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Integrated water management recommendations in practice: coexistence of old and new ways in Arizona

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Abstract

Integrated water management (IWM) is widely regarded as a key strategy in achieving a variety of urban sustainability goals. Despite the promise of this strategy, however, uptake of IWM practices has generally been slow. A central reason for this lies in the divergence of action recommendations in the literature and actual water management praxis. In this paper, we explore how action taken by governments relate (or not) to IWM dimensions found in the literature. We do this by combining a corpus of actions taken by local governments in Arizona with a systematic review of the IWM literature. More precisely, we identify a confined set of IWM action dimensions particularly relevant to current praxis and apply these to water management practices reported by local governments in Arizona. We find that governments in the state systematically use IWM strategies to complement or enhance traditional water management approaches. Uptake differs across management spheres in terms of magnitude and form and is informed by contextual characteristics. Overall, our study indicates that transition may be guided by bottom-up experimentation, context-sensitive selection, and incremental change. This is in contrast to how IWM is often understood in the literature – as sharp shift and break with old traditions.

Keywords: Arizona; Government action; Integrated water management; Sustainability

1. Introduction

Integrated water management (IWM) is widely seen as key in solving the plethora of water sustainability challenges facing cities across the globe (e.g., Biswas, 2008; Savenije & Van der Zaag, 2008). IWM 'is based on the premise that all forms of water in urban areas (rainwater, groundwater, surface water, drinking water, used water, fit-for-purpose reuse water) are linked and form a system that provides the most effective service when managed in an integrated fashion' (Daigger *et al.*, 2019, p. 2).

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Integrated management of water is expected to enhance multifunctionality of water services meaning the simultaneous creation of social, economic, and environmental benefits (Jønch-Clausen & Fugl, 2001; Mitchell, 2006; Paulson *et al*., 2017).

Despite a substantial push for IWM in the water management field, IWM is still far from a 'typical' strategy. While the literature depicts many reasons for this, among which are organizational obstacles, conceptual ambiguities, and path dependencies (e.g., Blomquist & Schlager, 2005; Brown & Farrelly, 2009), a root cause seems to be the gap between IWM action plans and actual water management practices (Rahaman & Varis, 2005). Most action recommendations found in the literature take the form of extensive lists. These lists tend to pay little attention to the interrelations of different action items as well as their linkage to current practices, other than that they are different and more desirable options. There are several problems with this, some of which we will outline below, but most importantly, these lists are difficult to overview and limited in their ability to inform transitions, which involve gradual change and systematic combinations. Meanwhile, there are many governments taking innovative approaches to water management, some of which are inspired by IWM concepts. If the IWM literature is to guide action, we need to learn from these governments and more carefully tailor recommendations to on-the-ground situations.

This paper takes a step back and explores what governments are actually doing and how this relates (or not) to IWM ideals and recommendations. Linking *suggested* to *actual* practices provides insights about the feasibility of recommendations and promising combinations of practices. This will help us to better understand IWM transitions and eventually draft a practicable road map for those places seeking to follow the leaders. To link actual and suggested practices, we combine a corpus of actions taken by local governments in Arizona with a systematic review of the IWM literature. More precisely, we identify a confined set of IWM action dimensions, informed by our corpus, and compare these to water management practices reported by local governments in Arizona. This paper consists of six parts. We start with an overview of the IWM literature. Next, we introduce our study approach before introducing the typology of IWM action dimensions and discussing their application to our action corpus. We end with a discussion of major limitations and a summary of our findings.

2. Integrated water management

Growing awareness of the complexity of water problems and the limitations of current management strategies motivated the development (or rediscovery) of alternative management approaches (Biswas, 2008). These approaches have been referred to by varying names, including Integrated Water Resource Management, Sustainable Urban Water Management, Sustainable Water Resource Management, Integrated Urban Water Management, and One Water. But they all share a common vision: a shift in priorities and values as well as in government devices away from fragmented service delivery and toward integrated water resource management. The vision commonly refers to decentralized technical systems, fit-for-purpose thinking, utilization of alternative water sources, greater use of green infrastructure (GI), integration of demand- and supply-side management, and stakeholder involvement (e.g., Mitchell, 2006; Savenije & Van der Zaag, 2008; Bahri, 2012). IWM is often labeled a 'new' paradigm – in contrast to the 'old' centralized and pipe-bound paradigm – that conflicts with or at least represents a massive modification of current strategies (e.g., Pinkham, 1999).

The transition from current management practices toward IWM has posed some difficulties on both the conceptual and practical levels. The literature offers a plethora of action suggestions and recommendations meant to support governments in implementing the 'new way.' Some of these such as the *One Water Blueprint* (Paulson *et al.*, 2017) take the form of consecutive steps; most, however, consist in the enumeration of management options (e.g., Loucks, 2000; Jønch-Clausen & Fugl, 2001; United Nations, 2002; Mitchell, 2006). These lists provide a valuable overview of available water management strategies. However, they are limited in their ability to structure and guide government action. The collections tend to be fairly extensive and difficult to overview, despite their incompleteness, and the strategies are often underspecified, consisting of keywords without detailed explanation. More importantly, however, it is unclear how the different tools relate or should relate to one another. This makes it difficult to locate government action within the IWM space beyond checking boxes for what they are and are not doing, and it also impedes policymaking. Individual intervention strategies do not operate in isolation but rather their efficacy and feasibility are dependent on the overall constellation of policy action (Howlett, 2004; Howlett & Rayner, 2007). Accordingly, the identification of synergies, complementarities, and conflicts between strategies is a central success factor.

