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Re-conceptualising Water Conservation: Rainwater Harvesting in the Desert of the Southwestern United States

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ABSTRACT: Water conservation technologies and programmes are increasingly important features of water governance in urban areas. By examining people's situated understandings and relationships with water, this article expands research on the human dimensions of water conservation beyond its traditional focus on uptake of technologies, incentives, and single metrics for evaluation. In the American Southwest prolonged drought conditions are boosting the popularity of small-scale rainwater collection systems, which are becoming formalised primarily through water conservation programmes. In Tucson, Arizona, one such programme was a success in terms of user uptake and public support; however, paradoxically, rainwater harvesting did not always result in reduced potable water consumption. To understand why this was the case, I draw on qualitative and semi-quantitative data describing how people manage their rainwater harvesting systems and how they understand and value their diverse benefits. This study contributes to ongoing policy debates over water conservation and in particular emphasizes the need to broaden our working definition of conservation beyond volumetric reduction in potable water use. Based on the observed motivations, values and practices of water users and experts, I suggest water conservation could be understood to include factors such as the reduction of waste across all water sources and the repurposing of captured water for diverse beneficial uses in urban environments.

KEYWORDS: Water conservation, urban water governance, green infrastructure, rainwater harvesting, US Southwest, Arizona

INTRODUCTION

In 2015, when drought-monitor maps coloured most of the Southwestern United States in shades of orange and red, indicating extreme and exceptional drought conditions, renewed calls for water conservation strategies resonated in the public discourse and policy debates across the country. In what is perhaps one of the most emblematic cases to date, California's governor issued mandatory water restrictions specifically targeted at reducing potable water use by 25 percent in cities and towns. When the state of emergency was lifted in April 2017, an executive order directed the Department of Water Resources to "make water conservation a way of life". Heightened attention to conservation strategies in water planning and management is by no means exclusive to times of emergency. Since the 1980s, water utilities have increasingly applied incentives, regulations and efficiency technologies to infrastructure networks in order to integrate water conservation into the lives of urban water consumers. Today water conservation technologies and programmes are ever more important features of water governance in the Western US and arid regions globally. In such efforts, the standard metric of success has generally been reduced consumption as determined through water metering. Given the call for more integrated approaches to urban water governance and the plural meanings of water that are documented in the literature (Bahri, 2012; Strang, 2004; Wescoat, 2014), this article expands studies of water conservation beyond the traditional focus on incentives, uptake of technologies, and single metrics for evaluation. It argues for the inclusion of an analysis of the range of values and of diverse engagements with water conservation technologies, and offers an approach to water conservation that takes into account people's situated understandings of, and relationships to, water, and their values based on water as a relational resource (see Krause and Strang, 2016). The residential rainwater harvesting programme run by the City of Tucson, Arizona offers an instructive case for studying these dynamics while also providing an example of the growing efforts to expand water conservation policy frameworks in rapidly urbanising areas of the Western US.

The implementation of urban small-scale rainwater harvesting for residential use is observing a global renaissance precipitated by interacting factors, including favourable water regulations and rebates offered by water utilities, water-pricing schemes, and current and forecasted water shortages (Chubaka et al., 2018; Domenech and Sauri, 2011; Meehan and Moore, 2015; Schuetze, 2013). Active rainwater harvesting systems capture, redirect and store precipitation for later use. In areas across Australia, as in several Asian and European countries, rainwater collection systems are increasingly connected to indoor non-potable end uses such as toilet flushing and laundry (Campisano et al., 2017). Reductions in potable water consumption have been observed in households that feature tanks connected to indoor water use (Burns, 2015; Umapathi et al., 2012). In the United States, by contrast, rainwater tanks are primarily promoted and used for outdoor irrigation. Water utilities actively seek ways to reduce the amount of water consumed by outdoor uses – which constitutes as much as 60 percent of water use in dry areas such as the Arid Southwest – by providing alternative sources (WaterSense, 2017). In this context, rainwater harvesting is presented as a way of keeping the landscape lush without overtaxing potable water supplies (Radonic, 2018).

In the rapidly growing American Southwest, prolonged drought conditions are boosting the popularity of small-scale and low-tech systems of rainwater harvesting, which are becoming formalised primarily through water conservation frameworks. Only a decade ago in Arizona, rainwater collection was an informal form of infrastructure outside the purview of the government. During the last decade, this low-tech and decentralised form of water infrastructure has gained popularity across the United States (Meehan and Moore, 2015; Thomas et al., 2014), with the number of installations in the southwest reportedly peaking in the course of the most recent drought of 2012 to 2017.

The City of Tucson, Arizona is at the forefront of what some have called the national rainwater harvesting movement. In 2011, Tucson expanded its already ample suite of water conservation initiatives by launching a new incentive programme to encourage residential rainwater harvesting. In less than six years, nearly 2000 households joined this programme, with hundreds more installing rainwater collection systems independently, thereby generating one of the largest populations of rainwater harvesters in the country. The new conservation programme was a success in terms of technology uptake and public support; however, an internal evaluation by the water utility (based on participating households' water metres) found that potable water consumption did not necessarily decrease following installation of rainwater harvesting systems. This surprising outcome suggests that the programme design did not adequately take into account people's complex relations with water in this urban environment, and in particular the relationship between the uses of potable water and this new water source. This situation raises several questions: 1) How do residential rainwater harvesters understand and value the effects of rainwater harvesting? 2) What are the core elements that form the basis for these understandings? 3) More specifically, what are the areas of alignment and divergence within this community of practice? I address these questions through a mixed-methods approach that focuses on understanding peoples' situated relations to water use. The study contributes to on-going policy debates over water conservation and in particular emphasizes the need to broaden our working definition of conservation beyond simply the volumetric reduction in potable water use. Instead, based on the observed motivations, values and practices of rainwater users, it suggests including factors such as the reduction of waste across all water sources and the repurposing of captured water for diverse beneficial uses in urban environments. This attention to peoples' everyday engagements with water enriches the emerging reconceptualization of rainwater and stormwater from waste to new resource observed in some urban areas.

