and analyzed using an elemental analyzer coupled with a continuous-flow ion ratio mass spectrometer (IRMS) by the Isotope Geochemistry Laboratory at the University of Arizona. Selenium speciation of soils was done by Applied Speciation of Washington State using extractions and high performance liquid chromatography linked to inductively coupled plasma mass spectrometry (HPLC-ICP-MS).

Findings of Initial Reconnaissance Investigation

Analysis of surface water samples indicates that selenium increases between upstream and downstream sampling stations and remains consistent in 1999 and 2009 data sets (Figure 1, Table 1). All creeks are perennial and samples were collected during a dry part of the season. No rain was recorded in the area for at least two weeks prior to the collection of all samples.

Selenium in San Diego Creek increased from 2.9 to 4.0 µg/L at the upstream station to 18.0 to 21.2 µg/L above the confluence of San Diego Creek and Peters Canyon Wash, a distance of 3.9 miles downstream (Figure 1, Table 1). Selenium in Como Channel was below 4.0 µg/L at the upstream sampling point, and tested at 33.4 to 38.0 µg/L at the confluence with Peters Canyon Wash, a distance of only 2.2 miles downstream. Selenium in Santa Fe channel was also below 4.0 µg/L at the upstream sampling location, increasing to 26.7 to 32.0 µg/L above the confluence with Peters Canyon Wash (Figure 1, Table 1).

Stream gaging indicates that discharge also increases between upstream and downstream locations in each of these channels (Figure 1, Table 1). The increase in streamflow is attributed to groundwater discharge to creeks. Measurements

Table 1. Results of stream gaging and total selenium analysis at upstream and downstream stream stations in 1999 and 2009 (see Figure 1 for locations).

Channel (Date)	Upstream Flow (ft^3/s)	Downstream Flow (ft^3/s)	Change of Flow (ft^3/s)	Upstream Se Concentration (µg/L)	Downstream Se Concentration (µg/L)	Change of Selenium (µg/L)
San Diego Creek (8/28/1999)	1.63	2.32	+0.69	4.0[a]	18.0[a]	+14.0
San Diego Creek (6/21/2009)	1.25	1.98	+0.73	2.9[b]	21.2[b]	+18.3
Como Channel (5/1/2000)	0.0004	0.44	+0.44	<4.0[a]	38.0[a]	~ +34.0
Como Channel (6/22/2009)	0.001	0.37	+0.37	2.9[b]	33.4[b]	+30.5
Santa Fe Channel (5/1/2000)	0.019	0.46	+0.44	<4.0[a]	32.0[a]	~ +28.0[a]
Santa Fe Channel (6/22/2009)	0.003	0.39	+0.39	1.4[b]	26.7[b]	25.3

[a] Analyzed using ICP-OES by Associated Laboratory of Orange, California (detection limit = 4 µg/L).
[b] Analyzed using HG-AA by University of California – Riverside (detection limit < 0.6 µg/L).

of water levels in nearby water wells indicate that water tables are typically higher than the stream stage in the creeks (Hibbs and Lee 2000). Water wells are very shallow and penetrate only the upper ten feet of the shallow water table aquifer. Water level measurements in the water wells indicate that water tables occur at depths as little as 5 ft below land surface, and rarely exceed 20 ft below land surface. Several springs and weepholes flow perennially into the creeks. Most groundwater discharge to creeks is by direct seepage along channels unlined with concrete grout. Along channels lined with concrete grout, groundwater flows from weepholes at rates as high as 2 gallons per minute.

The increase in selenium concentrations between upstream and downstream sampling locations in creeks is attributed to high concentrations of selenium in groundwater (Figure 2). In this hypothesis, selenium-laden groundwater seeps into the creeks, increasing selenium loads in surface flows. To verify the hypothesis, several water wells, weepholes, and springs were sampled for selenium (Figure 3). Springs, weepholes, and water wells provided samples of the same shallow aquifer zone.

Groundwater sampling confirms the source of elevated selenium is groundwater baseflow. Groundwater concentrations of selenium in areas where the marsh once existed usually exceed 25 µg/L, reaching concentrations as high as 478 µg/L. However, in areas where the marsh did not exist, selenium in groundwater is usually less than 25.0 µg/L (Figure 3). The highest selenium concentrations are clustered about an area that coincides with the interior part of the historic Swamp of the Frogs Marsh (Figure 3). Shallow groundwater sampled throughout the basin also contains 0.3 mg/L to 2.0 mg/L dissolved oxygen, reflecting contemporary oxidizing conditions (Hibbs and Lee 2000; Meixner et al. 2004).

Hypothesis Formulation for Selenium Remobilization from Marsh Deposits

From reconnaissance investigations done in 1999 and repeated in 2009, we found that the selenium concentrations increased between upstream and downstream sampling locations in creeks (Table 1). We attribute this phenomenon to seepage of

selenium-laden groundwater into the creeks that increase selenium loads by several factors.

Selenium concentrations are highest in the aquifer region around Peters Canyon Wash, extending from the area just above El Modena Channel and Peters Canyon Wash to the area just below Santa Fe Channel and Peters Canyon Wash (Figures 1 and 3). This area corresponds to the interior portion of the historic Swamp of the Frogs Marsh.

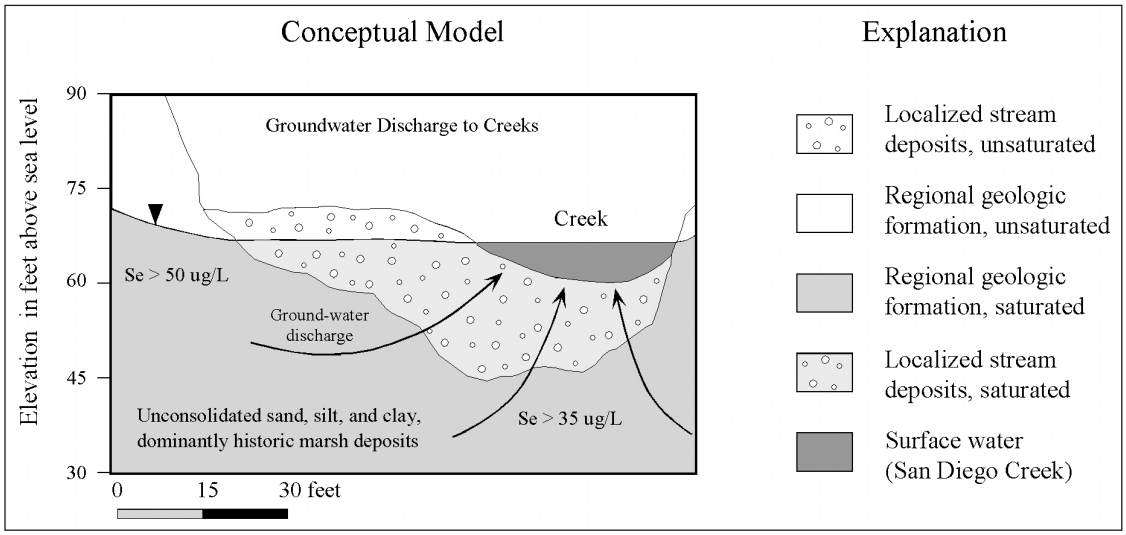


Figure 2. Conceptual model for selenium loading from groundwater baseflows. Extensive groundwater sampling and stream gauging confirmed groundwater baseflow as an important source of dry-weather pollutant loading in San Diego Creek Watershed. Increasing pollutant concentrations between upstream and downstream sampling stations is from the additive inputs of groundwater in specific channels shown in Figure 1 and Table 1.

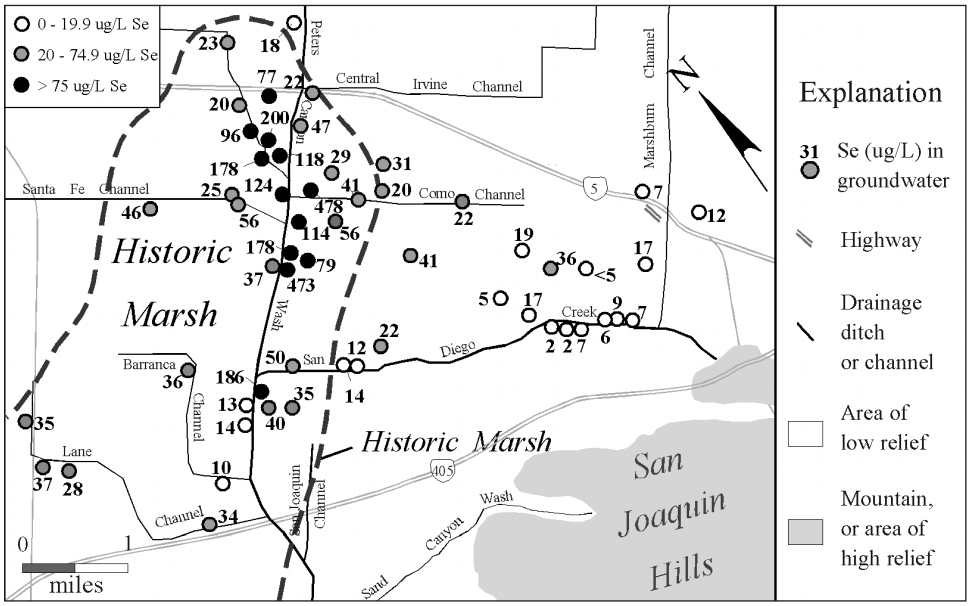


Figure 3. Selenium concentration in groundwater (µg/L). Sample points include shallow water wells, weepholes, and springs. Data indicate that selenium concentrations are highest in the historic marsh areas that were displaced by agriculture and urban development.

Within the interior portion of the former Swamp of the Frogs Marsh, where selenium in groundwater often exceeds 50 µg/L, we discovered a positive correlation between sulfate and selenium concentrations in groundwater. A possible explanation for this correlation is provided by an analysis of the chemistry of these elements. The chemistry of selenium is similar in many respects to the chemistry of sulfur. Both elements are located in Group VI of the periodic table of the elements. Both elements behave somewhat similarly in groundwater (Hem 1985; Johnson et al. 1999).

To assess further the correlation between selenium and sulfur in shallow groundwater, selenium and sulfate couplets in groundwater samples are plotted on a bivariate plot of ions (Figure 4). The relationship between selenium and sulfate becomes apparent when the data are divided into groundwater data sets extracted from areas within the historic Swamp of the Frogs and areas outside the former marsh. Selenium and sulfate are clearly elevated in groundwater within the marsh area. These observations suggest that the sediments of the historic marsh are a likely source of elevated sulfate and selenium in groundwater. The reason for two sub-linear trends in selenium and sulfate in the groundwater dataset inside the former marsh is not entirely understood, but may relate to soil facies changes within the marsh (Figure 4). Chloride data do not show a similar enrichment. Chloride data and water isotopes indicate the enrichment of selenium and sulfate in groundwater beneath Swamp of the Frogs Marsh area is not due to evaporation of groundwater (Hibbs and Lee 2000; Hibbs et al. 2016). Selenium and sulfate have an apparent geological source related to the historic marsh deposits.

Forms of Selenium and Sulfur in Oxidizing and Reducing Environments

The historic Swamp of the Frogs Marsh was described as a "giant peat bog" (Liebeck 1990)

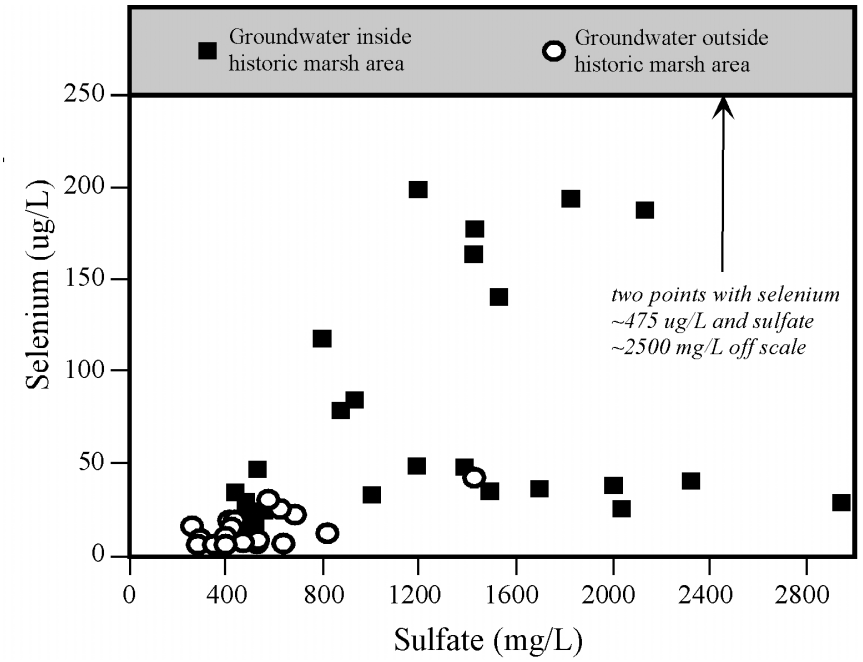


Figure 4. Bivariate scatter plot showing selenium/sulfate couplets for shallow groundwater samples in the study area for groundwater samples extracted outside of the historic marsh area (white circles) and for groundwater samples extracted within the historic marsh area (black squares), showing elevated selenium and elevated sulfate concentrations in groundwater collected in historic marsh area. The reason for two sub-linear trends in selenium and sulfate data in the groundwater data set beneath the marsh is not entirely understood, but probably relate to soil facies features within the marsh containing variable concentrations of selenium. Two anomalous samples with selenium concentration about 475 µg/L (sulfate ~2500 mg/L) are omitted from the graph due to scale. This figure includes most, but not all of the data in Figure 3, due to absence of sulfate data from a few sampling points in Figure 3.

that consisted of impassable marshy and wet areas that were overgrown with willows, tules, and water grasses. Similar wetland and marshy areas today are characterized as moderately to highly reducing (Drever 1997) because abundant organic material and dead and decaying plant tissue at the bottom of these marshy areas create anoxic, reducing environments.

To understand the fate of selenium and sulfur under the anoxic conditions that probably existed in the historic Swamp of the Frogs Marsh, it is necessary to review the different forms of selenium and sulfur in oxidizing versus reducing settings. Selenium can occur in four oxidation states under natural conditions. Selenium exists in its highest (+VI) oxidation state as selenate (SeO_4^{2}), in the (+IV) oxidation state as selenite (SeO_3^{2-}), in the zero oxidation state as elemental selenium (Se(0)), and in its lowest oxidation state (-II) as selenide (Se^{2-}) (Masscheleyn et al. 1990; White and Dubrovsky 1995).

In the highest oxidation state (+VI, selenate), selenium usually occurs as a dissolved ion in oxidizing aqueous environments. Selenate is a very mobile ion in oxic groundwater. In its next highest oxidation state (+IV, selenite), selenium can also exist as a dissolved ion, but frequently exists as a sorbed ion. Therefore, selenite is often somewhat mobile to highly immobile (White and Dubrovsky 1995; Lawrence Berkeley National Laboratory 1998). In the zero, or elemental Se(0) oxidation state, selenium exists as crystalline and amorphous polymorphs (Elrashidi et al. 1987; White and Dubrovsky 1995). In its most reduced form (-II, selenide), selenium is a solid bound with transition metals (Elrashidi et al. 1987). Thus, selenium is observed to cycle geochemically between species in different oxidation states, depending on oxidation/reduction conditions and external biogeochemical constraints (Losi and Frankenberger 1998).

Sulfur also exists as several possible species: SO_4^{2-}(VI), H_2S(-II), HS^-(-II), and S^{2-}(-II). In oxidizing environments, SO_4^{2-}, or sulfate, is the dominant species of sulfur. When SO_4^{2-} dominates, essentially none of the (-II) species (H_2S, HS^-, and S_2^-) are present. When conditions become reducing, the S(-II) species are the dominant forms of sulfur (Domenico and Schwartz 1990).

In the higher (VI) oxidation state, sulfate is dominantly a dissolved ion because there are no solubility constraints that remove the ion from solution. In reducing environments, nearly all of the sulfur is in the reduced (-II) form, and is removed from the system as insoluble metal sulfides and precipitates, although some sulfur may exist as H_2S gas in solution. Thus, sulfur in the oxidized (VI) form is the relatively mobile SO_4^{2-} ion in solution. Upon entering highly reducing settings, sulfate is typically reduced to H_2S and HS^- and is therefore transformed into insoluble metal sulfides and precipitates, or dissolved gas. Sulfur rarely exists in the S_2^- form because pH must be above 9 or 10 for it to precipitate (Hem 1985).

Fate of Selenium and Sulfur in the Swamp of the Frogs Marsh

During the historic period of the Swamp of the Frogs Marsh, any forms of selenium and sulfur that flowed into the marsh were likely dissolved in surface runoff from the highlands as the oxidized forms (SeO_4^{2-} and SO_4^{2-}). Once the oxidized forms of selenium and sulfur reached the anoxic waters of the marsh, these oxidized species were probably reduced to SeO_3^{2-}, elemental Se(0), Se^{2-}, H_2S, and HS^-. These forms would be expected to be removed from the waters in the marsh and sorbed onto solid particles, precipitated as crystalline and amorphous polymorphs, or transformed into volatile gases (Figure 5).

Once immobilized in solid forms, the selenium and sulfur solids would tend to remain stable in the soil substrate as new sediments and organic matter in the marsh continued to accumulate. Cores extracted from old marsh sediments reveal sedimentary facies consistent with anoxic environments, including thick sequences of olive-gray clay, dark gray to dark brown silt and silty clay, and sandy clay and clayey sand that is usually medium to dark brown (Silverado 1997). Some of the core logs show traces of carbonized fragments indicative of decaying plant material.

When the Swamp of the Frogs was drained in the late 1800's and early 1900's, the shallow subsurface was transformed into an oxidizing environment. In fact, the shallow groundwater flow system today is being recharged by oxygen- and nitrate-enriched water that retains some dissolved oxygen and

nitrate as it flows through the old marsh deposits. The groundwater data collected during this study indicate that groundwater contains moderate to relatively high concentrations of dissolved oxygen (usually 0.3 to 5 mg/L), very high ratios of dissolved nitrate to nitrite, and the general absence of iron and manganese. These hydrochemical signatures indicate an oxidizing groundwater flow system.