On the practical side, uptake of integrated strategies has generally been slow (Biswas, 2008; Brown & Farrelly, 2009; Daigger *et al.*, 2019). This is in contrast to the notion of a paradigm shift, which in conceptual discussions tends to take the form of more radical change and 'breaking with old traditions.' The slow uptake is attributed to a variety of social and organizational barriers related to, among others, decision-making arrangements, accountability, power, organizational capacity, knowledge, vision, and laws (e.g., Blomquist & Schlager, 2005; Brown & Farrelly, 2009; Pivo *et al.*, 2020). In addition, contextual factors seem to play a role. Feasibility and efficacy of strategies are dependent on contextual characteristics such as climate, geographical location, local norms, and governing system (Niemczynowicz, 1999). The barriers and contextual factors are viable explanations and they merit further exploration. However, there may be more to learn from the observation of slow change. Most importantly, it may teach us about the accuracy of our change models. Put differently: Is the way that we think change occurs from a conceptual perspective the way change actually happens in practice? Getting the model of change right is essential to provide viable action recommendations.

Given the current stagnation, authors have called for a better integration of conceptualization and water management praxis (Rahaman & Varis, 2005). To do this, we suggest three interrelated steps. The first step consists in the identification of a confined set of IWM dimensions of particular relevance to praxis. The goal is to reduce the vast list of management strategies into a manageable selection of dimensions that are suitable to characterize, compare, and contrast government action. The second step lies in applying these dimensions to understand the action strategies currently being taken by governments and how these relate (or not) to the principles of IWM. Delineating the current space of water management and the ways in which, if at all, integrative strategies are part of this space is an initial step toward comprehending transitions toward more integrated approaches. In doing so, it is important to sufficiently account for the context-embeddedness of strategies. Finally, the third step consists in identifying major barriers to the transition and so-called bridges to overcome them.

This paper focuses on the first two steps. For this, we combine a corpus of government actions reported by representatives of municipalities in Arizona with a systematic literature search. More specifically, we triangulate between the IWM literature and our data to identify a confined set of dimensions that is rooted in the literature and suitable to describe our action corpus. We then apply these dimensions to our corpus to understand how governments in Arizona combine different action strategies. Given the limited scope of our data, which consists of actions implemented in a very particular US region, we do not claim the resulting typology to be universal. However, we provide an initial classification scheme and an analytic strategy that can be adapted to data from other places. Next, we will briefly outline the study context and methods before delving into the typology and its application.

3. Methods

Study context: Arizona

Data for our study stems from Arizona. The State of Arizona encompasses 15 counties, 91 municipal governments, and 22 sovereign Native American communities. Apart from local utilities, the state includes five major water managers on the state and federal levels, namely Arizona Department of Water Resources, Arizona Department of Environmental Quality, Salt River Project, Central Arizona Project, and Bureau of Reclamation (Emanuel, 2005). Water management is driven by a set of key contextual factors, including:

- *Climate*: Arizona is characterized by hot desert and semi-arid steppe climates. Extreme temperatures of up to 49 °C in the summer months, high evapotranspiration, and intense, spatially localized rainfalls caused by American monsoon provide a challenging context for water management (Gelt *et al.*, 1999; Sheppard *et al.*, 2002; Morin *et al.*, 2006).
- *Growth*: Arizona is one of the fastest growing states in the United States. In the 2019 US Census Bureau statistics, Arizona ranked third in terms of growth. Growth and economic prosperity are inextricably tied to the ability of governments to ensure affordable, reliable, and safe water.
- *Groundwater overdraft*: In the past, many Arizonan cities heavily relied on groundwater pumping to satisfy the need of the growing population. The resulting overdraft led to significant subsidence, dewatered rivers, and loss of natural habitat (Gelt *et al.*, 1999; O'Neill *et al.*, 2016). Today, cities are trying to reduce their groundwater withdrawals and replenish groundwater stocks through, among others, large-scale recharge projects.
- *Central Arizona Project*: The Central Arizona Project (CAP) delivers Colorado River water over 336 miles from Lake Havasu to central and Southern Arizona. CAP is linked to a complex rights and administrative setup. Prerequisites to gaining access to Colorado River water consisted of drastic measures to address western water problems and the acceptance of junior water rights. The Groundwater Management Act (GMA) was created to tackle the former. The act limits groundwater withdrawals in four areas, namely Phoenix, Tucson, Prescott, and Pinal County (Coeurdray *et al.*, 2017). The latter condition, acceptance of junior water rights, means that Arizona's water allocation is among the first to be cut in case of shortages in the Colorado River basin (O'Neill *et al.*, 2016). This creates uncertainty as to the future availability and reliability of CAP water supply.