Framing water conservation

In the last half-century, public and policy interpretations of water conservation have changed substantially in the United States. The earlier approach, which emphasised the role of the state in building large infrastructure to control run-off and store water, was expanded to include demand-based approaches focused on individual responsibility and the individual's relationship to household water infrastructure (Gleick, 2000; MacDonnell, 1999; Worster, 1985). Two postal stamps issued half a century apart succinctly illustrate this paradigm shift (Figure 1). The first stamp, which was issued in 1960 as part of a series on resource conservation, depicts a droplet falling from a leaf and, opposite to it, a reservoir neighbouring a town and a farm. The second stamp, which was issued in 2011 as part of a 'Go Green' series, portrays a hand on a faucet and reads 'fix water leaks'. This trend is part of a broader paradigm shift in water governance from focusing exclusively on state engineering of new sources of supply, towards an integrated approach that emphasises managing demand partially through water conservation schemes targeting individual consumers. Along with the focus on demand, this paradigm shift is associated with changes in the identity of water utilities and the role assigned to consumers through new technologies and programmes. Water utilities are increasingly becoming privatised, and the public – among them, residential water users – are emerging as co-designers and co-managers of ecologically and economically more sustainable water systems (see Sharp, 2017).

Figure 1. Stamps issued by the US Postal Service.

Studies of water conservation are extensive and adopt a range of perspectives. Research on the human dimensions of water conservation most often takes one of three interrelated approaches. The first approach focuses on the attributes that shape the individual behaviour and attitudes of water users – that is, the internal factors that curb individual consumption. This body of work explores how socio-demographic factors such as age, gender or income may impact values and practices associated with domestic water management (Clark and Finley, 2007; De Oliver, 1999; Gilg and Barr, 2006; Hurd, 2006; Lam, 2006; Randolph and Troy, 2008). A second approach focuses on attitudinal factors relating to a range of variables that may influence individual behaviour. This body of work explores how factors such as perception of water rights, environmental threats, or social desirability may impact household practices around water consumption (Corral-Verdugo et al., 2003; Gilg and Barr, 2006; Jorgensen et al., 2014; Lam, 1999; Syme et al., 1990). The third approach explores the mechanisms developed by water agencies to influence individual behaviour. This line of work explores how pricing schemes, financial incentives, or educational campaigns may induce specific water consumption practices, and how this can be measured (Donoso, 2017; Howe, 1982; Liang et al., 2017; Syme et al., 2000; Trumbo and O'Keefe, 2005). With either the individual consumer or the water utility as the subject of analysis, most studies rely on quantitative analyses of survey data, at times complemented by structured interviews with closed-ended questions. They also generally focus on incentives and metrics associated with the decision-making processes of individuals portrayed as rational agents, even while recognising that individuals may be differentially gendered, classed, or even racialised. Such work has thus overlooked a much-needed examination of people's situated engagement with water.

To expand the rationalist perspective that underlies most of this water conservation literature, this article is conceptually built around the notion of situatedness in human – water interactions. Influenced by insights from cognitive anthropology and feminist scholarship in science and technology, I use the term 'situated understandings' to explain how an individual's conceptualisation of a system is influenced by what they have learned and internalised over the course of their experience as members of a community of practice, as well as by mundane human – environment interactions. Methodologically, I document situated understandings of water conservation by eliciting individual mental models – graphic representations of a system – of rainwater harvesting, and complementing them with qualitative data on everyday relationships between residents and rainwater in the domestic sphere. This approach thus aligns with a fourth body of scholarship on water conservation. This growing literature undertakes interpretative research on water management – much of it using a social practice theory approach – to document everyday experiences, social norms, and diverse meanings attributed to water resources (Delaney and Fam, 2015; Fam and Lopes, 2015; Pullinger et al., 2013; Sofoulis, 2005; Strang, 2004; Woelfle-Erskine, 2015). In what Sharp et al. (2011) describe as a post-positivist paradigm, this scholarship highlights that water demand – and by extension water consumption – is shaped by physical opportunity, the meanings and values related to everyday water practices, and formal water institutions (Allon and Sofoulis, 2006; Nevarez, 1996; Shove, 2003; Sofoulis, 2005).