Oxidizing groundwater flowing through the old marsh sediments today remobilizes the bound forms of selenium and sulfur into their oxidized and mobile forms (SeO_4^{2-} and SO_4^{2-}). Thus, we can account for high sulfate and selenium in groundwater in large part from remobilization of reduced forms of selenium and sulfur as oxidizing soil water and groundwater flows through the historic marsh sediments (Figure 5).

Based on the thickness of sedimentary strata and estimated sedimentation rates (Herndon and Reilly 1989), the selenium and sulfur probably became concentrated during hundreds to thousands of years in the marsh sediments. In more recent times, these elements were remobilized in great amounts by oxidizing soil water and groundwater, reaching concentrations that exceed by many factors the concentrations of selenium that are considered safe in aquatic systems (EPA 2016). Insofar as it has been established that many drainage ditches and channels are replenished by seeping groundwater, it is apparent that the selenium-laden groundwater and surface water exceed EPA (2016) recommended criteria for protection of aquatic life.

Hypothesis Testing

The hypothesis of the remobilization of selenium and sulfur due to drainage of the Swamp of the Frogs Marsh and conversion to an oxidizing environment was formulated with reconnaissance

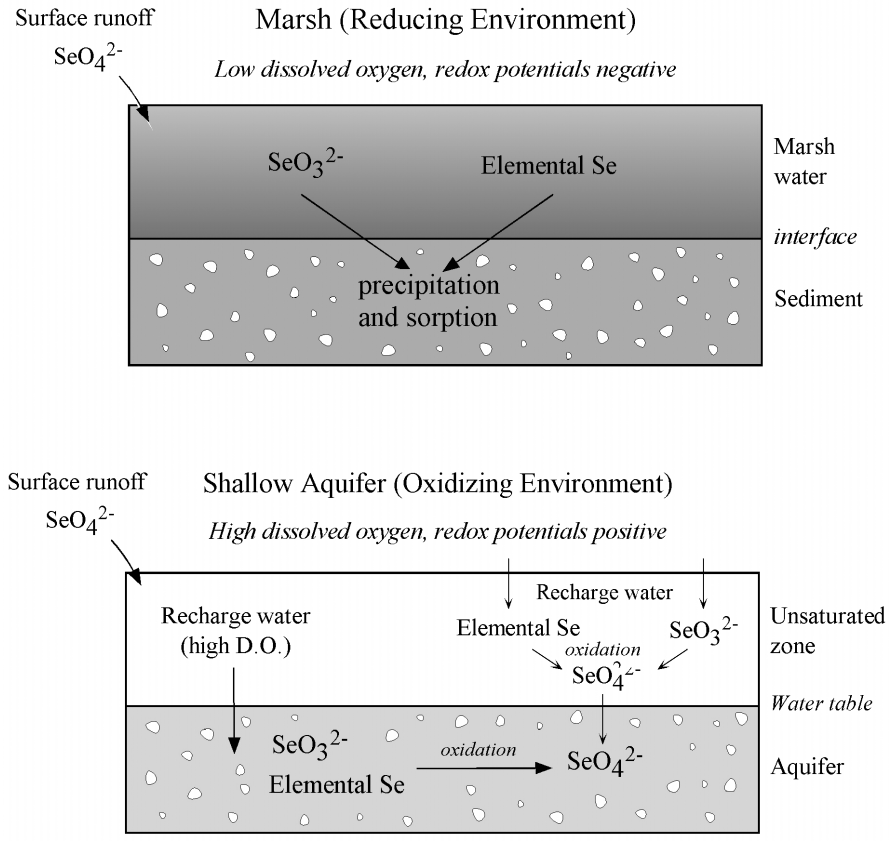


Figure 5. Conceptual model for accumulation of selenium in the anoxic Swamp of the Frogs Marsh due to reducing conditions that prevailed there (top image). When the marsh was drained, oxygen-rich waters were able to remobilize the reduced forms of selenium (SeO_3^{2-} and elemental selenium) into selenate (SeO_4^{2-}), a mobile and oxidized form of selenium (bottom image).

data sets based on total dissolved selenium and major ion concentrations. The spatial relationships are compelling but additional data were needed to evaluate and lend possible support to the hypothesis. The additional data collected in subsequent studies included groundwater flowpath analysis, selenium speciation of water and soils, and sulfate isotope analysis in groundwater. This new information is presented in these subsections:

- Evidence from Groundwater Flowpath Analysis
- Evidence from Selenium Speciation Analysis of Groundwater
- Evidence from Selenium Speciation Analysis of Soils
- Evidence from Sulfur Isotope Analysis of Groundwater

Evidence from Groundwater Flowpath Analysis

Previous investigations by Hibbs and Lee (2000) indicated that many of the subsurface storm drain laterals in the San Diego Creek Watershed receive a significant amount of dry weather flows from groundwater seepage. Baseflow was confirmed by analysis of concentrations of hydrochemical constituents (e.g., selenium, nitrate) emitted by the drains, and by inspection within the drains which indicated flowing weepholes and flowing seams where groundwater was identified by sampling and analysis of hydrochemistry.

Valencia Drain, a key storm drain in the watershed, was investigated for flow sources inside the drain. This was done to identify possible seeps, springs, weepholes, and dewatering operations. Inspection within Valencia Drain indicated a large number of groundwater flows from seams and weepholes that were sampled for selenium and other constituents (Figure 6). Sample points in Figure 6 are labeled by distance from Peters Canyon Wash to the point in the drain where the sample was collected, in feet. The data proved to be a fortuitous information set because Valencia Drain is oriented almost perfectly in-line with a shallow groundwater flowpath in the shallow aquifer. This provided an opportunity to assess how selenium changes along the groundwater flowpath that moves downgradient above and then through the historic Swamp of the Frogs Marsh region, into Peters Canyon Wash (Figure 6). A shallow monitoring well very close to Valencia Drain, IRWD Well 86N, was included in the flowpath analysis. This well is the upgradient point in flowpath analysis.

Selenium concentrations between IRWD Well 86N and the first sample point (3533 ft) in Valencia Drain are less than 30 µg/L. Concentrations then increase within the historic marsh region to more than 50 µg/L dissolved selenium (Figure 6). For an uncertain reason, selenium concentrations reach concentrations in excess of 175 µg/L close to Peters Canyon Wash (Figure 6). This could be due to: 1.) gradation of reducing conditions that may have existed historically within the interior of the Swamp of the Frogs Marsh, or 2.) a soil facies change at the lower end of the groundwater flowpath. The marsh boundary clearly delineates a region of increasing selenium along the well-defined groundwater flowpath, offering support for the Swamp of the Frogs Marsh selenium remobilization hypothesis as a principal source of selenium in groundwater.

Evidence from Selenium Speciation Analysis of Groundwater

The hypothesis of selenium remobilization from the Swamp of the Frogs Marsh predicted that oxidizing conditions in shallow groundwater accounted for selenium release from marsh sediments. Speciation analysis was not performed in the report by Hibbs and Lee (2000) where the hypothesis was first formulated. Only total dissolved selenium was tested in shallow groundwater in that early report. Several samples were later collected from shallow groundwater in 2005-2006 and tested for selenium species. A set of these are presented here, including three groundwater samples collected above the marsh, and ten samples collected within the marsh boundary (Table 2).

Selenium speciation data were used to compute oxidation-reduction potential (Eh) using the Nernst equation as follows:

$$Eh = E^o + (RT/nF)\,[\log a(SeO_4^{2-}) - \log a(SeO_3^{2-}) + 2pH] \qquad \textit{Equation 1}$$

where $E^o = -(\Delta Gr^o/nF)$; R = ideal gas constant; T = temperature in degrees Kelvin; F = Farraday's constant; a = activity of the species shown in

parenthesis (with the assumption that activity is equal to molar concentration); and ΔGr^o = the Gibb's free energy of formation given the following reaction:

$$SeO_4^{2-} + 2H^+ + 2e^- \rightarrow SeO_3^{2-} + H_2O \qquad \textit{Equation 2}$$

Selenium speciation data used in the Nernst equation computed redox potential (Eh) in millivolts. Selenium speciation revealed that Se^{6+} makes up 92% to 99% of total dissolved selenium in all except one sample, Val-Jeff Spring (Table 2). Figure 7 shows where these waters plot on an Eh-pH diagram, showing the stability range for samples based on speciation results as dominating in the oxidizing range.

Selenium speciation and other groundwater data allowed the characterization of these waters as oxidizing. The concentrations of other redox-sensitive trace species included generally low (<0.1 mg/L) to non-detectable concentrations of iron and manganese (Andrus 2008; Hibbs et al. 2008). Selenium-nitrate correlations were also noted in shallow groundwater, where nitrate was frequently measured between 2.0 and 20 mg/L

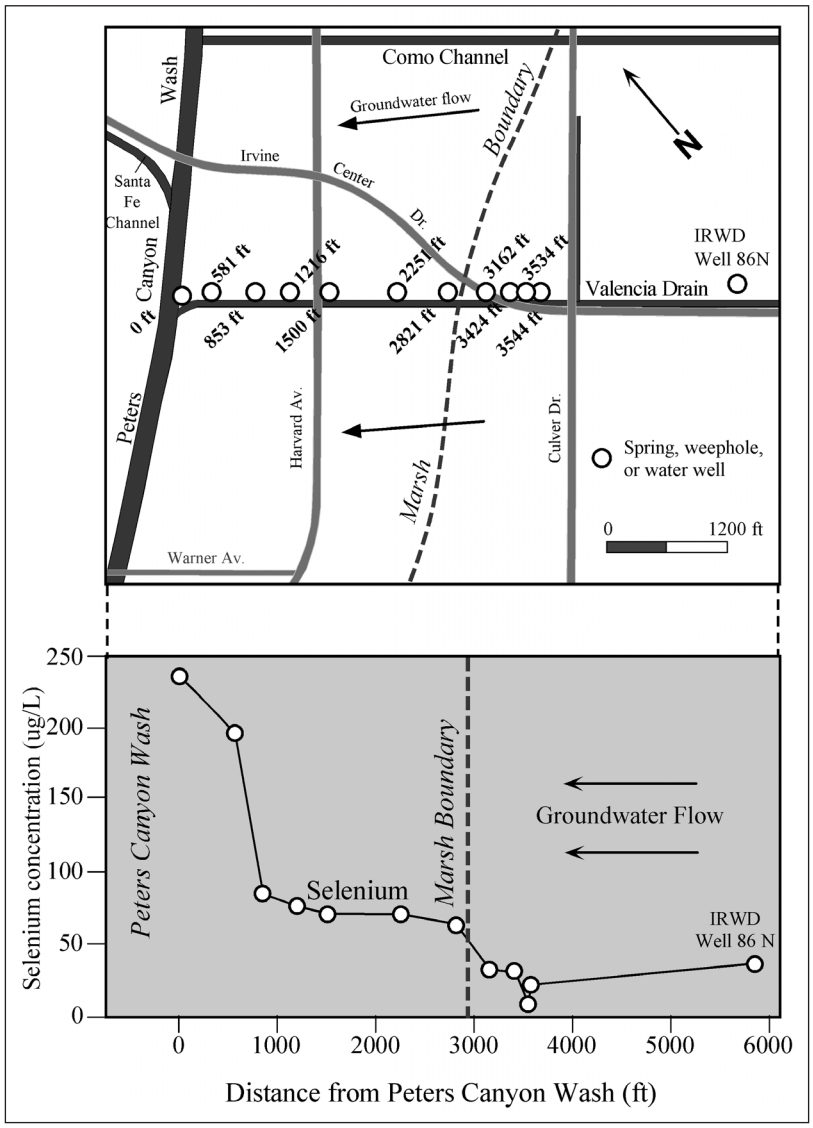


Figure 6. (Top) Groundwater at discrete points within Valencia Drain oriented along a groundwater flowpath. Samples are identified by distance from Peters Canyon Wash. (Bottom) Concentrations of selenium in groundwater flowing into Valencia Drain. Marsh boundary indicated by dashed line. Selenium elevates in concentration when the marsh boundary is crossed.

Table 2. Results of selenium speciation analysis of shallow groundwater samples located within and outside the limits of the historic Swamp of the Frogs Marsh.

Groundwater Sample	Type (µg/L)	Se(VI) (µg/L)*	Se(IV) (µg/L) *	Organic Se (µg/L) *	Total Se (µg/L) *
Above Swamp Boundary					
B2 El Modena	Weephole	11.25	0.76	<DL	12.01
Val-Jeff Spring	Spring	5.94	0.95	<DL	6.89
Well 103-N	Well	14.99	0.74	<DL	15.74
Within Swamp Boundary					
B4 El Modena	Weephole	51.34	1.31	<DL	52.65
B3 El Modena	Weephole	79.26	0.83	<DL	80.09
Valencia 1	Weephole	122.32	0.82	<DL	123.14
Valencia 2	Weephole	106.57	0.85	<DL	107.42
Valencia 3	Weephole	90.67	0.84	<DL	91.51
Well 85-W	Well	19.78	1.62	<DL	21.41
Well 63-S	Well	55.08	1.14	<DL	56.22
Bar-Alt-Spring	Spring	218.56	3.41	<DL	221.97
Como-Harv-Cul	Weephole	29.39	0.79	<DL	30.18
PCW-SW Rail	Weephole	47.24	1.49	<DL	48.74

* Analyzed using HG-AA by University of California-Riverside

NO_3-N when selenium was at least 20 µg/L (Andrus 2008; Hibbs et al. 2008). The fact that oxidized species such as nitrate and selenate (Se^{+6}) dominate in these groundwater samples, while dissolved iron and manganese are virtually absent, points to moderately to strongly oxidizing conditions in the shallow aquifer, as predicted by Hibbs and Lee (2000). Such conditions favor oxidation and remobilization of selenium that was once bound in sediments under reducing conditions typical of marsh settings (Masscheleyn et al.1990; Dowdle and Oremland 1998).

Evidence from Selenium Speciation Analysis of Soils

Soil samples were collected for testing selenium content of soils: three soil samples collected within and two outside of the historic marsh boundary (Figure 1). Two clays were collected from a fresh trench along Peters Canyon Wash within the boundary of the historic swamp. The "upper clay" was collected approximately 8 feet below land surface from the unsaturated zone. From a lower layer within the same trench, local channel construction at a temporary dewatering operation permitted the collection of a "blue clay", which normally resides below stream head in the saturated zone, from approximately 20 feet below land surface. A blue clay about 1 foot beneath land surface was also collected near Santa Fe Channel (Figures 1 and 8). Soils were also collected for control from the dry streambeds of Hicks Canyon and Round Canyon washes (Figure 1). Brief physical descriptions of these soils are shown in Table 3. Soils were analyzed in most samples for total selenium and selenium speciation. Blue clays and upper clay were collected within the Swamp of the Frogs Marsh boundary while Hicks Canyon and Round Canyon streambed soils were collected in the uplands, well above the marsh boundary (Figure 1).

Background concentrations of total selenium in typical soils (i.e., those that are not impacted by selenium) are on the order of 0.4 mg/kg, while

soils derived from some fine textured marine rocks have higher total selenium content on the order of 5 mg/kg (Thomas et al. 1998). Data for total selenium and selenium species in soils are shown in Table 3. Selenium data reveal that total selenium levels in the upland soils as well as in the "upper clay" are comparable to those found in normal soils without selenium enrichment. Selenium data reveal the blue clay has order of magnitude higher concentrations (Table 3). Speciation data show that selenium oxyanions comprise about 40% of total selenium in the soils collected from within the boundary of the historic swamp. The dominant form of selenium in the "upper clay" is selenate (Se^{6+}), whereas there is more than twice as much selenite (Se^{4+}) as selenate (Se^{6+}) in the "blue clay." This indicates that selenium in these soils exists in leachable forms.

Results of this limited soil investigation reveal that much higher quantities of selenium are present in soils within the marsh area. Also apparent at one site is the large difference in selenium content between vertical clay horizons in the same location. Blue clay is found commonly in shallow vadose zone and shallow saturated zone horizons within the historic Swamp of the Frogs Marsh boundary (Figure 8).

Evidence from Sulfur Isotope Analysis of Groundwater

Several groundwater samples sampled for sulfur isotope were collected from shallow water wells, springs, and weepholes within and outside of the region formerly occupied by the historic Swamp of the Frogs Marsh (Figure 9). The sulfur isotope work is done to further delineate regions of sulfur/selenium reduction and to further refine conceptual

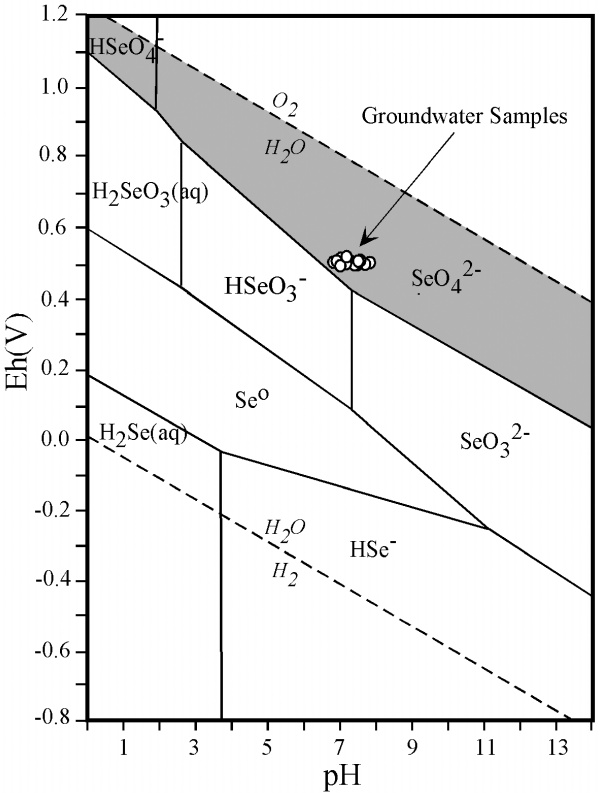


Figure 7. Eh-pH diagram for groundwater from Table 2 indicates stability in the domain occupied by the oxidized form of selenium, Se(+VI), in the shaded area of the figure.