Corpus of government action

The corpus of government action used for our data-driven literature review is based on survey responses from local government representatives involved in water governance in Arizona. The initial sample of government representatives was constructed based on the US Census of Governments and consisted of public officials in local governments whose FY 2012 budget included expenditures on water services, including management of supplies, wastewater, groundwater, floods and watersheds. The sample was expanded by adding representatives of governments relevant to water management as identified by survey respondents, experts in the field, and through the grey literature.

The survey data contain information on a variety of factors relevant to urban water management. This study focuses on a particular subset of this information, namely the sustainable water innovations. In an open-ended survey question, respondents were asked to describe up to five innovations 'that your local government is particularly proud of.' Innovations in this context refer to 'programs, technologies, or processes that represent new ways to improve the environmental performance, resilience, or social equity of water systems.' A total of 280 innovations was reported by the representatives of 54 local governments, including 45 city governments, 8 county governments, and 1 tribal government. This open-ended list generation allowed us to collect data on the broad array of solutions in place.

Identifying and applying IWM dimensions

To identify a confined set of IWM dimensions suitable to describe our corpus, we used an iterative approach. This involved two interrelated processes. Moving from the literature to the data, we identified candidate dimensions prevalent in the literature and then tested these on our corpus. The choice of candidate dimensions was guided by prevalence in the literature. Moving in the other direction, we conducted exploratory analyses of the actions in our corpus to inform the search for dimensions in the literature. These processes were repeated until nearly all actions in our corpus (over 98%) could be characterized in terms of at least one dimension. Once the dimensions were identified, we conducted more in-depth reviews of the relevant literature to gain a better overview of the current discourse associated with each dimension. It is important to note that the dimensions vary in their representation. Some are gradual or binary (e.g., centralized/decentralized) in that they include two opposites of the spectrum related to the 'new' and the 'old' ways, respectively. Others are categorical (e.g., functional domains) in that they distinguish different types of practices and the relations of these.

Next, we applied the thus identified IWM dimensions to all actions in our corpus. Each action was coded in terms of as many dimensions that would apply. This allowed us to gain an overview of how IWM principles are implemented (or not) in Arizona.

Finally, we explored the relation between different dimensions in the action in our corpus. This was done by means of co-occurrence of dimensions. The majority of actions reported by local government representatives relate to two or more dimensions. This allowed us to compile a matrix showing, for every pair of dimensions, how often they co-occur as attributes of innovations. This matrix was then submitted to hierarchical cluster analysis to identify coherent groups of dimensions. We used the Association Strength Index (Eck & Waltman, 2009) as a measure of association and complete-link as the clustering method.

4. Typology of IWM dimensions

Our iterative process yielded seven IWM dimensions, namely technology/infrastructure, centralized/decentralized water systems, policy instruments, stakeholder involvement and collaboration, functional domains, planning and urban design, and alternative water sources. Each of these dimensions is rooted in IWM conceptual work. It is important to note that the dimensions are not mutually exclusive and a particular action may be classified in terms of only one or multiple dimensions. In the following, we briefly outline these dimensions as they are discussed in the literature before discussing their application to our corpus.

Dimension #1: infrastructure/technology

The first dimension relates to technology and infrastructure. The literature broadly distinguishes three categories, namely physical infrastructure, digital technology, and GI. Physical infrastructure includes installations such as dams, pipes, pumps, fixtures, appliances, and treatment facilities (Kiparsky *et al*., 2013; Crow-Miller *et al*., 2017). Physical infrastructure can be implemented at the city, neighborhood, and household scale. Having been in operation for decades or even centuries, physical infrastructures of many cities around the globe are increasingly facing aging problems including inefficiency and system interruptions (Deloitte, 2016). The degradation of large-scale physical technology and the tremendous investments needed for upgrading and replacement are sometimes seen as a chance to switch to or incorporate alternative technology types such as digital tools or GI.

At the heart of the current discourse on digital solutions to water management are the unprecedented possibilities resulting from the Fourth Industrial Revolution, the Internet of Things, artificial intelligence, cloud computing, and big data analytics (Deloitte, 2016; Hays, 2018; Sarni & Stinson, 2018). So-called 'smart water' or 'digital water' technologies are predicted to revolutionize water services (Hays, 2018). An illustrative example is smart water meters. Similar to smart electric meters, smart water meters combine data measuring technologies with modern communications technology to collect and transmit real-time data on water use (Boyle *et al*., 2013). These data can be used for monitoring purposes, to analyze consumption patterns, and for alternative pricing strategies (Boyle *et al*., 2013).

Finally, GI solutions have recently received much attention as 'a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits' (U.S. EPA, 2019). GI such as bioswales, green roofs, and permeable pavement are regarded as an alternative or complementary approach to traditional large-scale grey infrastructure in achieving a variety of water-related sustainability goals (Kramer, 2014).