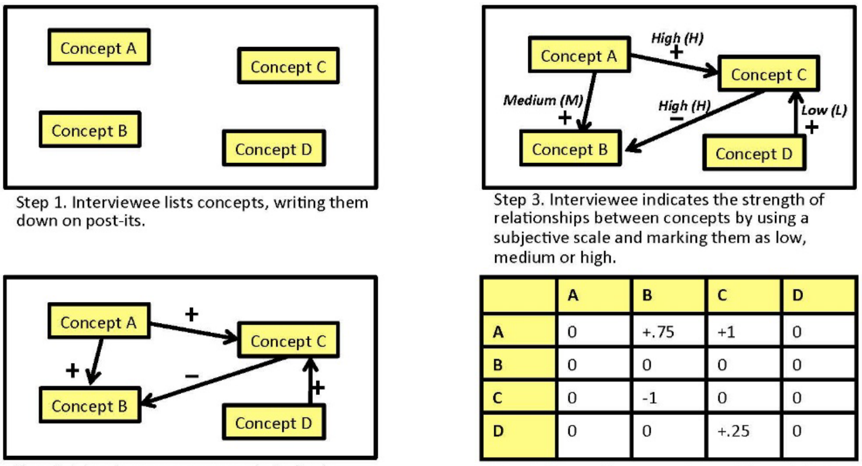
RESEARCH APPROACH

This qualitative research began as an independent ethnographic study and grew into a two-year collaboration with professionals at the City of Tucson Water Department and the University of Arizona, Pima County Cooperative Extension/Smartscape Program. My research collaborators – practitioners dedicated to water conservation education and policy – agreed with the need to look beyond the water metre and draw from the experiences of participating households to evaluate this water conservation programme. To understand why adoption of water conservation technology was not necessarily accompanied by the expected decrease in potable water consumption, and to examine the driving motivations and effects of the programme, we documented why people opted for implementation of rainwater harvesting, how they managed their systems, and how they valued its different impacts. This qualitative data was collected between 2015 and 2017 through a case study approach (Ragin and Becker, 1992; Stake, 1995). Such a methodological approach allows in-depth, multifaceted explorations of complex issues in real-life settings.

For the case study, from a list of rebate participants provided by the local water utility, we randomly selected 30 households which had their tanks installed within the previous 24 months. The rainwater storage capacity for all participating households ranged between 865 gallons (3274 litres) and 3400 gallons (12,870 litres). In the course of a year, participants were asked to submit a detailed monthly survey reporting on their use and management of their rainwater system. At the beginning and end of the study period, we visited every household and interviewed all participants using semi-structured interviews which ranged from one to three hours. Household visits began with a tour of the home's outdoor space so that we could make note of the placement of the cistern(s), the type and extent of vegetation, and any other water use features like swimming pools or hot tubs. These tours also yielded information about weekly outdoor watering practices and participants' views on what they considered to be examples of environmental stewardship by urban residents. Through the semi-structured interviews, we collected data on participants' demographic backgrounds, on their experiences with water harvesting including their motivations for implementation, cistern use and maintenance practices, and elicited their perspectives on Tucson's water security. In addition to these interviews, I conducted another 50 semi-structured interviews with people involved in water harvesting policies and implementation, specifically landscape architects, rainwater harvesting installers, and decision makers. These interviewees were selected according to a purposive sampling approach.

To document how individuals understand the working dynamics of urban rainwater harvesting we elicited individual mental models from all participants. Mental models are a person's representation of cause and effect relationships within a given system. I asked all participants to identify – based on their experiences – the direct and indirect benefits they found to be associated with rainwater harvesting, and to define the causal relationships between these benefits by indicating the directionality and strength of the connection between concepts (see Radonic, 2018 for a detailed methodological discussion). I used a technique known as fuzzy cognitive mapping (FCM) to systematically unpack how individuals think about the dynamics of a system with which they are interacting on a daily basis, and to measure the degree of conceptual agreement within the group (Kosko, 1986). For the purposes of this paper I primarily focused on centrality scores. The centrality of a concept is a measure of its relative importance within the entire system as scored by a single participant. It is calculated by adding the out-degree and in-degree. The out-degree measures the cumulative influence of a concept on all other concepts within a model, as indicated by the absolute value of all the arrows pointing away from the concept. The in-degree indicates the cumulative influence on any given concept from all other concepts, as indicated by the absolute value of all the arrows pointing to that concept (Kosko, 1986; Ozesmi and Ozesmi, 2004) (see Figure 2).

Figure 2. Steps for eliciting fuzzy cognitive mapping (adapted from Radonic**,** 2018).



Step 1. Interviewee lists concepts, writing them down on post-its.

Step 3. Interviewee indicates the strength of relationships between concepts by using a subjective scale and marking them as low, medium or high.

Step 2. Interviewee uses arrows to indicate whether concepts are related to each other, and shows the directionality of that relationship by adding + or – signs.

	A	B	C	D
A	0	+.75	+1	0
B	0	0	0	0
C	0	-1	0	0
D	0	0	+.25	0

Step 4. Researcher converts mental model into similarity matrix. To allow for quantification, subjective ratings of strength are converted to -1 to +1 scale.

	A	B	C	D	In-Degree	Out-Degree	Centrality
A	0	+.75	+1	0	1.75	0	1.75
B	0	0	0	0	0	1.75	1.75
C	0	-1	0	0	1	1.25	2.25
D	0	0	+.25	0	.25	0	.25

Step 5. Researcher calculates in-degree, out-degree, and centrality values.