Figure 8. Blue clay near land surface on the side of Santa Fe Channel within the historic marsh boundary is indicative of sediment formed in an anoxic marsh environment.

Table 3. Soil selenium content and selenium speciation data (see Figure 1 for location).

Soil ID	Soil Type	Selenium IV (mg/kg)	Selenium VI (mg/kg)	Total Selenium (mg/kg)
Santa Fe Channel Blue Clay	blue clay	--	--	13.3
PCW Blue Clay	blue-grey clay	2.98	1.27	10.4
PCW Upper Clay	brown clay	< 0.02	0.155	0.383
Round Canyon Streambed	grey-brown silty sand	ND (< 0.02)	ND (< 0.046)	0.360
Hicks Canyon Streambed	grey-brown silty sand	ND (< 0.02)	ND (< 0.046)	0.198

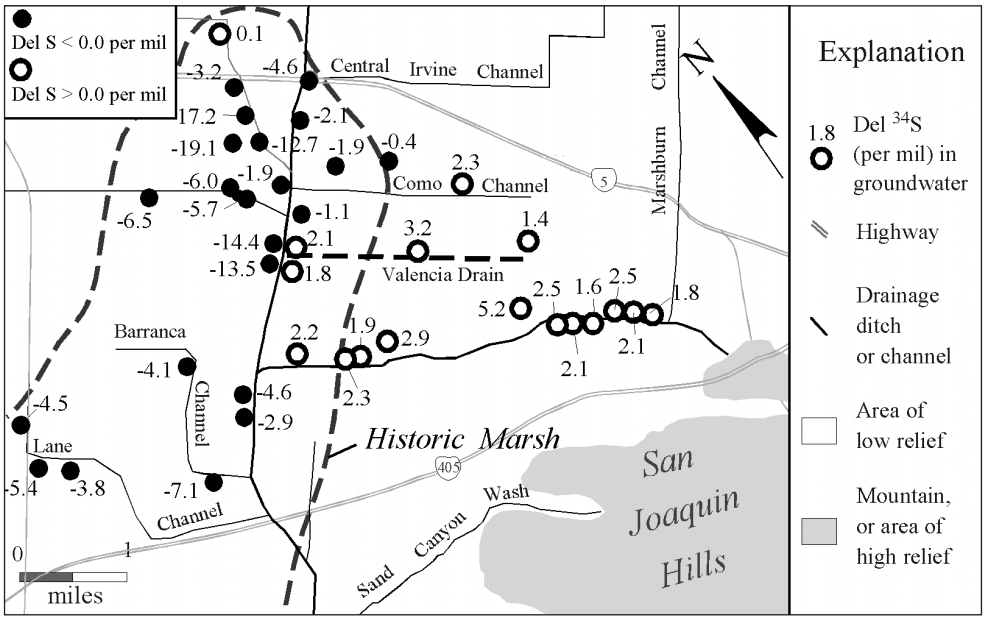


Figure 9. Per mil values of sulfur isotopes in groundwater collected from springs, weepholes, and shallow water wells in the study area. Mostly negative sulfate sulfur isotope values within the historic marsh boundary imply oxidation of metal-sulfides that were originally sequestered in the marsh sediments.

understanding of the flow system for groundwater model development. East of the Swamp of the Frogs Marsh area, measured $\delta^{34}S[SO_4^{2-}]$ values are positive in all except one groundwater sample collected from an IRWD well near Como Channel (-0.4 $\delta^{34}S[SO_4^{2-}]$). Inside the Swamp of the Frogs Marsh area, other sulfur isotope values in groundwater wells are negative in most samples (Figure 9). The -0.4 $\delta^{34}S[SO_4^{2-}]$ sample near Como Channel is located on the approximate boundary of the historic marsh, reflecting an intermediate sulfur isotope composition.

Positive sulfur isotope values varied moderately in groundwater, from 1.4 to 5.2 per mil $\delta^{34}S[SO_4^{2-}]$. Negative values varied more widely, from –0.4 to –14.4 per mil $\delta^{34}S[SO_4^{2-}]$. Positive $\delta^{34}S[SO_4^{2-}]$ values may indicate multiple sulfate sources and mixtures, including fertilizers, organic matter, marine salts, geologic strata, and atmospheric deposition (Krouse and Grinenko 1991). Negative sulfur isotope values are consistent with oxidation of Fe-sulfides, or dissolution of second-cycle terrestrial evaporitic salts that were derived originally from oxidation of metal sulfides (e.g., Thernardite or Mirabolite

salts). The negative $\delta^{34}S[SO_4^{2-}]$ signature often develops as a result of the lower energy required by bacteria to break ^{32}S – Fe bonds, resulting in a negative sulfur isotope signature (Toran and Harris 1989; Clark and Fritz 1997). The negative sulfur isotope signature across most of the Swamp of the Frogs Marsh region is generally consistent with the hypothesis of origin of sulfate from oxidation of reduced forms of sulfur. By proxy it is assumed the same set of redox processes operates on selenium redox systematics.

Summary Conceptual Model for Selenium and Sulfur Sequestration and Release in Marsh Sediments

The initial basic reconnaissance data provide a solid hypothesis for the origin of selenium from the Swamp of the Frogs Marsh (Hibbs and Lee 2000). The subsequent data provide strong supporting evidence for release of selenium from the historic marsh sediments. We suspect that selenium in groundwater in the San Diego Creek Watershed was originally derived from oxidation and weathering of Miocene marine sedimentary strata such as the Monterey and Puente formations exposed in the highlands flanking the watershed (Morton and Miller 1981; Tracy et al. 1990; Hibbs et al. 2008). Selenium, originally incorporated in marine soils and sediments deposited in Miocene time and subsequently lithified into shales and mudstones, likely existed as metallic selenide (FeSe) and metallic sulfide (FeS_2) in these parent rocks, which subsequently weathered to selenate and sulfate under alkaline oxidizing conditions in the Santa Ana Mountains (Figure 1).

Prior to the historic period of agricultural development in the watershed, selenium and sulfur weathered from upland marine sediments and rocks were transported in surface runoff and groundwater seepage to the Swamp of the Frogs marshlands (Figure 5). Runoff waters probably had very dilute concentrations of sulfate and selenate. The interior parts of the marshlands into which the runoff waters flowed were probably oxygen deficient due to decaying organic material in the marsh. When selenium and sulfur first entered the marsh by surface drainage and groundwater seepage, they were in the form of selenate and sulfate, a pair of water-soluble and oxidized anions. The deficiency of oxygen in the marsh created conditions in which selenium and sulfate acted as electron acceptors for microorganisms that decompose organic material (Quinn et al. 1994; White and Dubrovsky 1995; Zawislanski and Zavarin 1996; Losi and Frankenberger 1998). Most of the selenium became elemental selenium (a water-insoluble crystal) or selenite (often a sorbed anion) (McNeal and Balistrieri 1989). Likewise, most of the sulfur became insoluble metal sulfides. These immobile forms of selenium and sulfur accumulated in the organic-rich sediments in the marsh where they remained stable under the anoxic conditions that prevailed there (Figure 5). The chemical species were thus reconverted to reduced forms of selenium in the anoxic waters of the marsh where dissolved oxygen and oxidizing components were not available.

When the marshes were drained, oxygenated groundwater began to replace the oxygen-deficient waters within and below the marsh (Figure 5). Our hypothesis established that contemporary oxidizing groundwater flows through sediments beneath the historic marsh areas, remobilizing residual selenium and sulfur as dissolved selenate and sulfate, a highly mobile pair of ions in the oxidizing groundwater flow system. Increased loads of selenium in the watershed are likely a direct result of destruction of the marshland.

The conversion from a marshy environment to agricultural and later suburban land use changed the hydrology of the system to a shallow baseflow-dominated system. Drainage controls and depression of the water table allowed organic material in soils to rapidly oxidize. The groundwater flow system changed to an oxidizing environment in just over 100 years. Elements are released from bound forms in the soil matrix into groundwater, which flows directly into channels along lined and unlined segments of channel (Hibbs et al. 2016).

Selenium enrichment in the groundwater in the San Joaquin Valley of Central California is concentrated by a different set of hydrological processes. Common selenium enrichment processes in San Joaquin Valley include: 1.) leaching of soil salts and soluble selenium from infiltrating irrigation waters; 2.) evaporative concentration

of soluble selenium and other salts in areas where water tables are shallow; and 3.) release from weathering of selenium-laden bedrock material and sedimentary rock detritus (Deverel and Fujii 1988; Deverel and Gallanthine 1989; Dubrosky and Deverel 1989). The highest concentrations of soluble selenium in soils and groundwater in San Joaquin Valley are found where evaporation processes enrich soluble forms of selenium, leading to strong correlations between selenium and salt concentrations in groundwater (Deverel and Fujii 1988; Dubrosky and Deverel 1989). In San Diego Creek Watershed, sulfate and selenium enrichment are correlated, but chloride enrichment is not correlated with sulfate and selenium enrichment in groundwater (Hibbs and Lee, 2000; Hibbs et al. 2016). The information presented in this paper indicates that selenium and sulfur are released from marsh sediments following redox transformations during land use change in San Diego Creek Watershed. However, the weathering of selenium bearing rocks and sediments of marine origin, and subsequent runoff of both dissolved selenium and selenium particulates onto valley floor areas, is the initial source of selenium in both the San Joaquin Valley and Swamp of the Frogs Marsh.

Conclusions

The toxic trace element selenium occurs naturally in geologic units in the San Diego Creek Watershed. Release of selenium is related to land use modification and associated change of redox conditions. Land use change from natural marshlands to agricultural and urbanized landscapes resulted in drainage of the anoxic Swamp of the Frogs Marsh and conversion to a shallow, oxidizing groundwater environment. Many drainage channels initially installed to drain the marshlands still exist, preventing groundwater in the shallow water table aquifer from rising into residential and commercial areas. Selenium concentrations and stream flow increase along a downstream trend in these drainage channels in the San Diego Creek Watershed due to groundwater seepage. The highest concentrations of selenium in groundwater correspond to the marsh areas that were drained in the early 1900's. Contemporary oxidizing groundwater flows through the sediments beneath the historic marsh, dissolving selenite and elemental Se from shallow soils. Increased loads of selenium in the watershed are a direct result of destruction of the marshland. Concentrations of selenium in surface flows exceed the EPA aquatic standards by several factors, potentially placing waterfowl and other wildlife at risk. A lesson learned is that existing and proposed land use developments in other areas must consider how the modification of the hydrology of natural systems could impact ecosystems and beneficial uses of watersheds.

This first journal paper lays out a regionally-based model for release of selenium from the historic Swamp of the Frogs Marsh sediments. The model is operative at the macroscopic scale (Figure 5). Future papers based on our work will highlight site-specific analysis where redox phenomena are associated with small scale gradations in soil facies within the historic Swamp of the Frogs Marsh area. These papers will include discussions of arsenic and sulfur anomalies within the Swamp of the Frogs Marsh area, origin of salinity, and analysis of seasonal controls on trace element and nutrient loading to San Diego Creek Watershed.

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Model Water Transfer Mechanisms as a Drought Preparation System

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Abstract: This article evaluates the suitability of two supply-side drought management tools, Emergency Water Banks and Strategic Water Reserves for multi-year severe drought periods. The limited sample-size related to the implementation of either makes direct comparison impossible, but through case studies some cursory evaluation as to their efficacy and their limitations is possible. These short-term tools take different approaches to increase the amount of water available for reallocation during drought. While neither are stand-alone solutions, and may not be suitable for continual use, both hold potential to provide short-term relief during periods of severe shortage. Both however, carry drawbacks that can undermine their efficacy, or preclude adequate support for their implementation.

Keywords: *drought, water allocation, climate adaptation, planning*

Recent International Panel on Climate Change (IPCC) models project an increase in extended drought in many semi-arid areas around the globe over the next fifty years (Wilder et al. 2010; IPCC 2014). For the Southwestern United States, IPCC models suggest a simultaneous increase of temperature of 2-5 degrees centigrade by 2100 and a decrease of precipitation of 5-8 percent (Wilder et al. 2010), an increase in actual evapotranspiration (Cowell and Urban 2011), and increasing weather and climatic variability (IPCC 2011; Stroup 2011; IPCC 2014). While water storage can mitigate the effects of short-term water shortages, few freshwater-scarce areas are equipped to deal with prolonged severe drought events. This problem is compounded in regions lacking full adjudications of water entitlements, meaning the temporal and volumetric extents of water rights are unclear. While drought coping mechanisms are not new (Whittlesey et al. 1986; Howe 2000; Steinemann and Cavalcanti 2006), the predicted climatic variability will make it increasingly important for water managers to create actionable plans for shortages in spite of the lack of clarity of water rights (Corbridge 1998; Stakhiv 2011; Stroup 2011). This article will evaluate the strengths and weaknesses of drought-period water transfer mechanisms to temporarily reallocate freshwater supplies from willing sellers when conditions reach critically low levels.

Climate Change and Drought Planning

For this article, drought plans on file with the National Drought Mitigation Center (2016) from 44 states were evaluated; of the 19 member states of the Western Governors Association, the portion of the country with the highest concentration of semi-arid areas, 18 states have created state-wide Drought Plans, but only six of these plans have been updated since 2010 (National Drought Mitigation Center 2016). Inspection of these plans (Table 1) reveals most western states (n=15) have quantifiable definitions of drought conditions, and most (n=12) have clearly stated drought actions. Few plans (n=10) contain what Rossi et al. (2008) labeled Drought Contingency Plans, specific actions and implementation strategies to mitigate drought, and even fewer states (n=12) discuss

water reallocation as a strategy for dealing with water shortages. Review of the plans also showed a close balance between drought plans that are mitigation-based and response based. Drought plans in the United States have historically relied upon response-based measures (Wilhite et al. 2014). In part, this is due to the inherent nature of drought, including its multi-modal and diffuse spatial impacts, which makes adaptive measures difficult for policy-makers to identify (Wilhite et al. 2014). Mitigation measures exist for the impacts drought inflict on local and regional water supply systems (Rossi et al. 2005; 2008).

Reducing the impacts of drought can be separated into two categories: risk management and crisis management (Wilhite et al. 2014). Similar to other natural hazards, drought management policy has historically centered around crisis management or those tools put into action following the drought event (Wilhite et al. 2014). Crisis management is defined through its effort to recover the area affected; this is done through first assessing the impact, responding to those impacts, putting recovery efforts in place, and, finally, beginning reconstruction (Wilhite et al. 2014). In recent years, drought policy has moved towards more adaptive measures and began focusing on risk management (Hayes et al. 2004; Cooley et al. 2015), as well as crisis management (Wilhite et al. 2014). These tools are put into action when drought is not occurring and defined by efforts to protect vulnerable areas. Focus is placed on planning and reducing risks, rather than recovering from impacts (Wilhite et al. 2014). A key component of any risk management strategy is including early-warning indicators (Wilhite et al. 2014), which can often be achieved through the close monitoring of drought indices.

As part of its National Integrated Drought Information System, the National Oceanic Atmospheric Administration's NOAA Palmer Drought Severity tools can help determine when emergency drought management measurements should be implemented. The Palmer Drought Severity Index (PDSI) uses a series of algorithms to analyze an array of hydrologic supply and demand indicators (Dai et al. 2016), creating a local drought index (Table 2). Specifically, the PDSI accounts for current weather patterns and previous moisture levels to provide a quick-responding, broad assessment of drought conditions. The Standardized Precipitation Index (SPI) proposed by McKee et al. (1993) defines drought through probability and is based on long-term historical records at a specific temporal resolution (Vicente-Serrano et al. 2012). Drought is generally defined in one of four ways: meteorological, hydrological, agricultural, and socioeconomic (Wilhite and Glantz 1985). Meteorological drought simply compares the actual amount of precipitation to the average amount for a given area; hydrological drought demonstrates a lack of precipitation and its effects on both surface and groundwater and is measured on a watershed scale (Wilhite and Glantz 1985). Agricultural drought is generally defined through meteorological and soil characteristics (Nam et al. 2012); socioeconomic drought draws on criterion from all three to highlight supply and demand measures (Wilhite and Glantz 1985). The PDSI data are updated weekly, providing a timely overview of hydrologic availability.

NOAA maintains a series of local drought observation tools. Under the National Integrated Drought Information System Act (NIDIS) NOAA was appropriated $84 million dollars (USD) between FY 2007 and FY 2012 to carry-out the purposes of the act, which primarily focus on integrating "information on the key indicators of drought in order to make usable, reliable, and timely drought forecasts" (NIDIS PL 109-430, 2006). NOAA's considerable research into the linkages between oceanic temperatures and drought are ongoing (NOAA 2012), and may provide a robust predictive model in the future. NIDIS funds helped to create Regional Drought Early Warning Information Systems (DEWS) (National Integrated Drought Information System 2016).

This paper will evaluate two supply-side drought management tools, Emergency Water Banks and Strategic Water Reserves, as mechanisms to deal with multi-year droughts. The purpose is not to determine the suitable 'trigger' to identifying drought conditions that warrant action; that determination is best left to local water managers, since the implications of drought in a given watershed are a function of what Howe (1992) labeled, the "uniqueness of water supply system management", a complex calculus of water demand, storage, evapotranspiration rates,

Table 1. Identified state drought plans from National Drought Mitigation Center (2016) database.