Despite their immense potential to address current infrastructure problems, uptake of digital and GI inventions has generally been slow (e.g., Kiparsky *et al*., 2013). Reasons for this relate to path dependencies created by socio-technical regimes (e.g., Geels, 2002; Brown *et al*., 2013). Technological transitions 'do not only involve changes in technology, but also changes in user practices, regulation, industrial networks, infrastructure, and symbolic meaning or culture' (Geels, 2002, p. 1257). As such, the success of a technological intervention – and hence the contribution it can make to addressing water problems – is determined not only by its merits but also by the institutional, social, and economic context (Kiparsky *et al*., 2013).

Dimension #2: centralized vs. decentralized water systems

While the first dimension focuses on the type of infrastructure, the second dimension relates to the installation and size of these solutions. Traditional centralized or consolidated water systems provide water services using large-scale engineering solutions and extensive pipe systems. In contrast, the ideal of decentralized or dispersed systems is to provide water services through small- to medium-scale infrastructure components installed at the household or neighborhood levels (Sapkota *et al*., 2015). Illustrative examples of decentralized components are water harvesting systems (Domènech, 2011), local wastewater treatment plants (Libralato *et al.*, 2012), and low impact development techniques (Spatari *et al.*, 2011).

In practice, full decentralization is rarely found in developed countries, as the existing water systems of most cities were engineered according to the consolidated paradigm and full replacement is neither financially attractive nor feasible (Sapkota *et al.*, 2015). However, numerous governments promote the integration of dispersed technologies into their consolidated systems leading to so-called hybrid approaches. Hybrid approaches combine a consolidated water supply system, which serves as the predominant model, with alternative strategies of water supply and wastewater management (Daigger & Crawford, 2007; Marlow *et al.*, 2013; Sapkota *et al.*, 2015). Even though decentralization is associated with significant policy challenges (e.g., Pearce-Oroz, 2006; Marlow *et al.*, 2013; Sapkota *et al.*, 2015), hybrid approaches are considered a viable alternative to purely centralized systems and an important part of IWM.

Dimension #3: policy instruments

The concept of policy instruments originates in the policy literature and describes devices that organize the relationships between those who govern and those who are governed (Le Galès, 2011). Despite critiques and alternatives (e.g., Hood, 1983; Salamon, 2000; Vedung, 2010), a tripartite concept inspired by Schneider and Ingram (1990; see also Reed, 2012) tends to dominate the water management discourse, particularly water conservation studies. The three dimensions are as follows:

Regulatory instruments, which cover regulatory actions that make use of the force of law to instill desirable behaviors and encompass strategies such as rationing, water use restrictions, and standards for technologies (Renwick & Green, 2000; Campbell *et al.*, 2004; Reed, 2012);

Market instruments, which monetarily incentivize certain strategies through prices, grants, and taxes for water-efficient technologies, etc. (Campbell *et al.*, 2004; Reed, 2012; Saurí, 2013); and

Educational instruments, which cover actions that increase the awareness and propensity of people and organizations to make a positive difference for a given policy issue. Such instruments may include public information campaigns, radio messages, flyers, and programs for children (Renwick & Green, 2000; Campbell *et al.*, 2004; Saurí, 2013).

Dimension #4: stakeholder involvement and collaboration

The fourth dimension is the involvement of stakeholders in addressing water problems. Increasing stakeholder involvement in water management decisions is thought to mitigate two important sets of problems. First, the collective action problems that arise from water as a common pool resource, and the inefficiencies that emerge from stakeholders making decisions in their individual interest rather than the common interest (Benvenisti, 1996; Lubell *et al.*, 2002; Meinzen-Dick *et al.*, 2018). The second problem relates to water issues as 'messes' and 'wicked problems' (von Korff *et al.*, 2012, p. 1). Wicked problems as defined by Camillus (2015, p. 53) are characterized by an unclear problem definition, 'multiple, significant stakeholders with conflicting values and priorities who are affected by the perceived problem and responses to it,' many 'inextricably tangled' causes, and uncertainty in terms of solution strategies. Wicked problems cannot be solved unilaterally as there is no clear and undisputed solution (Roberts, 2000).

Traditional legalistic approaches are limited in tackling collective action and wicked problems and governments dealing with these problem types are advised to aim for consultative and collaborative approaches (Benvenisti, 1996; Lubell *et al.*, 2002; Head, 2008). Collaborative strategies have the potential to create mutual understanding, exploit dispersed knowledge, and identify solutions that receive the support of a broad stakeholder base (see, e.g., Taylor *et al.*, 2017; Meinzen-Dick *et al.*, 2018; Daigger *et al.*, 2019). Or, as Warner (2006, p. 20) put it, 'a wider range of actors brings a wider range of capacities, knowledge and alternatives, which can bring space and fresh air to an overloaded governance system.'

Dimension #5: functional domains

The fifth dimension of our IWM typology refers to the domain, or domains, of water sustainability that a particular action targets. IWM approaches encourage a coupling of management strategies across all domains, rather than one domain at a time (e.g., Rahaman & Varis, 2005; Mitchell, 2006; Savenije & Van der Zaag, 2008; Hering & Ingold, 2012). Domains refer to the various ways, sometimes artificial, in which governments compartmentalize responsibility. In the water sphere, for instance, one set of actors may have responsibility for ensuring water quality, while a different set of actors may have responsibility for dealing with issues related to flood risk. The compartmentalization of responsibility in policy 'silos' is not unique to water and is part of a larger issue of fragmentation of authority across functional domains – this is widely believed to inhibit the effective management of complex, emerging, and divisive policy problems (Henry, 2017, 2018).