STUDY CONTEXT: WATER SUPPLY AND GREENNESS IN A DESERT CITY

Tucson is located in the Sonoran Desert, a region with an average annual precipitation of 11.6 inches (295 mm) and characterised by a fair amount of year-to-year variability. Roughly half of the annual rainfall comes with the summer monsoon and the other half during the winter. The city has no combined sanitary and sewer system so during heavy rain events water flows off into streets and ephemeral arroyos (dry stream beds), which serve as storm drainage. Much of the moisture that remains on yards and paths quickly evaporates under the intense summer heat. During the summer the average daytime high temperature is 99°F (37.2°C), and temperatures of above 100°F (37.7° C) normally occur from May to September, with many days exceeding 110°F (43.3°C). Over the last decade, Tucson has observed an upward trend in record-breaking temperatures. As succinctly summarised by a meteorologist at the National Weather Service Station, "[In 2017] we didn't just beat the record, we crushed it" (Christy, 2018).

Tucson's half a million residents have three water sources that are physically and legally available for municipal supply: Colorado River water pumped through the Central Arizona Project (CAP), groundwater from the underlying aquifer, and a small amount of recycled effluent water (Tucson Water, 2015). Water from the Colorado River – constituting the main source of municipal potable water – is pumped uphill for 336 miles (541 km). As determined in 1928 by the Boulder Canyon Project Act, the states of Arizona, California and Nevada have the right to extract Colorado River water from Lake Mead, an artificial reservoir constructed in the lower basin.[1] Arizona holds junior water rights relative to its neighbouring states, meaning that in the event of a water shortage the state's water supply would in theory be the first to be curtailed (Hirt et al., 2008). After two decades of drought, water levels in Lake Mead are lower today than they have been since its construction, as evidenced by the calcium markings (commonly called bathtub rings) on the rocky shorelines of this man-made lake.

In Arizona it is not uncommon for water-related issues to appear in the news. Over the last five years there has been much news coverage of Lake Mead's declining water levels and the potential impact of this decline on the delivery of Colorado River water through the Central Arizona Project (CAP). Across the political spectrum, the issue of water scarcity is kept present in the collective imaginary by articles with titles such as "Lake Mead at Historic Low as Storage Dispute Heats Up" (Craft, 2017), and "Big CAP Cuts Coming as 3-State Water Agreement Nears" (Davis, 2016). In response to this public anxiety about a water crisis, policymakers at the state and city levels work to reframe the problem by continuously reminding the public that Arizona does not have a water problem. As declared by Governor Ducey in his 2016 State of the State speech, "It's often misreported that there is a 'Western Water Crisis', but the facts show, we would be more accurate to call it a 'California Water Crisis'. We have planned ahead. If there's one thing Arizona is best in the nation at, it's water" (Ducey, 2016).

Today in water governance circles the City of Tucson is often heralded as a pioneer in water conservation due to its early establishment of demand-management programmes (Logan, 2006; Megdal and Forrest, 2015; Tarlock and van de Wetering, 2007). Based on archived annual reports and reflections from water managers, we understand that this emblematic water conservation agenda initially arose as a capital savings agenda. The summer of 1974 was one of the driest and hottest experienced in Tucson – a record-breaking season that, with climate change, has since been exceeded numerous times. Water treatment plants were at their maximum capacity, the city well system was unable to consistently meet peak demand, and funds for expanding the infrastructure were difficult to obtain. Logan (2006) recounts that after an approved increase in water rates was overturned amid political uproar, a water conservation

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[1] The Colorado River irrigates more than four million acres of cropland in the US and Mexico and supplies water to more than 30 million people (USGS, 2016). It is publicly acknowledged that the Colorado River is over-allocated. In 1922, during an abnormally wet year, American politicians and hydrologists estimated an average flow of 16.5 Mm^3 and proceeded to grant water rights to the seven basin states based on that calculation (Hundley, 1966; Summitt, 2013; Worster, 1985). The Lake Mead reservoir was built between 1924 and 1936 in the lower basin of the Colorado River and has the largest storage capacity of any reservoir in the United States. California is entitled to 4.4 million acre-feet (MAF) of water, Arizona to 2.8 MAF, and Nevada to 0.3 MAF.

agenda emerged as a mitigation strategy. It constituted a measure of relief that would allow the city to continue growing by delaying investment in infrastructure improvements. As Howe and White (1999) explain, it is not uncommon for demand-management programmes to be presented as lower-cost solutions to water supply deficits. Putting forward the concept of citizens taking responsibility for the common good through voluntary compliance with water conservation measures, the Tucson campaign urged residents to reduce outdoor water usage during the summer months when demand was highest. As a water manager explained when reflecting on the history of water conservation, it was the inadequate infrastructure and the inability to meet summer peak demand that led the city to launch its first water conservation programme, which set it on a progressive water governance path.

Since then, Tucson Water has implemented a series of water conservation strategies. Some of these have been codified into law via ordinances aimed at more water-efficient urban construction, while others are structured into rebate programmes targeting individual households' decision-making.[2] There are rebates for residential installations of low-flush toilets, water-efficient washing machines, and now rainwater harvesting tanks. In terms of residential water consumption, the water conservation programmes have resulted in a reduction from 188 gallons per capita per day (GPCD) (712 litres) in 1989 to 130 GPCD (492 litres) in 2015. This is a 31 percent reduction in residential water use. As summarised by the water utility, "In 1987 Tucson's average system production was 96.4 million gallons per day (MGD) [0.36 billion litres], but in 2015 it produced only 93.3 MGD [0.35 billion litres] even as the population grew by 40 per cent" (Alliance for Water Efficiency, 2017). Estimating that 45 percent of all water consumption in the service area is for outdoor usage, in 2008 Tucson passed ordinances mandating the installation of grey water discharge pipes[3] and water harvesting in new residential constructions. In 2011, they launched the residential Rainwater Harvesting Rebate programme. Funds for the programme were justified under the rationale that rainwater and stormwater could be developed as supplemental water sources that would reduce pressure on the Colorado River and local aquifers – the main water sources for the city. The passage of these ordinances is indicative of the upsurge of support for more progressive water conservation policies across diverse stakeholder groups.