State	Last Updated	Quantifiable Definition of Drought (Y/N)	Clearly Identified Drought Actions (Y/N)	Plan to Implement Drought Actions (Y/N)	Discussion of Water Reallocation Mechanisms (Y/N)	Response-based or Mitigation-based (RB/MB)
Alabama	2013	Y	Y	N	N	RB
Arizona	2004	Y	Y	Y	Y	MB
California	2010	Y	Y	Y	Y	MB
Colorado	2013	Y	Y	Y	Y	MB
Connecticut	2003	Y	Y	N	N	MB
Delaware	1982	Y	Y	Y	N	RB
Florida	2007	Y	Y	N	N	RB
Georgia	2015	N	Y	Y	N	RB
Hawaii	2005	Y	Y	Y	N	MB
Idaho	2001	Y	Y	N	Y	RB
Illinois	2011	N	N	N	N	MB
Indiana	2015	Y	Y	Y	N	RB
Iowa	1985	N	N	N	N	RB
Kansas	2012	Y	Y	N	N	RB
Kentucky	2008	Y	Y	Y	N	MB
Maryland	2000	Y	Y	Y	N	RB
Massachusetts	2013	Y	Y	Y	N	RB
Michigan	1988	N	N	N	N	RB
Minnesota	2009	Y	Y	N	N	RB
Missouri	2002	Y	Y	Y	N	RB
Montana	1995	Y	N	N	Y	MB
Nebraska	2000	N	Y	N	N	MB
Nevada	2012	Y	Y	Y	Y	RB
New Hampshire	1990	Y	Y	N	N	RB
New Jersey	1991	Y	Y	N	N	RB
New Mexico	2006	Y	Y	Y	Y	MB
New York	1988	Y	Y	N	N	RB
North Carolina	2005	N	Y	N	N	RB
North Dakota	1981	N	N	N	N	RB
Ohio	2009	N	Y	N	N	RB
Oklahoma	1997	Y	Y	Y	N	RB
Oregon	2016	N	Y	N	Y	RB
Pennsylvania	2010	Y	Y	N	N	RB
Rhode Island	2002	N	N	N	N	RB
South Carolina	2009	N	Y	N	N	RB
South Dakota	2015	Y	Y	Y	Y	MB
Tennessee	2010	N	Y	N	N	RB
Texas	2005	Y	Y	Y	Y	MB
Utah	1993	Y	N	N	Y	RB
Vermont	2005	N	N	N	N	RB
Virginia	2003	Y*	Y**	Y	N	RB
Washington	1992	Y	Y	Y	Y	RB
West Virginia	2002	Y	Y	N	N	RB
Wyoming	2003	Y	N	N	Y	RB

* Parameters differ by month.

** Mandatory restrictions only implemented in emergency phase.

Table 2. Palmer Drought Severity Index (PDSI) and Standardized Precipitation Index (SPI) categories comparison (Adopted from NOAA 2012; World Meteorological Organization 2012).

Palmer Index Score	Category	Standardized Precipitation Index Score	Category
4.0	Extremely Moist	2.0+	Extremely Wet
3 to 3.9	Very Moist Spell	1.5 to 1.99	Very Wet
2.0 to 2.9 to -1.24	Unusual Moist Spell	1.0 to 1.49	Moderately Wet
1.9 to -1.9	Near Normal	-0.99 to 0.99	Near Normal
-2.00 to -2.9	Moderate Drought	-1.0 to -1.49	Moderately Dry
-3.00 to -3.9 and below	Severe Drought	-1.5 to -1.99	Severely Dry
-4.0 or less	Extreme Drought	-2.0 or less	Extremely Dry

groundwater stores, threatened and endangered species, and myriad other factors (Steinemann and Cavalcanti, 2006). However, utilizing tools such as the PDSI or SPI can provide a quantitative metric to depoliticize the process of evoking severe drought policies and procedures. Precedent exists for this practice at the municipal level (Moreau and Little 1989; Howe 1992), but review of drought plans shows few river basins have clear, actionable response mechanisms in place to cope with drought.

Emergency Water Banks

Water banks are institutional structures allowing water right holders to lease, and interested parties to purchase water (Michelsen 1994). State-brokered water transfers, or Markets by Agency (MBAs) (Ballestero et al. 2002) are generally not an appealing option during times of 'normal' water supply and the appropriateness of their use has been questioned (Dellapenna 2000; Ballestero et al. 2002; Zetland 2009; Debaere et al. 2014). Despite substantial efforts to study and facilitate their functioning, free-market reallocations of bulk water have proven to be too difficult to reallocate substantial quantities of water in short periods of time, because of political, administrative, social, implementation, monitoring, and enforcement costs (Gould 1988; Barthold 1994; Bauer 1997; Howe 2000; Hennessy 2004; Krutilla 2010; Dustin and Aylward 2012). Having the ability to institute an Emergency Water Bank (EMB), which may vary in operation from any existing water transfer mechanism in how it temporally, spatially, and institutionally reallocates water (Ballestero et al. 2002), during times of extreme water duress can be viewed as a contingency option to avoid water allocations being made via judicial decree; this should be viewed as particularly advantageous in basins lacking water rights adjudications as determining priority of water use in those locations is particularly difficult.

Once drought conditions begin, creation of a water bank would be difficult as tensions among various water users escalate. Studying the creation of a water bank needs to be done as a proactive measure, and at least the discussion of adding a drought water bank would be a worthwhile addition to drought management plans. Effective implementation of an EWB or any MBA requires deliberation over a series of engineering and administrative hurdles, which include:

- determining the best method for initiating such a water bank;
- evaluating several options for determining eligible sellers of water;
- identifying water users with critical needs and determining the order in which they can purchase water;
- determining how much water a given entity can buy;

- investigating how prices for purchasing and selling water should be made;
- creating a mechanism that protects third-party property rights; and
- how best to protect ecosystem functions.

The California Model

In 1991, the State of California implemented its Drought Emergency Water Bank (CDEWB) state-run drought water bank that was successful in reallocating 800,000 acre-feet of water in approximately two months (Wahl 1993; Israel and Lund 1995). The operators of the CDEWB were praised for their innovative approaches to deal with the many hurdles that prevent effective water banking (Wahl 1993). While far from perfect, the CDEWB represents the largest short-term water reallocation mechanism ever utilized in the western United States.

An EMB, like what was used in California, varies in operation from a 'traditional' water bank (Dellapenna 2005). By necessity, they involve substantial state government involvement. For example, the CDEWB required certain short-term administrative changes in how water rights were evaluated. These administrative changes required legislative consent and could only be conducted by the state, necessitating the substantial government involvement (Wahl 1993). This kind of "hands-on" approach by states is not something most water right holders and water professionals are comfortable with as a standard operating paradigm (Dellapenna 2000; Ballestero et al. 2002; Dellapenna 2005), but in times of extreme drought, for example, a score of -3.4 on the PDSI or -1.6 on the SPI (Table 2) for a given basin, this approach may be one of necessity.

In 1991, the State of California faced its fifth consecutive year of prolonged drought. The snow-pack for central California was low, and water available for diversion was expected to be near record lows, with irrigators in the Central Valley Project to receive between 10 and 75% of their normal water deliveries (Wahl 1993). In the spring of 1991, acting on the recommendations of the state Drought Action Team, then Governor Wilson signed California Executive Order W-3-91 (1991) creating the Drought Emergency Water Bank.

Water Bank Operations

The CDEWB began operations in April of 1991. The California Department of Water Resources (DWR) administered the water bank, evaluated water rights, and created strict rules over how all water would be purchased and sold. DWR identified the users that the agency deemed qualified to purchase water; those it identified as having "critical needs" could buy or sell water to the water bank. The water bank was strictly government controlled; the State of California was the only buyer (and the DWR made the determination of who was eligible to "bank" water) and the only seller of water (Wahl 1993; Dellapenna 2000; Yolles 2001).

The state recognized several methods for conserving water to sell in the water bank. These were:

- crop fallowing;
- substituting groundwater use for surface water use; and
- reallocating surface water, including transferring water from local reservoirs.

The contributions to the water bank by each of these sources can be seen in Table 3.

To increase the amount of water 'banked' by irrigation districts, the California legislature included a waiver regarding geographic considerations. For 1991 and 1992 any provisions prohibiting water from exiting the boundaries of an irrigation or conservation district were waived (DWR 1992). This administrative decision is one that could only be accomplished by the state, strengthening the case for a state-run water bank during severe conditions, and allowed water transfers that are not possible during 'normal' years.

Crop fallowing was the largest source of water entering the bank in 1991 with 325 fallowing contracts making 414,743 acre-feet of water available to purchasers fallowing 166,094 acres (Israel and Lund 1995). Crop fallowing made economic sense when the price the state was willing to pay for water per fallowed acre of cropland was higher than the net profit per acre of crop. Corn was the largest crop fallowed (Wahl 1993). Farmers had to show they had irrigated the land the previous year—this was one of the criteria implemented by the state to ensure what was being

Table 3. Sources of banked water for the 1991 CDEWB (CA Water Board 1992).

Source	Amount Transferred to Bank (acre-feet)	Percentage of Total Water Transferred to Bank
Crop allowing	414,743	50
Groundwater substitution	258,590	32
Reallocating surface water (including reservoirs)	147,332	18

banked represented "wet water." The quantity of water credited to a farmer for each acre of irrigated land retired was determined by a formula based on the crop grown the previous year. This fixed allotment was integral to quick water transfers; once a transaction began, determining the water credits being sold became a simple arithmetic equation. This consumptive amount served as the fallowed-acre credit for those 'banking water' (DWR 1992).

Third-Party Considerations

A water transfer has a high likelihood of impacting more than just those parties involved in the transaction. These third-party impacts are often difficult to assess and quantify, making this evaluation process the most common source of transaction costs (Gould 1988; Gould 1989; Howe and Goremans 2003). For the Emergency Water Bank, the California state legislature allowed the Department of Water Resources to largely ignore third-party impact investigations when making purchases of water using the criteria listed below (Wahl 1993). This significantly reduced the cost and time it took to purchase water. This approach expedited purchases by the Water Bank.

The state determined eligible buyers of water; only those deemed to have 'critical needs' for water were included (Wahl 1993; Yolles 2000; Zilberman 2003). Critical needs fell into one of the following categories (DWR 1992):

- water to meet identified emergency needs, such as health and safety;
- water for areas with critical needs defined as: urban water users with less than a 75% supply, agricultural users who need water to assure the survival of permanent or high value crops, and fish and wildlife resources;
- water for entities previously receiving allocations for critical needs and who need additional supplies to reduce substantial economic impacts resulting from reduced water supplies; and
- carryover water for the State Water Project (SWP). SWP purchase of any remaining, unallocated Water Bank supplies provided the financial backstop for the program.

In addition to these critical needs, 165,000 of the approximately 800,000 acre-feet purchased by the state were left in the Delta to improve water quality (Wahl 1993). Water quality issues, many of which (e.g. high salinity zones) have been linked to lower water levels, plague the San Joaquin-Sacramento River Delta, and have been identified as a likely factor in the peril of the Delta Smelt (*Hypomesus transpacificus*) (USFWS 2010; Interagency Ecological Program 2015). The ability of a drought water bank to provide more water for ecosystem protection reduces the likelihood irrigators will have their water deliveries shut-off. In this case, willing sellers would be compensated for providing water for the protection of Threatened and Endangered Species instead of that water coming from irrigation districts at large. In an additional initiative to provide ecosystem protection, the California Department of Fish and Game was also given the opportunity to purchase water from the 1991 water bank.

1991 Water Bank Pricing

The Department of Water Resources created a set purchase price for 'banked' water. No water bank of this scale had ever existed, so there was a lack of empirical examples from which to base

prices (Howitt et al. 1992; Wahl 1993). The DWR created a Water Purchase Price Committee to study this issue (DWR 1992). The Committee consulted many stakeholder groups, and farm budgets were analyzed to estimate a market clearing price that would entice irrigators to enter the water bank.

The Department of Water Resources offered $125 per acre-foot of water to eligible sellers (Wahl 1993). This uniformity of pricing eliminated the need for contract negotiations, reducing transaction costs and expediting transfers. It can be assumed most of those selling water to the bank were using water in a manner which yielded a net benefit of less than $125 per acre-foot.

The DWR purchased 820,665 acre-feet of water in 1991 from 351 sellers (DWR 1992). The Department of Water Resources sold water to interested parties at the cost of $175 per acre-foot. The actual cost of the water was $125, the same price at which the bank purchased water. A $45 fee was charged to cover transaction costs and administrative fees, and $5 was a conveyance fee for moving water through the Sacramento-San Joaquin Delta (Wahl 1993). Water was 'delivered' by the Department of Water Resources to the State Water Project's Delta Pumping Plant. Purchasers of water were responsible for contracting with whatever agencies necessary to move water from the Delta to their place of use. The majority of water users contracted with the State Water Project to deliver water from the San Joaquin Delta to their place of use (Israel and Lund 1995) with most uses occurring south of the Delta.

1991 Water Bank Purchases

The Department of Water Resources' narrow determination of entities eligible to purchase water constrained the quantity of water purchased: there were only 12 buyers of water. Had the DWR defined "critical needs" more liberally, it is likely demand would have exceeded available supply. Such an event would have required water bank administrators to make further determinations on who should have the right to purchase, and how much water they should be able to purchase. The largest purchaser was the Municipal Water District (MWD) of Southern California; the MWD accounted for 55% of all purchases (DWR 1992).

Agriculture accounted for 13% of the water purchased from the Water Bank despite the relatively high price of $175 per acre-foot. Irrigators of permanent crops made purchases to keep perennial crops alive (Wahl 1993). This provides empirical data that farmers can be a primary beneficiary from water banks during periods of water scarcity—sellers benefit from higher returns than they would receive from growing crops, and those growing perennial crops can obtain the water necessary to keep those crops alive.

Roughly 40% of the water banked in 1991 was not purchased. This can be attributed to the constraint on the number of purchasers (Wahl 1993). Alternatively, this could be viewed as a form of "market failure"; supply was poorly linked to demand of those with designated critical needs. While a market equilibrium was not established, the 'surplus' water purchased by the state was stored for the following year.

The State as a Broker

The state's manipulation of the water allocation was so invasive the operation of the CDEWB failed to meet the textbook definition of a market (Dellapenna 2000; Dellapenna 2005). Dellapenna's contention "true" markets do not, and likely will not exist for bulk raw water, is valid. Subsidies, transportation costs, and informational asymmetries do prevent perfectly functional markets. But, does this really matter? Rogers (2006, 29) states: "Today the honeymoon with the *laissez-faire* market-led model is over…", yet economic transactions not only still occur, but, as former U.S. Secretary of the Interior Babbitt stated, "Without water markets, we can't solve the problem of meeting the future water needs of the West" (McCoy and Zachary 1997).

If water can be reallocated to higher economic uses with price signals, while protecting third-party interests, is the fact that the reallocation does not meet the textbook definition of a market important? One of the primary critiques of the CDEWB was its failure to price water correctly (Wahl 1993; Dellapenna 2000). Most commodities are sold in imperfectly competitive markets; should water be different (Sax 1965; Pease 2012)?

During periods of severe water scarcity, spot-market conditions are likely to pervade; as long as transfers involve voluntary parties, and protect third-parties, is that not enough? These are the kinds of decisions policy makers must address and incorporate into drought plans before the next period of severe shortage.

Fast Forward: 2008

In 2008, much of California was at the end of the second straight year of drought, with projections of lower than normal snowpack for the winter of 2008-2009. In September 2008, the Department of Water Resources announced the planning phase of another EWB. Director Snow of the Department of Water Resources stated, "We would be negligent if we didn't prepare for the worst" (Weiser 2008). Snow added that administration of the bank would operate within the purview of the current state water operations Environmental Impact Study.

Since the 1991 CDEWB, the delta smelt (*Hypomesus transpacificus*) has been listed under the Federal Endangered Species Act and the California Endangered Species Act. This listing, along with renewed efforts to increase water levels in the Delta and its tributaries for the protection of Salmon runs (Chen 2011), reduces the managerial options to meet rising demands when streamflows drop. This is particularly significant for water transfers from Northern California to Southern California that must pass through the Delta, an issue exemplified by changes to water operations for the Central Valley Project and State Water Projects, which disallow pumping of water through the Central Valley Project under certain conditions (USFWS 2012).

In February 2009, then California Governor Schwarzenegger declared a Drought Emergency; this declaration also created the 2009 EWB. The 2009 EWB, with the goal of following the successful path of the 1991 and 1992 EWBs, was designed to allow environmental groups to purchase water and leave it in the Delta for ecosystem protection. The 2009 EWB exemplifies the need for pre-drought planning, and for the need for clear implementation steps linked to drought intensities. Several interested groups filed a protest to the implementation of the EWB without a California Environmental Quality Act (CEQA) compliance document (*Butte Environmental Council v. CA Department of Water Resources* 2010). The judge, in ruling in favor of the protesters said, "drought is not an emergency" covered under the Public Resources Code which may allow the state to avoid compliance with the California Environmental Quality Act (*Butte Environmental Council v. CA Department of Water Resources* 2010). Clearly, the ability to create a water bank in the same year as it is to be implemented is a relic of a bygone era. Drought water bank infrastructure and compliance work needs to be completed in periods of greater water abundance so they can be implemented when needed.

One of the primary critiques of EWB is their potential to negatively impact employment in basins of origin of any reallocated water (Bauer 1997; Howe 2000; Hanak et al. 2012; Broadbent et al. 2014). For any future CDEWB, socio-economic impacts must be addressed by a programmatic CEQA document. These types of analysis can be lengthy to complete and require public comment periods, meaning the time from initiation to implementation is likely to take over a year. To gain a better understanding of the economic and employment impacts of the drought, Howitt et al. (2014; 2015), used an IMPLAN economic input-output model to measure economic and employment losses. Their estimates suggest the 2014 drought led to the loss of 17,100 jobs (Table 4). These employment losses would have been greater had it not been for additional groundwater pumping of approximately 5 million acre-feet, which resulted in estimated direct costs to irrigators of $447 million USD (Howitt et al. 2014). The sustainability of this additional pumping can be questioned (Hanak et al. 2012; Christian-Smith et al. 2015; Cooley et al. 2015). These can be considered part-and-parcel the same issue. If water banking were effective, annual crops can be voluntarily fallowed and economic losses in higher marginal return areas can remain active, without additional groundwater pumping, something that will be constrained when the California Sustainable Groundwater Management Act (2014) becomes fully active across the state in 2042.

Table 4. Estimated socio-economic impacts of recent drought years in California (derived from drought data Howitt et al. 2014; Howitt et al. 2015; NOAA 2016).