Dimension #6: planning and urban design

Traditionally, urban growth planning and water planning have been detached. Land use planners 'have focused on how much and what type of growth may take place in their communities while water resource managers have focused on ensuring adequate water availability' (Babbitt Center & Sonoran Institute, 2018, p. 10). IWM emphasizes the consolidation of these two spheres of action to create water-sensitive development (Babbitt Center & Sonoran Institute, 2018; Stoker *et al.*, 2018). This ideal grounds in extensive research on the effect of building and urban design on hydrology.

The built environment or urban design is a major determinant of water use, flood patterns, and water quality. Stoker *et al.* (2019a) found that up to 85% of the variation in urban water use can be explained by five characteristics of the built environment: lot size, total assessed value, housing age, vegetated surface, and housing density. Among these, landscaping and vegetation take a leading role in terms of explanatory power (Gage & Cooper, 2015; Stoker *et al.*, 2019b). During summer and spring, more than 50% of water use is dedicated to outdoor watering for landscaping in certain communities (Babbitt Center & Sonoran Institute, 2018). Apart from water demands, the characteristics of the built environment also co-determine flood risk. Installation of low impact development practices, such as rain gardens, permeable pavement, and riparian buffers, decrease surface runoff and peak flows (Korgaonkar *et al.*, 2018; Hoghooghi *et al.*, 2018).

These close relations between land use, water use, and flood risk offer the opportunity to enhance water sustainability by means of systematic city planning and design. In doing so, it is important to consider social dynamic and tradeoffs between different goals. The built environment is closely intertwined with social dynamics (Stoker *et al.*, 2019a). Neighborhood trends or esthetics working alongside with other structural factors, such as income, ownership, and family status, may reinforce certain water use or landscaping patterns (Stoker *et al.*, 2019a). In addition, there is often tradeoff between different sustainability goals. Reduction of vegetation, for example, is a commonly recommended intervention to conserve water. However, it can have detrimental effects on heat and flood mitigation as trees provide shade and greenspaces enhance infiltration. The goal of integrated planning is to identify and manage such tradeoffs and opportunities.

Dimension #7: alternative water sources

The seventh dimension relates to the use of alternative water sources. We can broadly distinguish the use of alternative water sources for potable and non-potable purposes. The water sources tend to be the same in both cases. However, the mindset and purposes differ. The use of alternative water sources for potable purposes is driven by consideration of supply augmentation. Desalinated seawater, high-quality recycled water, or treated stormwater are regarded as means to supplement or replace traditional water sources, especially groundwater (e.g., March *et al.*, 2014; Lee & Tan, 2016; Luthy *et al.*, 2019). The use of alternative water for non-potable uses roots in a shift in mindset away from high-quality water for all purposes toward a 'fit-for-purpose' approach (Ahmed & Arora, 2012). The underlying principles are reuse and recycling (Ahmed & Arora, 2012).

In the IWM literature, non-potable use tends to take a leading role. The alternative sources used for non-potable purposes include rainwater, greywater, reclaimed water, and saltwater. The sources differ in terms of reliability, water quality, reuse options, and infrastructure implications. Rainwater, for example, is a relatively good quality source but characterized by reduced reliability due to dependence on rainfall patterns (Zhang *et al.*, 2009, 2010). In contrast, greywater is more reliable but more polluted (Al-Jayyousi, 2003). Health concerns arising from viral infection and microorganisms necessitate immediate reuse or treatment of greywater (Al-Jayyousi, 2003; Zhang *et al.*, 2009, 2010). The choice is to be informed by contextual characteristic and the intended uses and it is also possible to combine different options.

5. Applying the typology: government action in Arizona

In this section, we present the application of the seven dimensions outlined above to the innovations reported by local governments in Arizona. We will first discuss each dimension separately before exploring their interrelations.

Trends by dimension

Green and digital technologies are on the rise. The share of green and digital technologies in our corpus is considerable given the slow uptake described in the literature. GI solutions are the most frequently mentioned type of technology. GI projects implemented in Arizona include 'stormwater basins,' 'active and passive rainwater harvesting,' and 'rain garden areas.' Introduction of digital technology focuses mainly on smart meters and Supervisory Control and Data Acquisition (SCADA) systems.

Physical infrastructure upgrade and expansion takes place in a variety of areas, including wastewater treatment, groundwater storage and recharge, recycle, and reuse, rainwater harvesting, stormwater management, and household devices and appliances. We can broadly distinguish between small-scale technologies such as 'sediment catch basins' and 'drip irrigation systems' and large-scale technologies such as 'wastewater injection wells' and 'building new wastewater treatment plant.' The latter is more prevalent in our data.

Decentralized strategies are mainly used for stormwater management. We identified representations of both centralized and decentralized infrastructure in our data. The decentralized solutions mainly focus on the management of storm- and rainwater. Examples taken from the survey responses include 'low impact development techniques,' 'retention bioswales,' 'pervious parking lots,' and 'building catch basins to replenish aquifers.' Decentralized wastewater management strategies were less common with only two solutions reported.