FINDINGS AND ANALYSIS

Understandings of rainwater harvesting

During semi-structured interviews I asked residential rainwater harvesters to draw mental models to illustrate how they understood the benefits of rainwater harvesting in the urban context. Based on this data, in this section I present the diverse understandings of the benefits of rainwater harvesting as perceived by residents involved in rainwater collection. In order to determine what benefits were most significant across all participants' mental models, I used the frequency and centrality scores yielded by fuzzy cognitive mapping. As mentioned above, frequency scores indicate what percentage of participants included any one concept in their model, while mean centrality scores provide information about the relative importance of a concept across individual models.

In the mental models drawn by residential water harvesters, the two most frequently mentioned benefits were water conservation and growth of vegetation, which were listed by 66.7 and 73.3 percent of participants respectively. Vegetation growth also had the highest centrality value, significantly above

[2] Other ordinances include a 1989 plumbing code requiring water-efficient fixtures in all new residential and commercial constructions, a 1991 xeriscape landscaping and screening regulation requiring the use of drought-tolerant plants in multifamily, commercial and industrial developments, and a 2010 residential greywater ordinance mandating the installation of greywater discharge pipes in new single-family homes.

[3] Greywater is wastewater collected from the drains of handwashing sinks, showers, bathtubs and clothes washers. Greywater discharge pipes allow households to install an outdoor irrigation system using their own greywater.

the score for water conservation.[4] On average, growth of vegetation had a centrality score of 2.3, while the average score of water conservation was 1.91. Accordingly, the establishment and growth of landscape vegetation was represented as conducive to many other welcomed benefits including shade, beautification of outdoor spaces, and establishment of wildlife habitats. Some interviewees also mentioned financial savings as a benefit, explaining that by creating tree shade they would reduce the need for irrigation in that area of their yard. Generally, residents identified and valued the benefits of rainwater harvesting in terms of their manifestation at the household level (i.e. shade around the house and water retention). Expert practitioners sometimes emphasised those same benefits as well but, by contrast, presented them as indices of the private provisioning of public ecosystem services (i.e. urban cooling and flood control).

While it was generally expected by decision makers that financial benefits would be a motivating factor, we found that this concept did not have a prominent position in the mental models. Financial savings were mentioned by slightly over half[5] of the residents, and this concept had a relatively low centrality across all mental models (0.63). When asked specifically if they thought rainwater harvesting had reduced their water bills, most residents automatically responded 'yes', a few of these added 'a lot!'; most others said 'slightly' or 'not to a great extent', and many replied with a hesitant 'I hope so…'. Except for three people, all residents admitted not paying attention to the graph in their monthly water bill that illustrates their month-to-month water consumption rates. Respondents often emphasised that their installation of the system was motivated by environmental reasons not financial ones. As stated by one interviewee, "I did not do [rainwater harvesting] to be cost-effective. I did it because saving water is good, [as it is conducive to] having hummingbirds and butterflies, and having plants that bloom flowers that attract them" (Rainwater Harvesting Interview 001, 8 September 2017, Tucson). It is also important to point out that given the low price of potable water in Tucson, its block-rate structure, and participating households' economic standing, small increases or decreases in the water bill make no significant difference to the monthly budget.

Rainwater harvesting and landscape practices

As with any other water conservation technology, it was expected that potable water consumption would decrease when households installed rainwater harvesting cisterns. The underlying logic in the rebate programme design was that rainwater would replace a portion of the potable water used by households in outdoor irrigation. However, water consumption data derived from household metering indicates a general problem: potable water consumption does not necessarily decline when households begin using rainwater, and thus far there is no clear correlation between uptake of this technology and reduction in potable water use. A similar pattern was observed by Delaney and Fam (2015) in their study of rainwater use in suburban households in Australia. In this section I explain why installation of rainwater harvesting systems do not necessarily result in reduction of potable water use. Data from semi-structured interviews, landscape surveys, and users' monthly logs provide potential explanations for this outcome, highlighting a link between water conservation technology, increased vegetation, and irrigation management. I will introduce two residents in order to illustrate the way in which the situatedness of water conservation technologies influences how individuals manage their rainwater cisterns in their domestic environments.

[4] This score is calculated based on the absolute sum of values given to all links connecting one concept to other concepts in a mental model. In other words, this is the absolute value of all incoming arrows to a concept and all outgoing arrows from a concept. The higher the value the greater the importance of a concept within a map. The centrality score for each concept is then averaged across the sample, yielding the mean centrality score for every concept. For a detailed explanation see Radonic (2018).

[5] This number climbed to 60 percent during the exiting interviews (mental model elicitation # 2).