Year	SPI	PDSI	Surface Water Shortage (m ac-ft/m^3)	Hectares Fallowed	Direct Job Losses	Total Job Losses	Direct Costs (million USD)	Crop Revenue Losses (million USD)	Total Economic Impact (million USD)
2014	-1.83	-4.41	6.6/8.14b	173,205	6,920	17,100	$1,500	$810	$2,200
2015	-0.72	-3.91	8.7/10.7b	218,530	10,100	21,000	$1,800	$900	$2,700

Creating an Effective Drought Management Model

In a December 2007, New York Times editorial, Friedman expressed skepticism towards the proposed Global Climate Change Initiatives discussed in Bali, stating, "If you need an environmental expert to explain it to you, it's not real" (Friedman 2007). The same is likely true about water banks. While water banks may have complicated underlying architecture, they need to have a simple interface for interested buyers and sellers. This requires that water banks have clear rules and make it possible for those holding rights or looking to purchase bulk water to understand whether they are eligible to participate, and to understand the cost structures.

Commoditization of water has the potential to increase net withdraws from the river basin (Gould 1988; Corbridge 1998; Howe 2000). When the consumptive amount of a water right is undefined, the potential for a transfer of water to conflict with the actual historical consumptive amount (Corbridge 1998) of the water right increases. A water banking credit determined by a crop fallowing formula serves as a reasonably accurate, but not precise, proxy for the consumptive amount when an adjudication of water rights has not occurred. It would be up to each state to determine whether such an approximation is adequately precise to protect downstream water users during drought periods.

One of the reasons the 1991 CWB was successful was the efficacy with which water was reallocated to willing buyers. In river basins lacking large storage reservoirs, water scarcity is as close as one or two years with below average snowpack followed by a dry spring and summer. Prior to the next sustained drought, states interested in adopting a drought emergency water bank as a planning tool should evaluate how water should be valued and purchased. For a water bank to function properly, water rights need to be accurately appraised. This raises the question of whether fixed prices or a market-based approach should be utilized. Coase (1960) argued efficient solutions occur when a limited number of parties are free to negotiate, and transaction costs are minimal. Empirically, this does not occur (MacDonnell 1999; Dellapenna 2000), and these negotiations could prolong the time until water can be transferred. While Americans are generally inclined to favor market-based approaches to valuation, when the commodity is water, and the time frame of the lease is short, perhaps a fixed price may be more beneficial — emergency water banks are temporary measures during times of severe shortage, periods when spot markets may cause distorted price signals. The downside to a fixed-price approach is it does not account for differences in the priority date of water rights; under such approach, the (potentially dangerous) assumption is made that all water rights "banked" represent "wet water."

Water-rights appraisers are a developing but not fully evolved industry in many basins in the West. The number of transfers is too limited to produce replicable price signals under a wide variety of climatic and hydrologic conditions (Gray 2008; Garrick and Aylward 2012; Broadbent et al. 2014). If the state is required to value each individual water right, the result will be delays in purchases, and transaction costs that may exceed the value of the water. Whatever approach is adopted, this decision is likely best made in advance of the next

drought so that guidelines can be developed to help the state agency in charge of making purchases. If this is left until the drought, the result may be delays and a more polarized and politicized system.

States can also expedite response to water shortages by creating the administrative documents for the operation of a drought water bank in advance. State legislatures could determine in advance what agencies, and what departments of these agencies are in charge of certain portions of the water bank. Additionally, documents such as the lease agreement could be drafted in advance, allowing potential participants to view the documents and start to make the decision whether they want to participate. Transparency in the form of making these lease agreements available in advance could affect water bank participation.

Creating a drought water bank framework in advance also provides the opportunity for stakeholders to decide whether to allow environmental groups the opportunity to purchase water for ecological needs. Allowing environmental groups an opportunity to purchase water arguably circumvents the appropriations system, when demand exceeds supply; purchases for the environment reduce supply for water right holders wanting to purchase water. Conversely, allowing purchases for instream flows is a mechanism to provide water to species and ecosystems in need of additional water — potentially reducing curtailment of diversions under the Endangered Species Act.

Alternative Drought Models

Two additional preemptive drought management tools are being implemented: Strategic Water Reserves (SWR) and reverse water auctions. Both of these models also involve substantial government involvement in water markets. While both of these methods are in their infancy, and little data are available, they both warrant consideration by water managers looking to diversify the mechanisms by which water can be reallocated in times of shortage.

SWR obtain water for use in periods of water shortage. This can take the form of obtaining permanent water rights, option leases, or physically storing water. In 2005, the New Mexico State Legislature created the "New Mexico Strategic Water Reserve" (New Mexico Statute 72-14-3.3, 2005). The purpose of this reserve is "to assist the state in complying with its interstate compacts and court decrees or to assist the state and water users in water management efforts for the benefit of threatened or endangered species or in a program intended to avoid additional listings of species".

SWR programs have some similarities to EMBs; both function on the premise of facilitating water reallocations to offset water shortages. Beyond this, the functionality of these two approaches quickly varies. The purpose for which SWR is obtained is usually limited. For example, the New Mexico SWR is only authorized to purchase water for two purposes, to help the state to comply with its Interstate River Compact obligations, and to "assist the state and water users in water management efforts for the benefit of threatened or endangered species or in a program intended to avoid additional listings of species". There is no mechanism to reallocate water to municipalities or other uses that may be suffering from severe water shortages.

Under the SWR legislation, the Office of the State Engineer is charged with the task of identifying basins in which to focus their purchasing efforts for that year. This decision is made based on the following factors:

1. The urgency of need for water or water rights to be held in the strategic water reserve in a river reach or basin.
2. The availability of water rights for sale or lease in the river reach or basin and/or whether storage exists for such water.
3. The cost, location, and seniority of the water or water rights in the river reach or basin.
4. Whether and to what extent water rights to be purchased or leased will assist the state in complying with its interstate stream compacts or court decrees or will assist the state in managing its waters for the benefit of threatened or endangered aquatic or obligate riparian species or avoid additional listings of species.
5. Whether water or water rights are available by donation. (NM Statute 72-14-3.3 2005)

Identifying priority basins is a logical method to focus water acquisition efforts. However, a

watershed priority system could constrain the flexibility of the reserve. By choosing a highest priority basin for a given year, it reduces the ability of the state to make purchases in other basins, reducing the reserve's effectiveness if a lower priority basin develops severe water shortages; for example, the Pecos River Basin and the Middle Rio Grande, two basins plagued with ongoing endangered species listings have been selected as basins of priority. Both are governed by Interstate River Compacts, and both contain federally listed endangered fish species, namely the Middle Rio Grande Silvery Minnow (*Hybognathus amarus*) and the Pecos Bluntnose Shiner *(Notropis simus pecosensis*).

The SWR specifies that the state "shall acquire water or water rights at a price no higher than appraised market value, based upon the best available information…" (NM Stat 72-14.3.3). This provision was instituted to ensure the state does not over-pay for water. During times of drought, spot market conditions can occur. This temporary inflation in price could prevent the state from acquiring water, arguably at a time when it needs it the most. At a July 2008 Public meeting, representatives from the New Mexico Interstate Stream Commission, the state entity in charge of carrying out the Reserve, readily admitted it is probable that the funds allocated to the Reserve will be insufficient to allow the state to engage in a "bidding war" for water during periods of shortage.

New Mexico is not alone in its approach to voluntarily reallocate water. In 2016, California created draft rules for purchasing water for the Sacramento-San Joaquin Delta (California State Water Resources Control Board 1992). Additionally, Washington State runs a "Trust Water Rights Program", created by the state legislature in 1991, and expanded in 2003. In 2007, Washington State's Department of Ecology (WDOE) operated a reserve auction of water rights in the Yakima River Basin "to enhance stream and tributary flows in the Yakima Basin" (WDOE 2012). The reverse auction was conducted by the Department of Ecology, and asked interested parties with valid water rights to submit a selling price for their water. The auction was a failure with only one offer to sell made to the WDOE. The WDOE then commissioned a survey to determine why the program did not solicit bids. The results varied, but were largely based on the lack of valuation of water, repeating one of the issues seen with the CDEWB. In 2015, the Reverse Auction program was repeated in the Upper Yakima Basin. In total, the state invited 650 water rights holders to participate. Only ten bids were submitted to the WDOE. Of those, six were accepted, and 878 ac-ft/yr were leased for environmental flows by fallowing 122 hectares (302 acres) (WDOE 2015).

Washington has expanded the Trust Water Rights Program statewide. Since 2010, most water obtained by the state has come from donations by various water users (Table 5). Temporarily donating water allows right holders to avoid periods of non-use. They can also use this donation as a tax benefit.

Table 5. State of Washington trust donations since 2010 (Adopted from WDOE data 2016).

Year	Number of Instream Flow Donations	Instream Flow Donations (ac-ft)	Number of Groundwater Replenishment or Reservation	Groundwater Replenishment or Reservation (ac-ft)	Number of Multiple Use/ Other Donations	Multiple Use/Other Donations (ac-ft)
2010	21	4,358	2	2,837	2	28
2011	25	17,817	12	2,394	4	148
2012	23	11,736	14	3,357	10	3,019
2013	30	17,240	13	1,837	6	1,126
2014	49	27,508	19	4,478	4	604
2015	47	66,264	24	5,805	2	472

Comparison of Drought Water Banks and Strategic Water Reserves

A comparison of EWBs and SWR reveal distinct advantages and disadvantages of each approach. The SWR has an inherent advantage over Emergency Water Banks in long-term planning because it allows for permanent water transfers. The state can increase its water supply by purchasing water rights, providing perennial water for the reserve, meaning water is available for every year without the need for the state to seek out willing sellers.

SWRs can also be constrained by limitations on scope; in New Mexico, the legislation authorizing the creation of the SWR states "The Interstate Stream Commission shall not acquire water or water rights that are served by an irrigation district established pursuant to Chapter 73, Article 10 NMSA 1978, except through a contractual arrangement with the district board of directors…." (NM Stat 72-14.3.3). This provision may undermine the effectiveness of the Reserve. Many of the water rights in the state of New Mexico are located within acequias, communally organized irrigation ditches, or formally recognized irrigation districts. If the governing agencies do not want to create a precedent of water leaving the boundaries of their district, they can prevent willing sellers from selling or leasing water to the state. This could severely constrict the number of potential sellers of water. This provision could also cause a delay in transfers until the irrigation or acequia district board votes on whether to allow the transfer. This may seem innocuous, but some stream reaches in New Mexico dry quickly; this delay could result in water not being available when it is most needed.

Another disadvantage of the Strategic Water Reserve over a drought water bank is its reliance on annual state funding. During periods of budget shortage, SWR programs can be viewed as "non-essential" programs, leaving them vulnerable to cuts in funding, regardless of the merit of the program. This happened in New Mexico only three years into the Program (Buynak 2009), and remaining funds were 'swept'. Because drought cycles can occur during these periods of budgetary shortage, there is potential for the Water Reserve to lack the funds necessary to purchase water necessary to meet compact deliveries and to protect endangered species.

Conclusion

Both the water reserve model as well as drought water banks may have a place in western water management. States, as the holder in trust of water, have inherent advantages over private initiatives such as water brokers for reallocating water during periods of drought. Neither of these MBA tools are meant to permanently reallocate water, designed to drastically increase the amount of water marketed, nor are they intended to replace market-driven reallocations of water by private entities. Instead, these are tools to prevent the need for more draconian measures during drought. By having myriad tools, states can design drought plans that address the dynamic hydrologic scenarios they face during drought, and reflect the regional preferences for water management. However, and this cannot be stated strongly enough, if states wait until water scarcity intensifies to make decisions, litigation and stagnation will surely result.

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The Extent and Nature of Potential Flood Damage to Commercial Property Structures in the Midwestern United States

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Abstract: Prior research on the extent of potential flood damage in the U.S. has focused on single-family residential structures, whereas this study evaluates the extent and nature of potential flood damage to commercial structures in two locations. Commercial buildings represent 13% of all structures in the 100-year floodplain in Sarpy County (Omaha, NE) and 16% in Fargo/Moorhead (ND and MN), yet account for half of total potential flood damage exposure as represented by depreciated structural replacement values (DSRVs). The most frequent commercial structures are special use, warehouse, and industrial properties, which are all well suited to DSRVs estimation. Commercial building characteristics are highly heterogeneous, making the extrapolation of their potential flood damage based on sample observations problematic. Commercial floodplain structures are older and/or less maintained and less valuable than non-floodplain structures, which, combined with the fact that higher valued multiple family, retail, and office structures were relatively rare in the 100-year floodplain, indicates that commercial property owners in general exhibit rational flood risk avoidance.

Keywords: *flooding, flood damage exposure, building replacement cost, commercial properties*

Research on the extent and nature of buildings susceptible to flood damage in the United States has focused almost exclusively on single-family residential (SFR) properties. However, reliable data on the potential damage to building structures (i.e., building damage exposure) is frequently for all (residential and commercial) properties required for a variety of flood mitigation planning activities including Flood Damage Analyses (FDA) by the U.S. Army Corps of Engineers (USACE 2012) and multi-hazard analyses through the HAZUS-MH program created by FEMA (Scawthorn et al. 2006). However, these prior studies have focused mostly on indirect intangible flood damage, and a thorough review of both the published and 'grey' (unpublished) literature indicates a stark absence of analyses regarding the flood risk exposure to commercial (retail, industrial, office, multiple-family residential, and special use) buildings.

This paper addresses this information shortfall by quantifying the extent and nature of potential flood damage, defined as monetary damage exposure of single-family residential and commercial buildings in two Midwestern U.S. locations. The first location: Sarpy County (Omaha, NE), is a suburban area with recent development growth that has not yet experienced significant flooding. The second study site location: Fargo/Moorhead (ND/MN) incorporates two adjacent cities on the Red River of the North with older development patterns (as compared to Sarpy County) and which have experienced significant flooding, both historically and in recent years. In each location, building values exposed to flooding are represented by the cost of replacing (i.e., rebuilding) existing structures while taking into consideration current building conditions which are formally defined as depreciated structural replacement values (DSRVs). Damage exposure values are calculated

for all structures within the regulatory 100-year floodplain (areas mapped by FEMA that have an estimated probability of flooding once every 100 years or 1% in any single year and where building development is highly regulated and/or where flood insurance is required).

It is hypothesized that commercial building damage exposure is a major component of total flood damage potential across typical (mid-sized) U.S. cities based on the frequency, extensive sizes, and relatively higher construction costs of commercial structures, as well as reported average national flood insurance payout values for residential and commercial properties (Floodsmart 2016). If confirmed, increased research into the nature and extent of commercial floodplain damage is warranted in order to facilitate the numerous flood mitigation efforts across the country. It is also hypothesized that, due to the highly heterogeneous nature of commercial structures, it is not possible to extrapolate potential flood damage based on a sample of commercial structures to the entire population, as is often possible with more homogenous SFR structures. Finally, it is suspected that commercial structures located in the 100-year floodplain are older, not as well maintained, and less valuable than otherwise similar non-floodplain commercial structures. If confirmed, this may indicate that commercial floodplain property owners are cognizant of floodplain risk in that they invest less in the construction and/or maintenance of buildings with relatively higher flood risks, and this may also imply that the use of non-floodplain structural inventory data may not be appropriate for quantifying the value of commercial structures within floodplains.

Literature Review: The Extent and Nature of U.S. Flood Damage

Quantifying Flood Damage

Potential flood damage, whether potential or actual, can be classified as either direct tangible damage (or building damage exposure, the focus of this research), direct intangible damage, indirect tangible damage, or indirect intangible damage (Merz et al. 2010). The dominant research on flood damage issues in the U.S. has historically focused on indirect intangible damages, by measuring the impact of flood risk on resale values, understanding property owners perceptions and decisions regarding flood insurance, and evaluating the efficiency and resiliency of the national flood insurance program.

Related to the focus of this research (direct tangible damage to buildings), both actual and potential flood building exposure damage estimates are compiled nationally by the National Weather Service (NWS), but these estimates have been determined to be inconsistent, inaccurate, and lacking in specificity with regards to types of flood damage in specific areas (Pielke et al. 2002; Cartwright 2005). Improved estimates of flood damage have relied on claims data from the Federal Emergency Management Agency Flood Insurance Program (FEMA/NFIP) (Kunreuther and Michel-Kerjan 2013; Kousky and Michel-Kerjan 2015). However, the majority of NFIP claims are focused on SFR structures and small business structures and generally exclude larger commercial structures that are only required to have flood insurance when financed using federally subsidized mortgages, which is relatively rare. Another reason why many commercial structures are not likely to participate in the NFIP is that coverages are limited to $500,000 for structures and $500,000 for contents. Detailed information on NFIP commercial claim payouts could not be found (via internet searches) but FEMA (2015) publicly reports that from 2010 to 2013 the average commercial flood claim amounted to nearly $89,000, substantially higher than the average SFR claim of $39,000 (Floodsmart 2016). Flood damage estimates can potentially be obtained from empirical data of past (historical) flood events and from private insurance loss data. In the few known (published) cases when this has been undertaken, estimates have either focused only on residential losses (CNT 2014) or total losses not aggregated by property types (Mohlejo and Pielke 2014).

The U.S. Army Corps of Engineers (USACE) estimates potential flood damage to all types of structures when conducting feasibility studies of flood mitigation projects (USACE 2012). These studies require structural building inventories where DSRVs (defined as new replacement cost minus depreciation) are calculated for all structures within a study area. Depreciation

is applied to replacement costs to account for the fact that buildings wear over time and need repair and/or refurbishments. Not accounting for depreciation would over-estimate actual sustained damage due to flooding. These structural damage data are incorporated into the USACE FDA program to estimate the likely flood damage to each structure under a full range of possible flood events (USACE 2011). The USACE structural inventories are often conducted by contractors and based on cost replacement data supplied by national vendors (typically Marshall and Swift or RS Means) in conjunction with site visits and ancillary data from county tax assessors. The resulting DSRVs are very likely the most accurate available estimates of potential flood damage, but these data usually are only collected for a limited number of USACE project site locations nationally. The nature and extent of the potential flood damage summarized by property sub-types is rarely described in detail within USACE project reports. Finally, raw (non-summarized) DSRV data are often difficult to locate and obtain from USACE contractors, particularly when feasibility studies were completed many years prior. However, such detailed DSRV data were obtained from the USACE for this research.