Centralized solutions relate to the upgrading of treatment infrastructure, monitoring and operation of water systems, system reliability, recharge projects, water transportation and distribution, and water reuse. Examples taken from the data include 'doubling size of the sewage plant,' 'extensive reclaimed water system,' 'new water treatment facility,' and 'purple pipes.' These thematic areas are interlinked with solutions often spanning multiple themes. Illustrative examples of this are the numerous initiatives aiming to upgrade water treatment in order to enable reuse or recharge of effluent.

Market-based instruments are popular. The most prevalent policy instrument type in our corpus are market-based solutions. These include pricing strategies, incentives, rebates, and grants aiming to encourage a particular behavior or action. Examples taken from the data are the 'adoption of a sharply tiered rate structure,' 'water conservation rebates for commercial,' and 'monetary incentives for the removal of lawns.' Also evident in our data, although to a much lesser extent, are mechanisms to ensure water affordability such as 'establish[ing] a fund to assist those with temporary conditions to meet their water bill and low water cost.'

Solutions in the regulation category include laws, standards, and policies that govern management, allocation, storage, use, and protection of water sources. Examples from our data include 'resource protection standards,' 'water harvesting ordinance for new commercial construction,' 'purchasing water distribution rights,' and 'prohibiting water features (e.g., fountains, splash pads, etc.) in non-residential developments.'

Least prevalent are educational instruments. These encompass initiatives aimed at teaching and informing stakeholders about and generating knowledge on infrastructures, appliances, practices, and processes. One respondent, for example, mentioned that their government 'outreach[es] to educate and inform large water users (turf facilities) on techniques to reduce water waste.' Educational innovations include both knowledge generation and knowledge provision.

Stakeholder involvement and collaborative solutions are underrepresented. Solutions following the principles of stakeholder participation such as partnerships, committees, collaborative, and agreements between governmental and non-governmental entities are underrepresented in our corpus. Examples from our data are 'participation in the Upper San Pedro Partnership,' 'formation of Citizens Water Conservation Committee,' and the 'Tempe Grease Cooperative.'

Water conservation initiatives are widespread. Using the notion of domains of water management, we conducted an inductive analysis to identify different functional domains evident in our corpus. We can broadly differentiate five domains, namely stormwater management, wastewater management, water supply, groundwater management, and water conservation.

By far most prevalent in our corpus were actions in the domain of water conservation. Almost two-fifths of the data could be sorted into this category. Water conservation refers to actions aiming at reducing urban water use and conserving or restoring natural systems. Examples taken from the data are ‘limit amount of turf in subdivision parks,’ ‘water conservation rebates for residential,’ ‘riparian habitat created with reclaimed water recharge basins,’ and ‘focus on the protection of Verde River.’

Solutions in the area of stormwater management relate to the preventive or corrective measures to reduce flood risk, management of water runoff, and collection of stormwater. Examples include ‘low impact development,’ ‘collecting water runoff,’ and ‘diverting rain runoff to water parks.’ Rainwater harvesting programs often combine considerations of flood risks with goals of water conservation as the use of rainwater reduces demand for potable water.

Wastewater management as evident in our corpus shows a strong focus on (re)use. Initiatives reported include ‘100% reuse of wastewater effluent,’ ‘injection wells for reclaimed water,’ ‘treated effluent used for landscaping,’ and ‘new water treatment facility.’

Groundwater management relates to initiatives aiming to protect, recharge, model, reduce use of, and regulate access to groundwater resources. Examples are ‘groundwater replenishment,’ ‘farm bringing CAP water to reduce groundwater pumping,’ and ‘protect the use of extinguishment credits.’ A groundwater management strategy repeatedly reported by local governments in Arizona consists in aquifer recharge with treated wastewater. This indicates linkages between the functional domains of wastewater and groundwater management.

Finally, water supply pertains to the operation and maintenance of water supply systems including acquisition and distribution of water to the public or to other local governments for domestic or industrial use. Solutions of this category include ‘100 year water supply assurance,’ ‘negotiating to acquire water service rights for areas serviced by an adjacent town,’ and ‘looking for future water sources.’

Shift toward low-water and lower-quality water landscaping. City design and the built environment are dominant topics in our corpus although often implicitly present. Many design interventions relate to the management of stormwater. In accordance with the literature, landscaping initiatives play a central role. We can broadly distinguish two main themes. The first theme relates to the use of native and low-water plants, often referred to as xeriscaping. Governments, for example, develop ‘xeriscape principles,’ foster ‘drought-tolerant landscaping,’ and offer ‘rebates for turf reduction.’ The second theme relates to using alternative water sources for landscaping, particularly water-intense landscaping. One city, for example, reports that they ‘installed [pipelines] to all large turf areas within the city to irrigate with reclaimed water rather than groundwater.’ Combined, these themes indicate a systematic shift toward low-water and lower-quality water landscaping. Explicit planning devices are present but underrepresented, which may in part be due to our respondents focusing on specific projects.