Linda is a novice rainwater harvester. She had four tanks with a total capacity of 2700 gallons (10,220 litres) installed in her backyard when she moved to Tucson from the East Coast after retiring. As part of her landscaping vision for her new home, she wanted a desert oasis with drought-resistant shrubs and vines that would add colour and attract pollinators. "The idea was not to water them once they were established", she explained looking at the colourful Mexican bird of paradise growing outside the window (Rainwater Harvesting Interview 001, 23 June 2016, Tucson). However, three years after planting, most of the vegetation in her yard is still watered through a drip irrigation system that automatically delivers a blend of Colorado River water and groundwater every other day, twice a day, for about an hour.

Across town, 75-year-old Mary-Jean also harvests rainwater. Two years ago, when she moved to Tucson from a nearby desert city to be closer to her children, she installed two cisterns with a total capacity of 2400 gallons (9084 litres). The yard in her new home is sparsely landscaped with reddish gravel and a handful of small native shrubs and succulents. The only tree is a mature grapefruit, which she decided to keep despite acknowledging how water intensive citrus trees can be. To water this thirsty tree, she relies entirely on rainwater. She connects a hose to the valve at the bottom of the cistern and sets up a timer in her kitchen. The hose has little holes on the underside so she can leave it running while she is inside the house. "It works like a slow drip system", she explained during our interview (Rainwater Harvesting Interview 029, 4 August 2016, Tucson). Like Linda, she had planned to plant more bushes and shrubs to create a lusher and cooler outdoor space but at her age she finds yard work to be too taxing on her body, and living on a pension does not afford her the funds to hire a landscaping company to do the work.

When looking at their potable water consumption rates as indicated by their metre readings over the course of the past year, we found that Linda's water consumption increased significantly after installing the cisterns. This increase was in part because the cisterns were installed at the same time as she undertook a large-scale renovation of her landscaping, adding extensive new vegetation to her yard. These new plants are connected to an irrigation system that is managed by a landscaping company, and she admitted having little understanding of either plant requirements or irrigation. By comparison, Mary-Jean's water consumption slightly decreased after installing the tanks. With rainwater capacity comparable to Linda's and without any new plants to water, she is replacing potable water with rainwater for irrigating the small amount of existing vegetation on her property, especially her thirsty citrus tree. Linda and Mary-Jean are extreme examples within our sample, yet they portray the diversity of the sample population and illustrate some trends in residents' management of rainwater at the household level.

We found that 72 percent of participants planted new vegetation after installing their rainwater harvesting systems and, of these, 28 percent (like Linda) installed their systems as part of large-scale landscaping redesign projects. In line with the xeriscaping principles dominant across the city, most new vegetation was either native to the Sonoran Desert or was drought-adapted. Technically, these plants are chosen because they are not water intensive; in fact, once they are established many of them can survive on rainfall alone. However, as numerous expert practitioners and homeowners explained, nursery plants often need supplemental watering in order to get established in a residential landscape even if they are native or drought-adapted. We observed that numerous households continued to irrigate their plants longer than necessary because they were unsure of when to wean them off the drip irrigation system. In addition, interviews indicated that aesthetic ideals have yet to be adapted to the seasonality of the Sonoran Desert. Concerned or bothered by the look of dormant vegetation during the hot, dry summer months, many participants over-irrigate during the summer, often turning to city water when their cisterns run dry before the summer rains begin.[6]

[6] As part of the monthly diary, we asked participants to roughly calculate the fullness of their tanks (empty, one-quarter full, half full, three-quarters full, or more). We found that availability of stored rainwater depended on annual rainfall as much as it did

With the installation of rainwater tanks, about one-third of participants also removed plants from their yards they considered 'too thirsty' for Tucson's hot and semi-arid environment. This is a phenomenon that I suggest is in part because rainwater harvesting makes water consumption into a relational and tangible experience (Radonic, 2019). Even when people had not been counting exactly how many gallons were going into watering a specific section of their yard, they often knew how much irrigating those plants had emptied their tanks. When using rainwater tanks, what otherwise is an abstract number of cubic feet of water (CCFs) recorded on their monthly water bills, becomes a tangible reality to participants who can compare water levels in their tanks before and after irrigating their plants. For example, Christine, a native Tucsonan who was shifting her outdoor space from what she described as a 'tropical paradise' to a diverse collection of drought-adapted plants, explained, "I just don't want to water them anymore, I don't want to waste my rainwater on big water users" (Rainwater Harvesting Interview 021, 25 July 2016, Tucson). Accordingly, soon after installing the cistern she tore out the little patch of lawn that remained in her yard and was waiting for a mesquite tree to grow and create shade so that she could plant low-water evergreen succulent groundcover. In short, participants consistently substituted exotic ornamentals with desert-adapted varieties.

All residents interviewed used rainwater to supplement potable water irrigation. A few people stated that their goal was to eventually rely completely on non-potable water sources for landscape irrigation. About half of the residents had a working automated drip irrigation system and the rest continued to water their landscape vegetation manually with hoses. About half of those who did not have an automated irrigation system were contemplating installing one in the near future, attracted by the possibility of becoming more self-sufficient in irrigation. Almost all participating households relied on hoses and buckets to irrigate their plants with rainwater. Low water pressure – which becomes even lower as water volume in the tank decreases – was a critical limiting factor on what and when they could water. Low pressure means that residents need to allow rainwater to slowly flow through the hose and drip onto some plants' roots and then move the hose onto the next plant, letting the dripping process follow its slow pace. We did not find a relationship between water usage level and adoption of drip irrigation technology;[7] instead we concluded that lower water consumption even among residents with large yards was a result of their knowledge about irrigation and vegetation.