A second potential source of flood damage data decomposed by structure types is the general building stock (GBS) of the FEMA Multi-hazard Loss Estimation Program (HAZUS), first developed in the 1990's in conjunction with the National Institute of Building Sciences (Scawthorn et al. 2006; Schneider and Schauer 2006; HAZUS 2009). The HAZUS GBS is closely tied to decennial census data and was first released in 2004 using year 2000 census data and recently re-released in the fall of 2015 based on 2010 census data. A particular concern with GBS methodologies used to calculate DSRVs is that building type data (styles, stories, existence of basements and garages) are both dated and based on regional and hence, greatly generalized data. Of even greater concern is that in 2000 the contractor Dunn and Bradstreet generated commercial GBS data using non-specified and unknown (i.e., proprietary) methodologies and data sources. The company did not update this commercial structural data for 2010 but rather FEMA used an unknown (not explained or publicly documented) approach to extrapolate commercial structural building data from 2000 to 2010. A few past studies have analyzed actual structural building data for comparisons with HAZUS GBS but they all focused only on SFR damage. The HAZUS-MH program provides a suite of flood depth damage curves for different building types, which, when combined with flood probability, modelling, and building replacement costs, can be used to generate estimates of potential flood damage exposure to buildings.

A third potential source of DSRV data for commercial floodplain structures is county tax assessors, who frequently rely on the cost replacement approach to value special use, industrial, and warehouse properties (Dornfest et al. 2010). In rare cases, assessors utilize the cost approach for all property types. Such a comprehensive dataset of DSRVs from the Sarpy County Assessor, NE is used in this study.

The Lack of Prior Research on the Extent of Commercial Flood Damage Exposure

There is an extensive quantity of published research dealing with flood risk management policy issues in the U.S. but these have focused on residential structures and can be generalized within three categories: 1) Quantifying the impact of flood risk on sale prices, 2) Evaluating the demand for flood insurance; and 3) Strategies to improve the efficiency and effectiveness of the NFIP. Almost none of this research has focused on commercial properties, likely because most have relied on real estate transaction databases and/or flood insurance premium and payout data that are almost exclusively associated with single-family residential properties. Considering the potentially large impact of commercial flood risk on total flood damage nationally, research specific to commercial structures is warranted. The scarcity of published information on commercial flood damage in the U.S. might be because site-specific flood damage inventories conducted by FEMA, USACE, local floodplain managers, and others are contained in unpublished project reports. The lack of other researchers' citations of such studies or reports suggest that they may not be very common, justifying the focus of this study: to quantify the

nature and extent of potential commercial flood damage in two Midwestern study locations.

Methods and Data Collection

The extent of potential commercial flood damage in Sarpy County (Omaha, NE) and Fargo/Moorhead (ND/MN) was quantified by classifying the structure types and related DSRVs both within and outside the regulatory FEMA 100-year floodplain. DSRVs for structures were obtained from two alternative data sources: The Sarpy County Assessor, and the USACE Fargo/Moorhead Structural Inventory (part of the Flood Diversion Feasibility Study). Each of the data sources estimate DSRVs of structures using Marshall and Swift (M&S) cost estimation software. Both potential flood damage areas were classified by property sub-types and floodplain status based on GIS analyses to identify whether structures and related DSRV were within the 100-year floodplain. It is important to note that this potential flood damage does not attempt to account for the relative elevation of individual structures, possible existence of flood proofing measures, interior content damage, or losses associated with clean-up costs, disrupted living conditions, and lost business opportunities. Instead, this DSRV based data should be considered to represent a generalized indicator of potential flood damage.

For the Sarpy County (Omaha, NE) analyses, DSRVs were obtained from the County Tax Assessors parcel level database that contains 47,157 SFR structures within 47,000 parcels, and 4,742 commercial structures within 1,783 parcels. Most of the real estate development in the County has occurred in the last 15 years due to accelerated suburban growth trends. FEMA d-firm regulatory floodplain polygons exist for the county and they are mostly associated with the potential flooding of the Papillion Creek system. No recent major flooding events in the county have occurred, but flood risk is increasing as the City of Omaha to the north continues to urbanize, increasing urban run-off into the Papillion drainage system. For that reason, a series of upstream reservoirs are being built by local agencies to control future flooding.

The quality or reliability of this DSRV data is considered high because the Sarpy County Assessor relies heavily on the cost replacement approach to assess all classes of properties, in contrast to many other assessors around the country who rely on the cost approach only for newer SFR, industrial, and special use properties. The assessor uses M&S cost estimation software (Marshall and Swift 2017) in conjunction with detailed structural characteristics and condition data collected by the assessor's office through both building permit reviews and site visits. Depreciation rates are calculated using a market extraction approach where sale prices of properties with varying conditions and improvements are compared. The county assessment data were supplemented by GIS-based spatial overlays (intersects) of building footprint polygons and 100-year FEMA d-firm floodplain boundary polygons. When more than 15% of a structure footprint was located in the 100-year floodplain the entire structure was classified as being in the floodplain.

Corresponding DSRVs for commercial properties were obtained for Fargo/Moorhead (ND/MN) from a USACE contractor (URS 2009) who collected the data as part of the 2011 USACE (St. Paul District) feasibility study to evaluate a diversion-based flood mitigation project (the Fargo/Moorhead Diversion). Although the population of this metro-area is less than 220,000, it has a very large 100-year floodplain and has experienced both historical and recent significant flooding and damage, although a catastrophic (i.e., 500-year) flood event has not yet occurred.

As part of the feasibility study, the USACE contractor (URS, 2009) conducted a structural inventory of most of the two cities (both 100- and 500-year floodplain areas). The inventory was based on structural characteristic data obtained from local tax assessors combined with on-site inspections of structures to collect data on structure types and uses, foundations, exterior materials, roofing systems, first floor elevation, construction quality, and current condition. Cost estimates were generated using the M&S estimation software, while depreciation was calculated by dividing effective age, representing age adjusted for current building condition based on contractor assessments of building condition, by the expected typical life of structures.

The resulting DSRV database obtained from the contractor for this current research

effort contained DSRV estimates and a limited amount of structural information for 40,128 SFR structures and 8,956 commercial structures. Parcel identification numbers, addresses, M&S occupancy codes, structure style/type, foundation height, and effective age data were provided. Key missing data were actual age, building life expectancy, size dimensions, condition and quality measures, floodplain status, and tax assessment values. Of particular importance, the provided dataset did not contain depreciation value, nor were non-depreciated structural values included, making the calculation of depreciation rates by comparing non-depreciated and depreciated building values impossible.

Missing information was supplemented by relational joins with tax assessor data and GIS overlays of building footprints within the regulatory (d-firm) 100-year and 500-year floodplain boundaries. For both study locations, the data on building damage exposure, represented by DSRVs within the 100-year floodplain, were first compared across SFR and commercial structures and then by six commercial structure sub-types (industrial, multiple-family, office, retail, and special use). These classifications follow owner occupancy classes (OCC's) developed by M&S that were adopted by both the Sarpy County Assessor and the USACE/URS when compiling DSRV data. Such detailed commercial structural classifications were not available for Moorhead, MN so the comparisons by property sub-types were only undertaken using the Fargo data. DSRVs are compared in terms of absolute values (totals) and on a size-adjusted basis (DSRV per square foot of structure).

Methodologies to compare commercial structure characteristics and DSRVs by floodplain status varied slightly across the two study site locations: In Sarpy County, where only 100-year floodplain areas are mapped, comparisons of 100-year versus non-100-year floodplain areas were made only within neighborhoods (census blocks) close to the 100-year floodplain. In Fargo/Moorhead, where the 500-year floodplain has been mapped, the 100-year floodplain was compared to nearby 500-year floodplain structures.

Finally, measures of central tendency (means, medians, and standard deviations) of structural characteristics and values of commercial structures are compared across floodplain status, and paired t-tests at the 90% confidence level are used to evaluate whether noted differences are statistically significant.

Results

Single Family Residential Versus Commercial Potential Flood Damage

In Sarpy County, 3.6% of all structures were located in the 100-year floodplain versus 5% in Fargo/Moorhead. The proportion of these floodplain structures by property type (SFR versus commercial) and their respective cumulative (total) DSRVs are summarized in Table 1 and Figure 1. Commercial structures only represent 13% to 16% of all floodplain structures (Sarpy and Fargo/Moorhead, respectively) yet commercial damage accounts for 54% of all potential damage in Sarpy County and 50% in Fargo/Moorhead, assuming that all residential and commercial buildings are equally susceptible to flood damage. The discrepancy between structure numbers and damage exposure is likely a result of most commercial structures being larger and more expensive to construct than typical SFR structures. However, it should be noted that these potential commercial flood damage estimates might be exaggerated since some valuable commercial floodplain properties may have higher levels of flood proofing (i.e., raised elevations, special building materials) than exist with SFR structures. Unfortunately, the databases relied on for this study did not have any details regarding the level of flood proofing for individual structures to confirm this hypothesis. Still, the implications from these findings are clear: Commercial flood damage is likely a major component of total flood damage in each of these two Midwestern communities, and not accounting for the predominance of potential commercial damage when evaluating and/or designing flood mitigation/management activities could lead to economically infeasible public policy decisions.

The Characteristics of Potential Commercial Flood Damage

The number and value of commercial 100-year floodplain structures categorized by six property sub-type classifications in Sarpy County and Fargo,

Table 1. Structure frequency versus Depreciated Structural Replacement Values (DSRVs) in the 100-Year floodplain.

	----------Sarpy County----------		----------Fargo/Moorhead----------	
Structure Type	**# Structures**	**DSRV (Millions)**	**# Structures**	**DSRV (Millions)**
All	1,239	$369	2,503	$818
Single-family Residential	1,079	$167	2,152	$411
Commercial	160 (13%)	$197 (54%)	351 (14%)	$407 (50%)

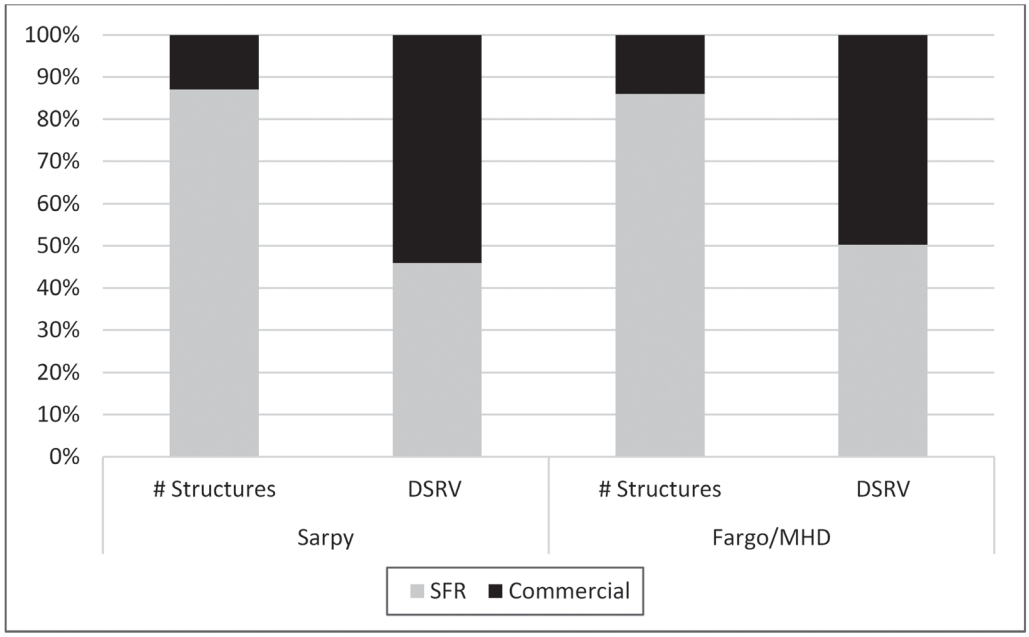


Figure 1. Structure frequency versus DSRVs in the 100-year floodplain. DSRV = Depreciated Structural Replacement Value. SFR = Single-family Residential.

ND are summarized in Table 2 and Figure 2. The types of commercial structures within the 100-year floodplain across the two locations are not identical; the majority (82%) of commercial structures in the Fargo floodplain are special use properties, whereas Sarpy County has a wider variety of commercial property types present. This is likely because the Fargo 100-year floodplain has been well established for many years and the community has been subject to several recent, large flood events, in contrast to the Sarpy County floodplain which was recently re-mapped (i.e., much of it was previously not designated as floodplain) and the area has not had any major flood events in the recent past.

In both study site locations, special use, industrial, and warehouse/storage structures are the most common and correspondingly generate the largest amount of potential flood damage. This bodes well for the use of the cost approach to value potential flood damage for floodplain properties since it is considered a reliable approach to value these types of structures which often do not have income rental revenue streams (used for the income valuation approach), and often do not sell frequently enough to utilize the comparable sales valuation approach. Finally, the finding that the highest valued commercial properties (multiple family residential, office, and retail structures) are

Table 2. Commercial structures and values by structure type in the 100-year floodplain.

	----------Sarpy County----------		----------Fargo*----------	
Structure Type	**# Structures**	**DSRV** (Millions)**	**# Structures**	**DSRV (Millions)**
All Commercial	160	$197	289	$357
Industrial	43 (27%)	$13 (6.5%)	5 (2%)	$6.9 (1.9%)
Multi-family Residential	5 (3%)	$26 (13%)	30 (10%)	$3.7 (1%)
Office	16 (10%)	$34 (17%)	0 (0%)	$0 (0%)
Retail	35 (22%)	$32 (16%)	14 (5%)	$8.2 (2.3%)
Special Use	27 (17%)	$83 (42%)	238 (82%)	$337 (94%)
Warehouse/Storage	34 (21%)	$9 (5%)	2 (<1%)	$1.5 (<1%)

*These calculations do not include Moorhead structures, which were not classified by property sub-type.
**DSRV = Depreciated Structural Replacement Value.

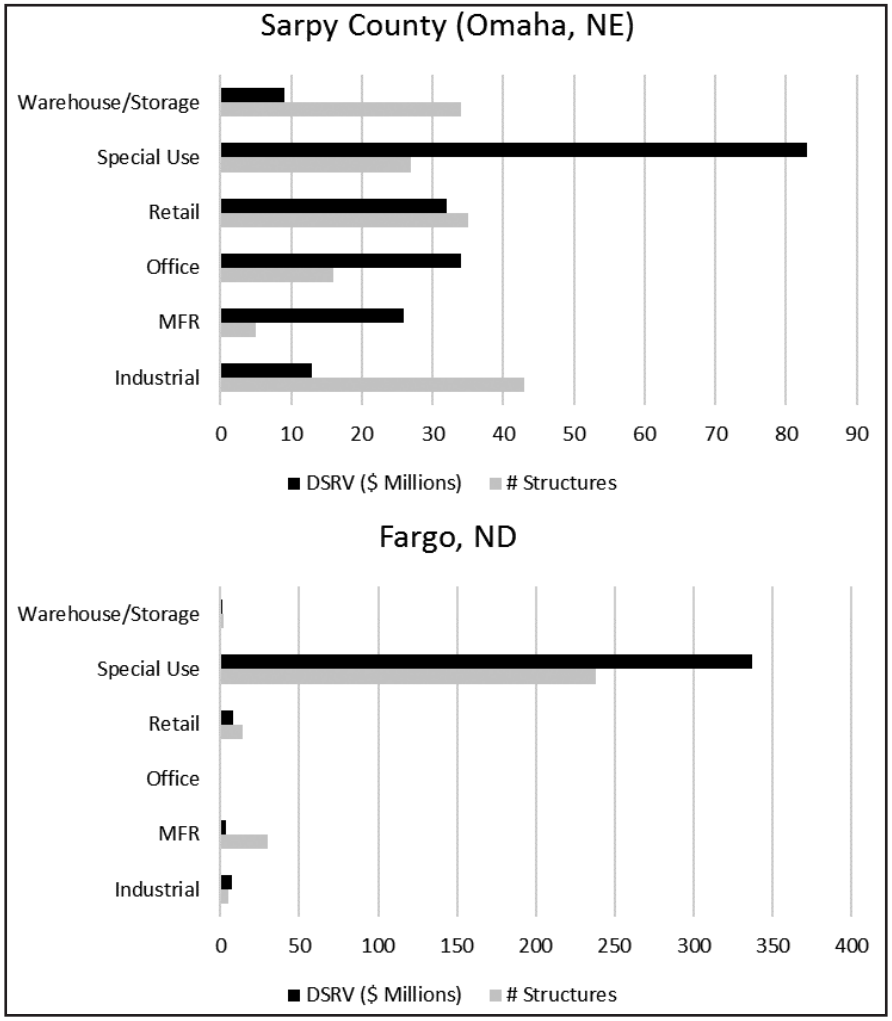


Figure 2. Commercial structures and values by structure type in the 100-year floodplain. DSRV = Depreciated Structural Replacement Value. MFR = Multi-family Residential.

relatively absent from the 100-year floodplain may indicate rational risk avoidance among commercial property owners.

The characteristics and values of commercial floodplain structures by detailed property subtypes (Table 3) indicate a high degree of variation (heterogeneity) in the age and value of structures across each of the six commercial sub-property type classifications. In Sarpy County, office, retail, and special use properties have the highest size adjusted potential flood damage, whereas in Fargo/Moorhead multiple-family and special use structures have the highest damage potential. There are many sub-classes of structure types for industrial, office, retail, and particularly special use categories in both locations and these property types also have a high degree of heterogeneity with regard to average size adjusted prices (as measured by standard deviations). In particular, office, multi-family residential, and special use properties have widely varying potential flood damage costs on a per square foot basis. This indicates that estimating commercial flood damage based on average values and/or sample observations is problematic, particularly when commercial property sub-types differ across areas where estimates and

Table 3. Characteristics of floodplain commercial structures by property sub-types.