Alternative water sources are popular but how they are labeled varies greatly. Alternative water sources are popular in Arizona with governments reporting a broad array of sources, including rainwater, runoff, stormwater, greywater, effluent, reusable water, raw water, recycled water, and reclaimed water. Notable is the ambiguity in terminology; a particular source may be named differently across places.

In sum, the application of the dimensions to our corpus yields three interesting findings. First, water management in Arizona shows manifestations of both the ‘old’ and the ‘new’ paradigms. Second, we find systematic connections and overlap between different action types. Illustrative are the use of dispersed strategies for stormwater management or the use of effluent for recharge purposes. Finally, the selection of strategies as well as their connections is influenced by contextual characteristics. The popularity of GI choices is likely a result of monsoon-induced flash floods and the need for cooling mechanisms. Dominance of water conservation strategies and recharge of reclaimed water are an effect of the dry climate and the history of groundwater overdraft.

Pulling it together: water management in Arizona

The final step of our analysis focuses on the relations between dimensions. To study relations, we analyze the co-occurrence of dimensions within innovations. Put simply, we are looking for systematic patterns in how dimensions co-occur as attributes of innovations. It is worth keeping in mind that relations may be generic meaning that they are a reflection of the underlying conceptual space or they may be distinct meaning that they represent distinctive solution strategies characteristic of a place.

Figure 1 shows the result of our cluster analysis as a heat map. Dark colors indicate strong associations, meaning that there is a relationship between the respective dimensions. Whereas light colors indicate weak associations, meaning that there is no relationship between the respective dimensions. The cluster analysis reveals three main clusters. The first cluster (upper left corner) includes the dimensions digital technology, centralized, large-scale technology, waste water management, and groundwater management. The actions of this cluster focus on providing water services using a large-scale, centralized approach.

The second cluster (middle) concentrates on management of stormwater using decentralized solutions, particularly GI. It contains the dimensions decentralized, GI, stormwater management, water conservation (general), built environment and city design, and alternative water sources. The alternative water source dimension likely fell into this cluster due to the popularity of rainwater as a water source in Arizona.

Finally, the third cluster (bottom right corner) encompasses the dimensions water conservation (use reduction and environmental), stakeholder involvement, education, landscaping, water supply, small-scale technology, markets, and regulation. The underlying topic of this cluster is citizen involvement. Citizens or consumers of water services are actively involved in achieving water management goals such as water use reduction or environmental conservation. They contribute by installing fixtures, adjusting landscaping practices, and use of alternative sources among others.

At first glance, the analysis reveals two management approaches mimicking the two paradigms described in the IWM literature. The first approach – relating to the ‘old’ paradigm – coincides with the first cluster and emphasizes service delivery. The utility or city government is responsible for providing water services, while citizens take a passive consumer role. The second approach – relating to the ‘new’ paradigm – comprises the second and third strategies and focuses on co-production and citizen empowerment. This strategy is characterized by overlapping or shared responsibilities between utilities and their customers.

A closer look, however, reveals a more complex and more interesting picture. Both (or all three) strategies involve elements of IWM although these take different forms and vary in terms of the degree of implementation. The first cluster, for example, is characterized by a *coupling of domains* across groundwater and wastewater management. Reclaimed water is used to replenish groundwater stocks. Integration of functional domains is a central recommendation in the IWM literature. The stormwater management and water supply clusters show a more evident and dominant uptake of IWM. They are characterized by a high degree of *decentralized solutions* and considerable *citizen involvement*. *Accordingly, rather than doing things the ‘old’ or the ‘new’ way, governments in Arizona systematically combine elements of both paradigms*. These combinations often take the form of partial implementation