Conceptualisations of water conservation

Given that in the local policy arena rainwater harvesting has been primarily framed as a water conservation technique, in this section we first present an overview of how people view Tucson's water availability, and then explain how they understand water conservation to work in relationship to residential rainwater harvesting. Drawing on interview data and mental models, we found that while most people saw water conservation as a benefit associated with rainwater collection, they had very diverse understandings of what water conservation meant and how it was accomplished. Furthermore, while most participants are well aware of Tucson's water challenges, their decision to harvest rainwater is not primarily driven by a sense of water crisis, as would have been expected (Baldassare and Katz, 1992; Radonic, 2019).

All research participants had a general understanding of Tucson's water supply system, pointing to the Colorado River and local groundwater sources as the city's primary sources of potable water.

on the household's tank capacity, their landscape's demand for rainwater, and their water-use practices. Overall, stored rainwater could last for most of the year, often running out in early summer before the beginning of the monsoons. A helpful innovation would be the installation of gauges inside tanks, which could determine exact amounts of water remaining, thus allowing residents to ration water use. At this point such helpful devises are not part of most tanks used across Tucson, so users have learned to tap on the sides of their tanks to estimate the water level.

[7] Drip irrigation delivers water directly to the soil near the roots of the plants through a network of valves, pipes and emitters. Originally developed for the agricultural sector, drip systems have been widely adopted in urban areas because they are more water efficient than are other common systems such as sprinklers.

Everyone also expressed some level of concern about Tucson's water security over the next generation, and 35 percent of respondents believed that Tucson is already experiencing a water deficit. Prefacing their reflections with some variation on 'we live in a desert', participants attributed the city's vulnerable resource security to continuous real estate development, prolonged drought in the Colorado River basin, and/or precarious water allocations through the Central Arizona Project. People who had relocated to Tucson within the last decade consistently mentioned overuse of water resources due to ever-increasing population and real estate development. By contrast, long-time residents were more prone to emphasise the recurrent drought conditions affecting the region for the last 25 years, along with historical pressure on water resources. Nevertheless, about 65 percent of participants also expressed some degree of confidence in how local and regional water authorities were handling the challenges at hand. As evidence for this, people cited large-scale conservation initiatives such as recharge of the local aquifer and water storage in Lake Mead, small-scale initiatives such as residential rebates, and the city's reported decrease in per capita water consumption.

In this context, even when mental models indicate that water conservation is not the most significant component of participants' understanding of how rainwater harvesting works in their urban environment, during interviews their motivation for collecting rainwater was discursively articulated around water conservation. Within this community of practice, participants offered distinct yet interrelated explanations for how residential rainwater harvesting is connected to water conservation. The first and most common explanation linked the household's rainwater capture to a reduction in extraction from the local aquifer and/or the Colorado River. As one resident explained, "Whatever we use from the tanks doesn't come out of the ground… so that means that we keep the water table a little higher" (Rainwater Harvesting Interview 012, 11 June 2016, Tucson). The second explanation emphasised the relationship between rainwater use and potable water reallocation. Recognising that making water potable is capital- and energy-intensive, a household's use of rainwater harvesting was seen as offsetting the use of potable water in irrigation and making that water available for drinking elsewhere in the network. As one resident explained, "I don't have to use water that had to be pumped and treated. It doesn't make sense to spend a lot of money on treating water [to be potable] and then dump it on the ground for your vegetation when you can use rainwater" (Rainwater Harvesting Interview 011, 7 July 2016, Tucson). The third explanation described water harvesting as contributing to the recharge of the local aquifer through localised retention and infiltration of water in people's own yards. In this view, individual engagement in rainwater collection contributes to conservation by adding water – even if a marginal amount – to the strained local hydro-ecological system.

Furthermore, individual understandings of how their own engagement in rainwater harvesting could contribute to water conservation were largely qualified through landscape water use, and varied temporally. Some residents saw their use of rainwater as providing them with a replacement source of water and thus being conducive to using less potable water for outdoor irrigation. These participants explained that with rainwater collection they were able to keep a lush landscape while simultaneously (and immediately) reducing their potable water consumption, even if the reduction was marginal. For example, one participant explained, "Probably what is happening more is that we used a little less from the tap to water our yard, and we made our yard look a little bit nicer by feeling like it was okay to water plants extra with rainwater" (Rainwater Harvesting Interview 028, 3 August 2016, Tucson). By contrast, other residents saw rainwater harvesting as an additional source of water that could be used to cap – rather than reduce – potable water consumption, and thus curtail future demand. For these participants, maintaining and/or growing the vegetation around their homes was not contingent on harvesting rainwater, but access to an additional source of water allowed them to build a desert oasis while not increasing their water consumption (too much). As one participant explained, "We have lots of trees and put additional trees. We have citrus trees, which are very thirsty. Rainwater harvesting has enabled us to water our landscaping without having to use nearly as much city water" (Rainwater Harvesting Interview 030, 8 August 2016, Tucson). Most rainwater harvesters felt there was a connection between their household use of rainwater and the municipal water supply system; the temporality, strength and nature of the connection is what differed.