	# Sub-Property Types	Most Common Sub-Types	Mean Age (Yrs.)	DSRV*/Sq. Ft. Mean	DSRV/Sq. Ft. Std. Dev.
Sarpy County					
Industrial (n=44)	5	Equip. Shop Service Repair/Garage	25	$24	$15
Multi-family Residential (n=6)	2	High Rise Low Rise	31	$38	$22
Office (n=16)	5	Office (general) Medical Office	26	$65	$44
Retail (n=35)	4	Shopping Restaurants	23	$63	$34
Special Use (n=29)	14	Auto Dealerships Lt. Commercial Utility	14	$56	$51
Warehouse/Storage (n=37)	3	Warehouse Storage Mini-Storage	22	$27	$10
Fargo/Moorhead					
Industrial (n=5)	5	Repair Shop Light Manuf.	38	$72	$19
Multi-family Residential (n=30)	4	Low Rise High Rise	23	$256	$341
Office (n=0)	NA	NA	NA	NA	NA
Retail (n=11)	3	Shopping Restaurants	8	$101	$59
Special Use (n=219)	12	Mixed Use Utilities	91	$168	$82
Warehouse/Storage (n=2)	2	Warehouse Storage	7	$86	$18

*DSRV = Depreciated Structural Replacement Value.

extrapolations are made. It is likely that future efforts to estimate the DSRVs of commercial floodplain properties will have to continue to rely on complete inventories of all structures.

Commercial Structure Characteristics and Potential Flood Damage by Floodplain Status

Commercial floodplain structures in Sarpy County are 26% smaller and 16% more depreciated than nearby non-floodplain properties, but they have similar values, both in absolute and size-adjusted terms (Table 4). Fargo/Moorhead 100-year floodplain buildings were older and 44% less valuable than 500-year floodplain structures (Table 5) but actual depreciation rates were not available for comparison – although it should be noted that mean quality/condition measures were identical across floodplain status. Therefore, the hypothesis that commercial structures in the 100-year floodplain are markedly inferior in construction quality and maintenance as compared to nearby non-floodplain properties appears to hold but the hypothesis that floodplain properties are less valuable than non-floodplain properties

Table 4. Commercial structures by floodplain status (Sarpy County, NE).

	100-Year Floodplain (n=167)		Non-Floodplain (n=1,016)		Difference
	Mean	Std. Dev.	Mean	Std. Dev.	(Floodplain - Non)
DSRV[1] ($)	1,211,133	5,471,387	1,138,961	3,180,360	6%
Total Sq. Ft.	17,495	37,934	23,502	50,876	-26%*
DSRV per Sq. Ft. ($ / Sq. Ft.)	43	36	44	29	-2%
Age (years)	24	18	26	22	-10%*
Quality (M&S[2], 10-60)	20	3	20	2	-1%
Condition (M&S, 10-50)	30	2	30	6	-1%
Depreciation (Assessor Estimate)	36%	30%	31%	28%	16%*

*Statistically significant difference at the 90% confidence level or higher.
[1]DSRV = Depreciated Structural Replacement Value.
[2]M&S = Marshall and Swift cost estimation.

Table 5. Commercial structures by floodplain status (Fargo/Moorhead, ND/MN).

	100-Year Floodplain (n=778)		500-Year Floodplain (n=3,964)		Difference
	Mean	Std. Dev.	Mean	Std. Dev.	(100-Yr - 500-Yr)
DSRV[1] ($)	1,577,205	3,526,660	794,710	1,651,971	98%*
AGSF[2]	25,681	42,493	15,868	31,007	62%*
DSRV per AGSF ($ / Sq. Ft.)	82	42	147	2,106	-44%*
Age (years)	61	28	45	39	36%*
Effective Age	13	8	22	74	-40%*
Quality (M&S[3], 10-60)	30	10	30	20	0%ef
Condition (M&S, 10-50)	30	20	30	30	0%

*Statistically significant difference at the 90% confidence level or higher.
[1]DSRV = Depreciated Structural Replacement Value.
[2]AGSF = Above Grade Square Footage; differs from total square foot values as it exludes below grade (i.e., basement) square footage, and is a more appropriate metric for comparing floodplain versus non-floodplain properties since many floodplain properties do not have basements.
[3]M&S = Marshall and Swift cost estimation.

only appears to hold in Fargo/Moorhead where the floodplain is more established and flood events are more common.

Conclusion

This research has identified a lack of previous studies and reports on the extent of potential commercial damage exposure in the U.S. It has also demonstrated that in at least two medium sized Midwestern urban areas, commercial structures make up a large share of building exposure to flood hazards. It is proposed that this research be replicated in other geographical locations across the U.S., particularly in non-urbanized areas, which may contain relatively smaller frequencies of commercial structures (even though such areas are likely to have fewer structures and hence relatively less potential flood damage). If it is confirmed that commercial flood damage is a major part of total flood damage exposure in other regions of the U.S., it is recommended that these values be more explicitly quantified and reported by Federal agencies (NWS, NFIP, and USACE) as well as by state and local governments and/or floodplain managers.

Since this present research focused only on potential flood damage exposure, it is recommended that future research efforts attempt to quantify the relative amounts of commercial versus SFR flood damage associated with actual flood events. This would likely involve detailed reviews of local, state, and federal flood damage inventories and classifications combined with reviews of NFIP and private insurer claim payouts and Small Business Association disaster lending. It may be the case that actual commercial flood damage is less than potential flood damage due to the hypothesis that many commercial structures at risk of flooding (i.e., in the 100-year floodplain) have been subject to certain degrees of flood-proofing measures.

This research indicates that the owners of commercial structures appear to recognize the risk of flooding in that commercial structures are older, less well maintained, and less valuable than nearby and similar structures (i.e., same property types) that are not in the floodplain. This finding should be supplemented by additional research that quantifies both spatial trends in commercial damage exposure, and the extent to which commercial floodplain properties are flood-proofed and/or have flood insurance coverage through either the NFIP or private insurance. If commercial property owners are under-insured for flood risk and instead rely on government disaster recover support such as Small Business Administration (SBA) disaster recover loans or SBA disaster lending, this may demonstrate a public policy inefficiency.

Finally, additional research is recommended to develop approaches to more efficiently estimate potential flood damage to commercial structures in light of the fact that structural inventory databases analyzed in this study are very time consuming and expensive to create. New approaches for classifying different types of commercial structures with relatively heterogeneous structural characteristics and DSRVs is likely required. Such research would also facilitate the development of more accurate depth damage curves for different types of building structures. Future research could potentially be facilitated through the continued use of actual USACE inventories, collaborations with county tax assessors who utilized the cost approach for assessing commercial properties, and/or through collaborations with cost estimation companies. Optimally, this research could facilitate the correction of commercial flood damage estimates generated by the FEMA-HAZUS data set of potential flood damage, so widely utilized by flood mitigation professionals around the nation.

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Changing Student Conceptions of Arid, Urban Watershed Management

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Abstract: Despite the central importance of water, few students have the opportunity to study water resources management in secondary education. Even in tertiary education—unless they major in water resources or a closely related field—they are likely to receive only a week or two of instruction about water resources in introductory science courses. Typical instruction in such courses is textbook-based, with the course instructor lecturing on a broad range of topics. Complicating this, little is known about student preconceptions, which may interfere with—or be used to support—learning. We sought to identify preconceptions in an introductory environmental science course at an urban, research (R1) university in the arid Southwest of the United States. We used a pre/post design to assess student preconceptions about their urban campus watershed and designed a brief, experiential learning exercise. While experiential learning is common in water resources management programs, it is less common in introductory courses. We developed a coding scheme to analyze the pre- and post-test responses; results showed students held normative and non-normative preconceptions. There was significant growth in students' conceptual understanding between the pre-test and post-test, ($t(33) = -2.25$, $p < .05$), with a small to medium effect size, d = -0.393. This finding supports the use of experiential learning as a means to teach students about water resources, even in an introductory course. Understanding students' preconceptions of arid, urban watersheds can assist in how to better design curriculum. Such improvements in curricular design can empower students to make better decisions about urban watersheds.

Keywords: *experiential learning, water resources education, introductory university courses, Southwestern U.S.*

Water resources management is complex (Loucks 2008), especially in the western U.S. (Willardson 2005; Pease 2010). Adding to the natural water scarcity in the arid Southwest, urban centers continue to see population growth, increasing both water consumption and energy demand; energy production requires water, thus compounding the stressors on water resources (Ortiz et al. 2007; Garfin et al. 2013; Guldan et al. 2013). Another complication of Southwest watersheds is the North American monsoon, during which watersheds receive up to 50% of their total annual rainfall (Sheppard et al. 2002; Garfin et al. 2013). Monsoonal rains can bring about flash flooding events due to the impervious surfaces found in desert landscapes and urban environments (Garfin et al. 2013). Understanding water conservation in the watersheds of the urban Southwest has never been more urgent, given climate change predictions which suggest the Southwest will face increasingly severe droughts and challenges related to reduced water resources for agriculture (Elias et al. 2016).

Many approaches to watershed management include involving stakeholders and educating citizens to make informed choices (e.g., using water wise plants and rain barrels) (Webler and Tuler 2001; Sabatier et al. 2005; Genskow and Born 2006). Such approaches can provide important place-based perspectives and can make barriers to effective management visible, but involving the public can be a complex and fraught process. Having an informed citizenry could aid in water resource management efforts (Gunckel et al. 2012),

yet there are limited opportunities for students to learn about water resource management in their schooling if they do not choose to pursue a degree in the discipline. Even introductory university science courses that provide such opportunities, often do so through a few lectures, as their focus is typically to provide students with a broad foundation across environmental or geological science.

Our purpose in this paper was twofold. First, we aimed to identify the preconceptions held by students in an introductory environmental science class about specific watershed management topics. There have been calls for more research in this area (Dickerson et al. 2007; Keinonen et al. 2016), in part because comparatively little research has investigated students' preconceptions about watershed management, especially in urban, Southwest desert environments. While there is research reporting students' level of agreement with factual statements about water safety and access (Mahler and Barber 2015), this is a *drop in the bucket* compared to the depth and breadth of research investigating students' preconceptions about other science topics (e.g., hundreds of studies document students' preconceptions of topics such as climate change, force, and photosynthesis). Because we do not know much about student preconceptions in watershed management, it can be challenging to design effective instruction that can build on their preexisting ideas, as suggested by research on learning (e.g., Bransford et al. 2000).

Second, we sought to understand how a brief experiential learning activity could help these students learn about watershed management topics. Specifically, we focused on aquifer recharge, barriers to water infiltration, and actions that organizations and citizens can take to enhance water infiltration. In response to calls for further research on instructional approaches to teaching about water-related environmental science (Dickerson et al. 2007), we designed an experiential learning activity based upon research about how people learn. In particular, we focused on student preconceptions and how preconceptions can impair or propel learning outcomes. Additionally, we explored experiential learning, including ways it has been used in water resources education and closely related areas, such as sustainability and environmental education.

Misconceptions, alternative conceptions, preconceptions?

Researchers have debated the use of the term *misconception*, which some argue shows a deficit perspective (Hogan and Maglienti 2001; Maskiewicz and Lineback 2013), suggesting that the student is flawed in his/her ability to understand, thus placing blame on the learner (Leonard et al. 2014), rather than critiquing the instructional approach. Researchers like ourselves who take a constructivist stance (Piaget 1966) usually avoid the term misconception (Leonard et al. 2014); according to constructivism, there is no deficit or flawed knowledge. Rather, students' knowledge is constantly being shaped and reshaped by experiences, both in and out of school settings. As an example, consider the layperson's explanation of the cause of the seasons as "distance from the sun." Many people hold the preconception that summer heat is due to closer proximity to the sun. This notion is assembled from everyday experience; when you are closer to a heat source such as a fire or radiator, you feel the heat more strongly. But this notion is also based on formal schooling; commonly, textbooks show perspective drawings of the solar system, depicting it as highly elliptical and contributing to the notion that large changes in distance between the Sun and Earth occur seasonally (Schneps 1989; Atwood and Atwood 1997; Tsai and Chang 2005).

As researchers investigate the experiential and instructional roots of students' ideas, they often employ terms such as *alternative* conceptions, *naive* conceptions, and *pre*conceptions (Maskiewicz and Lineback 2013). We prefer the term preconception because this most accurately describes the experience an instructor faces: students arrive with various ideas prior to our instruction, some of which are normative, meaning they align to current scientific knowledge, and some of which are non-normative, meaning they do not align to current scientific knowledge (Clement 1993).

Students' preconceptions of water-related environmental science

Researchers have investigated students' preconceptions about various water-related environmental science issues. High school students

and college non-science majors tend to hold non-normative preconceptions about the water cycle, including evaporation and condensation (Mills 1983; Ewing and Mills 1994). Students often conceptualize groundwater as being stored in underground lakes or tanks, or traveling through pipes and underground rivers, but seldom envision it as occupying pore space in aquifers (Ben-zvi-Assarf and Orion 2005a, 2005b; Dickerson et al. 2007; Covitt et al. 2009; Unterbruner et al. 2016). They typically have confusion about systems and levels across systems, such as the relationships between water processes at the molecular scale and at the watershed scale (Covitt et al. 2009). Likewise, middle school students in one study held non-normative beliefs that pollution primarily has local and direct impacts, rather than moving through surface and subsurface waters (Rodríguez et al. 2015). Students also tend to hold non-normative preconceptions about how water moves through the environmental system (Ben-zvi-Assarf and Orion 2005a, 2005b). For instance, when drawing the hydrologic cycle, they did not depict groundwater. Adults tend to mirror these findings, as research has shown that they seldom know they live in a watershed or where their water comes from (Thompson et al. 2011).

Frameworks for water-related environmental science include both natural and human-engineered systems (Covitt et al. 2009; Gunckel et al. 2012), such as systems for cleaning and distributing water. Researchers have investigated students' preconceptions of access to safe drinking water. Stringent federal regulations apply to public municipal drinking water, whereas bottled water is under the purview of the FDA, which has enacted lower standards on the bottled water industry (Olson 1999; Fremerey et al. 2014). Yet, Saylor et al. (2011) showed that American undergraduate college students held preconceptions that bottled water is safer than municipal tap water. Likewise, Mahler and Barber (2015) showed that between 1993 and 2014, students enrolled in an introductory environmental science class tended to initially agree that bottled water is safer than tap water.

Preconceptions can be anchored quite firmly in students' minds and can prove difficult to change (Brody 1993; Fremerey et al. 2014). Without knowing students' preconceptions, instructors may waste time reteaching already well-understood topics or neglect weaker areas of comprehension. Understanding the breadth of what those preconceptions are is important for designing instruction that can facilitate conceptual change (Vosniadou et al. 2001; Fremerey et al. 2014). This allows instructors to meet students where their current understandings are rooted, and to use these starting points to build upon or deconstruct preconceptions. Confronting students with their preconceptions can help students develop more scientifically accurate conceptions (Sellmann and Bogner 2012) and may increase their interest in the topic (Franke and Bogner 2013). In contrast, traditional textbook and lecture approaches to instruction appear to do little to change these conceptions (Abraham et al. 1992; Brody 1993) and such approaches may even contribute additional non-normative conceptions (Brody 1993). These studies speak to the importance of designing learning experiences that can bring about conceptual change. One approach to promoting conceptual change is experiential learning (Sinatra 2005).

Experiential learning supports conceptual change

Experiential learning is an approach to learning by doing (Mayhew and Edwards 1936). It is "the process whereby knowledge is created through the transformation of experience" (Kolb 2014, p. 67). However, experiential learning does not just happen simply by doing; in order for experiential learning to be effective, the experience must be deliberately designed and include a reflection point (Reeves et al. 2014) to allow students to mentally organize ideas gained through activity (Dewey 2007). Experiential learning supports authentic learning by providing value beyond the classroom and opportunities to construct knowledge through disciplinary practices (Newmann and Wehlage 1993; Knobloch 2003).

Experiential learning activities are commonly advocated for and implemented in graduate level water resources programs (McIntosh and Taylor 2013; Kulcsar et al. 2016), as well as in upper division undergraduate coursework (Campana 2010; Dennison and Oliver 2013; Missingham and McIntosh 2013). For instance, a field methods

undergraduate capstone course took students to Honduras to design a sanitary water delivery system for a community (Campana 2010). In a campus-wide water resources education project, upper division undergraduate students and graduate students conducted research on the water management system on their campus, which included a wetland, raingardens, and porous asphalt (Welker et al. 2010). Experiential learning has been used in university-level short-courses to prepare future water professionals to accurately identify water resource problems and develop new solutions for global water resource management (Camkin and Neto 2013). During experiential learning projects, students work collaboratively on problems with water management professionals. Having students share their relatively novice personal experiences with water professionals allowed them to see their perspectives as valued and valuable. Likewise, experiential learning activities have been implemented in communities (Camkin and Neto 2013; Oliver and Dennison 2013) and out-of-school settings for high school students, resulting in significant learning gains (Dann and Schroeder 2015).

Experiential learning has also been used to teach elementary and middle school students about water-related environmental science. In one study of a set of units threaded throughout a year of instruction, urban elementary students learned how water moves through their local watershed (Endreny 2010); one insight from this study is that leveraging the local and therefore familiar environment can be particularly beneficial for learners with little prior knowledge of watersheds. Such approaches, especially when well designed within a problem scenario, can help learners connect the science they are learning to actions they can take (Gill et al. 2014). Well-designed experiential learning activities that include both indoor and outdoor activities have been shown to support middle school students to learn challenging, systems thinking aspects of water-related environmental science (Ben-zvi-Assarf and Orion 2005a). While these studies show the potential of experiential learning, there is little evidence to date for its benefit in early undergraduate coursework, especially in broad introductory courses.

Methods

We sought to investigate student preconceptions and whether a brief experiential learning intervention could help students develop a more accurate understanding of watershed management in an arid, urban environment. We sought to answer two research questions: 1) What preconceptions do students attending a university in an urban setting within an arid, Southwest desert environment hold about specific watershed management topics? 2) How might an experiential learning watershed makeover activity help students understand specific watershed management topics in an arid, urban, Southwest desert environment?

The participants were undergraduate students enrolled in an introductory environmental science class at a public university in the U.S. Southwest. A total of 79 students consented to participate; 73 students completed the pre-test and 36 completed the post-test; the lower response rate on the post-test was because students believed it would not count in their grade. Study procedures occurred in two 75-minute class meetings at the beginning of a unit on water resources.