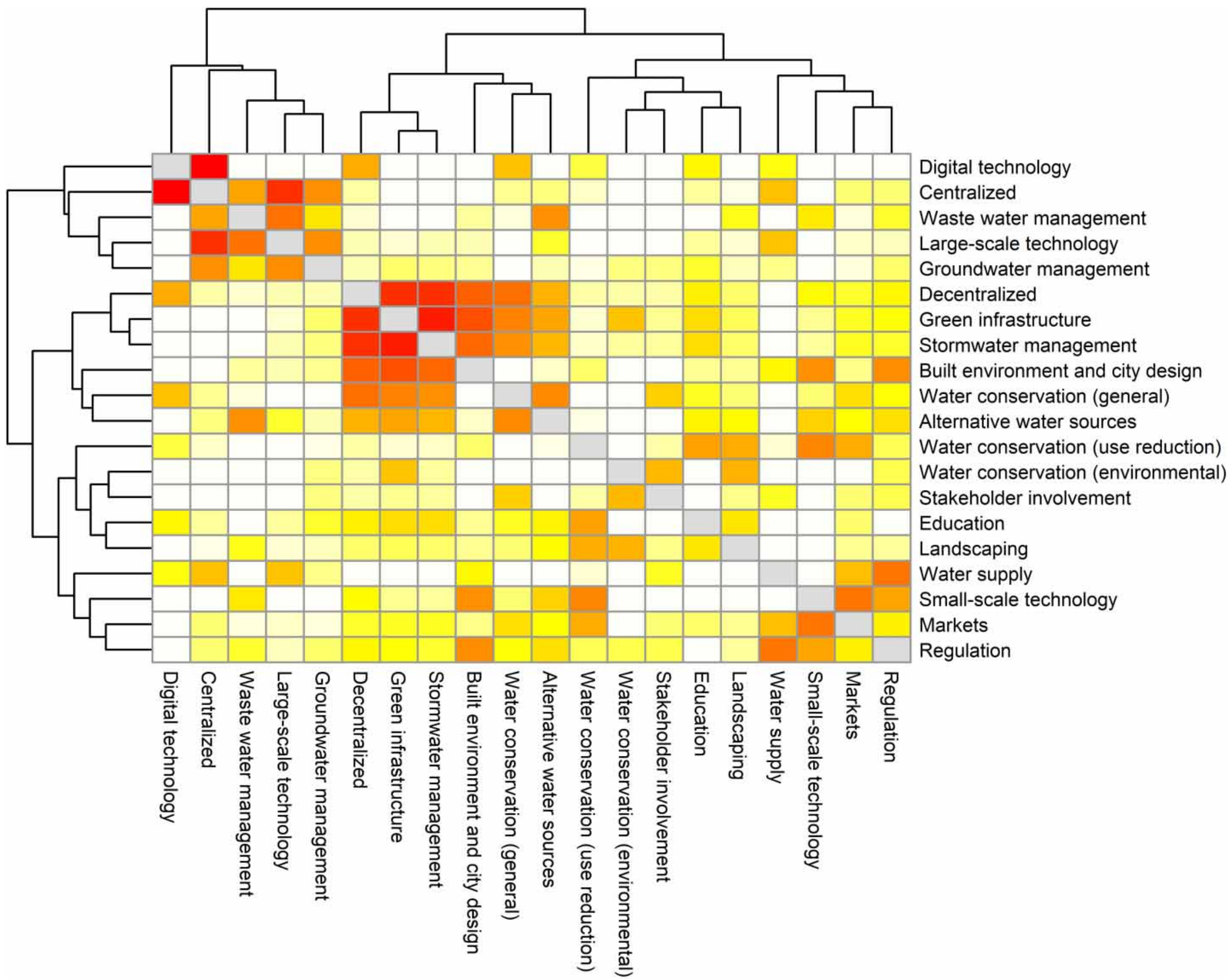

Fig. 1. Relation between dimensions in the corpus of government action in Arizona.

and experimentations. Our analysis suggests that utilities may run smaller, domain-specific experiments that, depending on the outcome, are systematically scaled. If this is the case, IWM transitions are achieved, at least initially, using a bottom-up approach consisting of incremental steps and systematic experimentation.

6. Limitations

Limitations of this study relate to our action corpus. The innovations collected through the survey are not a comprehensive set of all actions taken by local governments. Rather they represent a collection of items that in the eyes of our respondents are most proud of. Related to this, the description of the innovations was fairly short consisting of a few words to a sentence. While the survey approach allowed us to get a diverse action corpus from all over Arizona, this briefness of descriptions made it at times difficult to categorize actions. Finally, as already mentioned, our data are restricted to Arizona. This limits the generalizability of our findings. However, this being said, we plan to test and refine the typology presented here using comparable data from four other US regions.

7. Conclusion

In this paper, we explored how actions taken by local governments in Arizona relate (or not) to IWM action recommendations. The paper makes three main contributions. First, we used a data-driven literature review to identify among the vast amount of action recommendations in the literature a confined set of dimensions that are particularly relevant to current water management practice. This set delineates important areas of overlap between the conceptual and practical space, and while certainly incomplete, provides a clear focus allowing scholars to systematically study, compare, and contrast on-going IWM uptake.

Second, we applied these dimensions to actions taken by local governments in Arizona. Our analysis indicates that 'new' and 'old' strategies coexist in water management in Arizona. Governments in the state use IWM strategies to complement or enhance traditional water management approaches. Uptake differs across management spheres in terms of both magnitude and form. Groundwater and wastewater management are still dominated by a centralized service delivery approach with one-sided responsibilities. However, in accordance with IWM, the two functional domains are closely connected with wastewater often used to replenish groundwater. In contrast, stormwater management and water supply tend to be characterized by a co-production approach, wherein the city and citizens share responsibilities to achieve water sustainability goals. The differences in uptake can be read as a signal that governments tailor options to their needs and existing arrangements. They seem to conduct domain-specific, small-scale experiments with the potential to be scaled or extended to other domains.

Finally, our results reinforce existing notions of the important role of contextual factors. Factors such as climate, history, legal arrangements, and social and economic development co-determine the feasibility, efficacy, and attractiveness of IWM strategies. Thus, any viable action recommendation needs to account for the contextual differences between places.

Combined, these findings provide some guidance for further research on IWM transitions. Transition guided by bottom-up experimentation, context-sensitive selection, and incremental change as evident in our corpus is in contrast to how IWM is often described in the literature – as a sharp shift and a break with old traditions. Rethinking co-existence of the two paradigms and the role of partial adaptation may be key in understanding and fostering transitions.

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