Across these diverse interpretations of their individual relationships to water conservation via rainwater harvesting, homeowners agreed that engaging in water conservation was necessary because they live in the desert. Two somewhat contradictory common denominators across all interviews were the understanding that water in the desert is a scarce resource, and the desire for a household oasis in this hot and arid region. Emphasising their awareness of Tucson's limited water supply, participants valued rainwater collection for the way it provided them with pleasant green areas in their backyards without having to feel guilty for exhausting the city's potable water resources (Radonic, 2019). As one participant explained, "[Rainwater harvesting] is good for the desert. I like gardening, and I feel guilty when using tap water knowing that water is a limited resource" (Rainwater Harvesting Interview 014, 12 July 2016, Tucson). This water conservation technology thus allows urban residents to mitigate the inherent contradiction between these seemingly incompatible goals.

CONCLUSION: TOWARDS A BROADER CONCEPTUALISATION OF WATER CONSERVATION

This case study reinforces two important interrelated points. First, it reinforces the growing recognition by scholars and water managers that investigating situated understandings of water offers insights with practical applications for the design of water management programmes. For example, even within the existing constraints presented by water utilities' narrow programmatic emphasis on per capita water consumption, designing rainwater harvesting promotion and outreach materials that incorporate an awareness of how users understand and use rainwater could facilitate reductions in potable water demand. Second, this study suggests broader approaches to water conservation. Careful examination of users' everyday situated engagements with rainwater collection illustrates that residential rainwater harvesting provides diverse system benefits that are difficult to measure and often undervalued by water utilities. This study thus highlights the importance of paying attention to the benefits of water conservation programmes beyond per capita reduction in water consumption.

Mental models collected and analysed as part of an ethnographic methodology advance our knowledge of the complexities in peoples' situated understandings of water conservation. They show how individuals' perceptions of, and engagement with, rainwater harvesting involve a number of goals and values that are at times complementary and at times conflicting. Among rainwater harvesters there was no lack of concern about the city's water future, but concern for the local impacts of regional water scarcity alone was not a determinant of people's water use behaviour. The degree to which people reduced their water usage after installing a rainwater tank was in large part shaped by their relationship with, and valuing of, their backyard environments, including their knowledge of plant requirements and irrigation practices. If rainwater collection practices and policies are to continue to gain popularity, programmes will need to consider developing public education and training approaches which ensure that this technology is integrated into residential water budgets in such a way as to reduce potable water consumption. Nevertheless, the lack of reduction in potable water consumption does not negate the other ways in which rainwater collection is beneficial to the broader water system and to urban environments. Thus, despite rainwater harvesting failure to meet the narrow criterion by which 'unequivocal success' is measured as per the institutional metrics of water conservation (i.e. reduction in CCFs), members of this community of practice continue to see it is as 'working well' and support its implementation across the urban landscape. In recognition of this fact, researchers are increasingly attempting to identify and quantify the diverse benefits of rainwater harvesting in urban environments (Braga et al., 2018; Garcia-Cuerva et al., 2018; Pavao-Zuckerman and Sookhdeo, 2017; Stout et al., 2017).

In an increasing number of cities worldwide, rainwater is being reconceptualised from a nuisance that is drained from the city as waste to a valuable water resource that should be collected on-site and put to beneficial use (Cousins, 2017; Meehan and Moore, 2015; Radonic, 2018; Smaniotto Costa et al., 2015).

This case study thus also points to the emergent possibilities for broadening the working definition of water conservation beyond volumetric reduction in potable water use to include reduction of waste in overall water use and the repurposing of sources currently considered wastewater. This includes taking a source of water currently perceived and treated as waste and putting it towards beneficial uses such as increasing vegetation, mitigating the urban heat island effect, or reducing soil erosion. These interrelated benefits, which are associated with improvements in quality of life (Dwyer et al., 1992; Elmqvist et al., 2015; Smith and Levermore, 2008), reduce waste while not necessarily increasing demand on the drinking water system. Thus, rainwater harvesting programmes like the one in Tucson, Arizona indicate that a paradigm shift in the management of urban water flows is already underway. This study suggests that this paradigm shift and the re-conceptualisation of water conservation in water policy circles that underlies it, stems in part from the fact that technology and peoples' relationship to it do not fit neatly with other water-efficiency technologies in the suite of urban utilities' water conservation programmes.

Rainwater harvesting clearly is distinct from other demand-management technologies such as low-water toilets and water-efficient washing machines. A situated approach draws attention to the everyday practices through which users' relationship to water through harvesting technology is radically different, since they are required to directly manage it in situ in a way that is neither required nor afforded by other household appliances included in 'traditional' water conservation programmes. The relationship of rainwater harvesting cisterns to municipal water is also radically distinct in that cisterns can contribute to a household's water budget, potentially reducing potable water consumption without becoming integrated into the grid infrastructure, so their potential contribution only occurs through users' self-monitoring or through decentralised mediating technologies such as pumps and smart-controllers. In this sense, rainwater harvesting is a supply-side strategy that may result in demand reduction in potable water usage depending on human behaviours. Moreover, rainwater harvesting's relationship to urban hydrosocial systems is fundamentally different because in redirecting and storing rainwater it simultaneously alters urban water flows and households' domestic ecosystems in ways not afforded by other indoor water-efficient appliances. It is here that its potential to provide benefits beyond reduction in water potential is highlighted and realised.

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