The intervention was a two-day experiential learning activity. On day one, we directed the students to discuss local and regional water issues, posing questions such as: “Why should we care about water in the arid Southwest?”; “Are we currently in a drought?”; and “Are we wasting water on our campus?”. We then instructed students to take a watershed walk to assess the area around the lecture hall. We provided satellite maps of the building and instructed students to make notes of their observations on one map, and to use the other map to design a watershed makeover. We provided a list of relevant terms and encouraged students to use their smartphones to search for information while on the watershed walk. On day two, student groups gave five-minute presentations of their watershed assessment. This assessment included their concerns and how they would improve the watershed.

Students completed a pre-test and post-test that comprised three questions: 1) What kinds of things prevent rainwater from being absorbed into the ground? 2) What could our university do to waste less rainwater? 3) Why would this be a good

solution? We chose to use open-ended questions because previous research has demonstrated that students can sometimes select accurate answers on multiple choice tests, yet cannot explain or depict fundamental water-related environmental science concepts (K.L. Schwartz et al. 2011).

We used a common qualitative analysis technique to analyze student responses on the pre/post-test. We developed a coding scheme inductively (Strauss and Corbin 1998), then added codes based on an expert answer. We used an open coding process that established the credibility of our coding scheme using referential adequacy (Lincoln and Guba 1985), meaning we iteratively developed it with a subset of data, then applied it to the remainder. As we developed the coding scheme, we created an audit trail to track our decisions and versions in research memos and notes. We iteratively reviewed the coding scheme, combining codes that were conceptually similar, dividing complex codes to make them more reliable, and refining definitions to ensure the codes required little inference. We reviewed the scheme with our lab (which included multiple members not part of this project), triangulating across members, discussing any disagreements (Hammer and Berland 2014) and refined the coding scheme until two coders could reliably apply it. To enhance credibility, we held frequent debriefing sessions and opened our process to scrutiny by members of our research lab on multiple occasions throughout our research process (Shenton 2004). We conducted a dependability audit to ensure the data were accurate (checking for duplicate responses; checking timestamps to ensure data were from the expected timeframes; maintaining a raw data file and confirming that analyzed data conformed to raw data). With our research lab, we conducted a confirmability audit, in which we reviewed our research memos and notes where we documented our decisions, interpretations, and choices, finding that our process was understandable and logical to those outside the project.

We used a numeral 1 to indicate the code was present and a numeral 0 to indicate its absence (Table 1). To reduce bias, we coded student responses blind to timing (pre or post). We calculated a total score for each student by summing all normative codes. We omitted any students who did not have both a pre- and post-test response, resulting in a sample size of 33. We calculated the mean and standard deviation for both the pre and post-test. We also calculated descriptive statistics for each code. We used SPSS (version 23) to conduct a paired samples t-test. We hypothesized that the post-test scores would be higher than the pre-test scores.

Results

Student preconceptions

We investigated students' preconceptions about watershed management topics. Based on analysis of the pre-test, students held irrelevant, non-normative, and normative preconceptions (Table 2). Most students included multiple normative ideas. Slightly more than half of the students mentioned impervious surfaces as a barrier to aquifer recharge. Over 75% of students mentioned recharge in some manner. Over 60% of students mentioned some form of water catchment as a solution. Thus, over half of the students brought some important normative preconceptions to this learning experience. However, few students mentioned that drought, growing non-waterwise plants, and slanted surfaces contribute to the problem.

Many students also held non-normative preconceptions, some of which had not been noted in the research literature previously. For example, 18% of the students described pollution as a barrier to recharge. These students explained that some form of pollution, trash debris, oil residues, or chemical contaminants prevented water from infiltrating the ground and recharging our aquifer. Seventeen percent of the students mentioned evaporation, an idea that is irrelevant because evaporation cannot be managed out of a water budget within a watershed management plan. High rates of evaporation are a natural process in an arid climate. However, effective watershed management techniques in arid, urban environments can help reduce evaporative losses. Some students described plants absorbing all the water, preventing infiltration.

Conceptual change

We also investigated whether a brief experiential learning activity could change students'

Table 1. Coding scheme included irrelevant, non-normative, and normative ideas.

Codes tied to irrelevant ideas	***Description of student response***
Evaporation	Evaporation or an aspect of the evaporative process, heat, or too strong sun.
Plants absorb water	Plants absorb water but response does not differentiate xeric/water wise plants, or statement is vague in terms of whether absorbing water is good or bad. Don't count if reusing to water plants as a proposed solution.
Codes tied to non-normative ideas	***Description of student response***
Manmade is bad	Claims that manmade things are impervious and/or that natural surfaces are pervious.
Pollution	Pollution prevents rainwater from being absorbed.
Recharge is bad	Perception that any water being absorbed is a waste of water.
Too many plants	Adding plants will decrease absorption.
Dry ground	Dry ground prevents water from being absorbed.
Dirt field	A dirt scape will enable water absorption.
Codes tied to normative ideas	***Description of student response***
Impervious surfaces	Description of impervious, impermeable, hard packed, or rocky surfaces that prevent water from recharging the aquifer. Can mention specific surface (e.g., road, cement, sidewalk, buildings).
Recharge problem	An impervious barrier prevents water from sinking in, absorbing, soaking in, or recharging the aquifer; the word "aquifer" need not be mentioned. Does not need to be an accurate overall statement as long as response includes idea, process of water sinking into ground. Must include something that prevents water from being absorbed into the ground.
Slanted problem	Slanted or steep surfaces, including hills, roofs, sidewalks. Not proposed as a solution.
Non water-wise plants	Plants that are not drought tolerant or use too much water for the arid Southwest.
Use less water	Suggests watering less or using less water as a solution. Do NOT count if less water use is an outcome or justification.
Xeriscaping	Xeriscape, drought resistant plants, low water use plants.
Catchment	Some way to catch water or store water.
Rerouting	Methods to (re)route water.
Reuse	Later (re)use or having control over when water is used, possibly after cleaning or filtering the water. Can include using water for humans or for plants.
Recharge solution	Permeable surface as (part of) a solution (e.g., paver stones, or pebbly/crushed rocky surfaces, grassy field) to allow water absorption. Count as long as it is connected to the idea of recharging, soaking in, returning to the aquifer.
Runoff	Includes word run-off or runoff.
Drought	Includes word drought.

Table 2. Irrelevant, non-normative, and normative preconceptions identified in the pre-test.

Codes tied to irrelevant ideas (% of responses coded)	***Sample response***
Evaporation (17%)	Evaporation prevents rain water from being absorbed into the ground.
Plants absorb water (14%)	There are many things that prevent rainwater from being absorbed into the ground, but the major factors are for example: excess of paved areas and areas without vegetation to absorb the water.
Codes tied to non-normative ideas (% of responses coded)	***Sample response***
Manmade is bad (12%)	Things that prevent rainwater from being absorbed could be pesticides and manmade objects covering the ground.
Pollution (18%)	Contaminants and other debris lay over the ground and do not allow full absorption of the water.
Recharge is bad (8%)	Arroyos, drains, and barriers could prevent rainwater from being absorbed into the ground. These lead into the rainwater into filters that could clean the rainwater for Albuquerque. UNM could build a filter or some sort of device that contains the rain as it falls. These filters could be placed around campus. This would be a good solution because rainwater would not being wasted.
Too many plants (5%)	Because plants suck up water, so with less plants there is more water.
Dry ground (5%)	If the ground is too dry it will not absorb water.
Dirt field (3%)	Make a big field with nothing but soil so the rain can absorb into the ground to produce more groundwater.
Codes tied to normative ideas (% of responses coded)	***Sample response***
Impervious surfaces (58%)	Water can't be absorbed through asphalt and I think it is hard in big cities for water to be absorbed into the ground.
Recharge problem (77%)	Water can't be absorbed through asphalt and I think it is hard in big cities for water to be absorbed into the ground.
Slanted problem (0%)	None on pretest.
Non water-wise plants (3%)	Also, plants that are not suitable for certain environments may use up water before it can be absorbed.
Use less water (9%)	Not water when it rains frequently so the rain water is used more effectively.
Xeriscaping (3%)	One being green planting of native plant species.
Catchment (67%)	The storage system is used to hold the rainwater for future use; a barrel, a cistern or a tank is the items that hold the rainwater.
Rerouting (32%)	I think that this will be a good solution in wasting less rainwater cause the drainage system can lead to places that are good for absorbing rainwater into the groundwater.
Reuse (45%)	Could set up rainwater barrels or a pipe system that would use the rain water to water the plants and grass at night when less of the water will evaporate.
Recharge solution (15%)	If less of the campus is covered in concrete and instead covered with bricks or something like that then more water should make it down into the ground.
Runoff (11%)	We could use large barrels to collect water from rain gutters and other water runoffs.
Drought (5%)	We save the collected water for times of drought.

conceptions about watershed management. We found minor growth in students' conceptual understanding between the pre-test (M = 3.12; SE = 0.25, maximum possible score of 12) and post-test (M = 3.82; SE = 0.28), and though minor, this growth was significant, ($t(33) = -2.25$, $p < .05$), with a small to medium effect size, $d = -0.393$.

By looking at the frequencies of specific codes, we see that growth occurred in specific areas (Figure 1). For instance, 21% of students mentioned that rerouting water can provide a solution on the pre-test, whereas 39% mentioned it on the post-test. Fifty-five percent of students mentioned impervious surfaces as a problem on the pre-test, whereas 67% did so on the post-test. Six percent of students suggested using less water overall on the pretest, whereas 21% did so on the post-test. Sixty-seven percent of students mentioned catchment systems as a solution on the pre-test, whereas 76% did so on the post-test. Only 3% of students mentioned xeriscaping as a solution on the pre-test, whereas 21% did so on the post-test.

Many students brought the ideas of impervious surfaces and catchment systems with them to this experiential learning activity. There were opportunities for students who did not know about these ideas to learn about them from their peers, both during small group activities and in listening to their peers present their ideas. Students had opportunities to choose specific topics to investigate, and this is reflected in the learning growth regarding specific ideas, such as xeriscaping and using less water.

Discussion and Conclusions

Prior research on student preconceptions about water-related environmental science issues focused on the water cycle (Mills 1983; Ewing and Mills 1994), how water is stored and moves underground (Ben-zvi-Assarf and Orion 2005a, 2005b; Dickerson et al. 2007; Covitt et al. 2009; Unterbruner et al. 2016), and about systems thinking aspects of water (Ben-zvi-Assarf and Orion 2005a, 2005b; Covitt et al. 2009; Rodríguez et al. 2015). Likewise, preconceptions about the safety of tap water (Saylor et al. 2011; Mahler and Barber 2015) and its treatment (Fremerey et al. 2014) have been investigated. Past research has shown that instruction can increase students' level of agreement with factual statements about the amount of pollution in water resources and the safety of tap water (Mahler and Barber 2015). We extend this body of knowledge by investigating preconceptions about watershed management in an arid, urban, Southwest desert environment.

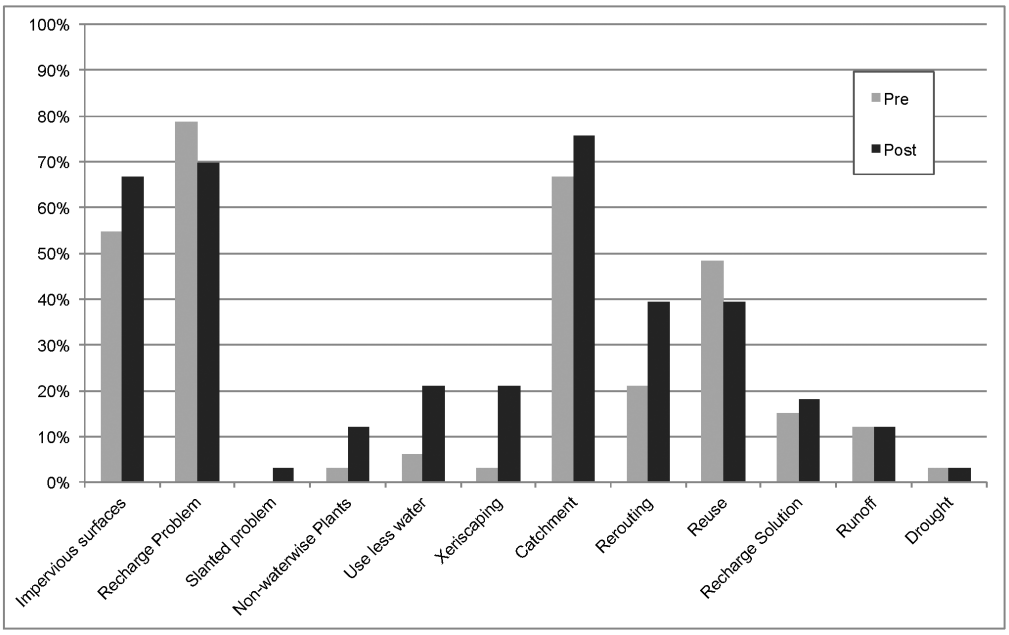


Figure 1. Percent of student responses containing normative ides on the pre-test and post-test.

We found most students described normative ideas, but many also included unexpected non-normative ideas; for instance, students explained that plants, pollution and trash, and man-made surfaces prevent water from recharging the aquifer. Based on the non-normative preconceptions we identified in our population of university students in an introductory course, we see a need for increased water resources education at the high school level. Such instruction could target the non-normative preconceptions we identified. The idea that pollution prevents water infiltration could be addressed by providing instruction about the actual effects of pollution. The idea that manmade surfaces are always impervious to water could be addressed to clarify that some human-designed objects can be very effective watershed management tools.

Preconceptions can be held quite firmly, preventing new learning from taking place. Understanding students' preconceptions can serve as a starting point to initiate conceptual change (Fremerey et al. 2014). One of the most promising approaches to conceptual change is experiential learning. Such approaches are deliberately designed experiences that begin with student ideas, followed by opportunities for experience, and finally ending with reflection (Mayhew and Edwards 1936; Dewey 2007; Reeves et al. 2014). The experience we designed included a carefully planned sequence backed by past research on learning. First, many studies underscore the importance of beginning instruction by first eliciting students' ideas (Linn et al. 2004; Linn 2006; Martin et al. 2007; Fremerey et al. 2014). In our design, the pre-test and small group discussion elicited students' preconceptions. Students then had opportunities for experiential learning in the field and time to conduct independent research (Mayhew and Edwards 1936; Dewey 2007; Reeves et al. 2014). Following this, students presented to one another as a form of direct instruction. This sequencing of direct instruction *following* an activity is also supported by research (D.L. Schwartz and Bransford 1998). Lastly, the post-test provided a specific reflection point, allowing students to further process newly acquired knowledge, as recommended by research on learning (Mayhew and Edwards 1936; Dewey 2007; Reeves et al. 2014).

Educators have advocated for experiential learning in upper-level water resources within undergraduate and graduate programs (Ballantyne and Packer 2009; Campana 2010; Camkin and Neto 2013; Missingham 2013). Our study builds on prior work by showing that this approach can extend to an introductory course. Our two-day activity is realistic and could easily be included in a broad introductory level course to teach about watershed management. Based on our findings, experiential learning is a promising approach, even for students with little prior knowledge of the specific subject area being introduced (Welker et al. 2010). Having multiple experiential learning experiences across subjects supports students to develop stronger teamwork skills (Coker et al. 2017). Our findings demonstrate the feasibility of incorporating brief experiential learning activities into an introductory level course, which could then encourage the development of teamwork skills among students in these early courses.

Few previous studies of experiential learning in water-related environmental science have assessed the impacts on learning (e.g., Thompson et al. 2011), though some have assessed participants' perceptions (Cockerill 2010). An exception is an evaluation of learning gains related to three Project WET lessons on the water cycle, which showed similar amounts of growth to our intervention (D'Agostino et al. 2007). However, no detail is provided on the type of activities included in the lessons and all questions in their assessment were multiple choice. Given concerns raised over this format (K.L. Schwartz et al. 2011), it is unclear if such gains represent increases in conceptual understanding. Our study assessed students' conceptual change related to water resources. Even though only minor growth was detected overall, we found larger increases for specific ideas, such as using xeriscaping, using less water, rerouting water, and using catchment systems as solutions. We encouraged students to engage with ideas tied to water resource management outside of class, and given the limited duration of the learning experience, we see that this growth can likely be attributed to the experiential learning approach. Overall, our findings suggest that implementing a brief experiential learning intervention on water resources can change students' preconceptions.

Limitations and Future Directions

Although our brief experiential learning activity appeared successful, we discuss methodological limitations to our interpretation and outline future directions. We lacked a control group and relied on students' pre-test scores to provide a covariate. This limits the degree to which we can attribute the observed changes to our intervention.

In future, we also plan to investigate refinements to our curricular design. One refinement would be providing feedback to students and asking them to revise their work based on that feedback. A second refinement would be to have students reflect on how their ideas had changed, supporting metacognitive processing. Future work could compare results from studies carried out in varied geographical regions, and in urban and rural areas, to better understand the breadth of students' preconceptions and ways these may be influenced by everyday experiences.

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Have an idea for a special session?

The Conference Planning Committee invites you to propose a Special Session for the conference. A special session organizers' role is to propose a relevant and timely topic, recruit speakers to submit abstracts to the session, and moderate the session during the June 2018 Conference. Special sessions can be in the form of a panel discussion, a group of 4 or more oral presentations on a specific topic, or a group of lightning (5 minute) talks followed by group discussion. Multiple session track proposals are welcome. Those interested in organizing and hosting a special session should provide the following information:

- Title of proposed special session
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- Type of proposed session(s): panel discussion, full length talks (20 min), or lightning talks (5 min) followed by discussion
- A draft list of presenters (to submit abstracts via the general call for abstracts) and their tentative titles.

The above information should be submitted directly to the Conference Chair, Kevin McGuire (kevin.mcguire@vt.edu), and Technical Program Chair, Bryan Swistock (brs@psu.edu), no later than September 22, 2017.



General questions about the conference can be directed to Karl Williard (williard@siu.edu), Executive Director of UCOWR, or Staci Eakins (ucowr@siu.edu), Administrative Assistant.

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