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Assessing sectoral heterogeneity and leadership in urban water management networks

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Abstract

Many urban systems worldwide face increasing complexity and uncertainty in water governance. As a result, integrated urban water management (IUWM) has become increasingly common. The IUWM paradigm conceptualizes water supply, conveyance, and treatment as an integrated system to improve water management efficiency and sustainability. This approach often presents new responsibilities that require coordinated efforts and leadership, but factors such as professional protocols, limited time, legal mandates, and budgetary constraints may limit joint implementation. To understand how policy stakeholders translate goals into action, we ask: How do sectoral affiliation of governance stakeholder organizations and leadership influence patterns of joint implementation of programs and policies over time? Using inferential social network analysis, this paper examines how coordination and leadership play a role in the implementation of IUWM. We find that the presence of leaders has a significant effect on joint implementation of integrated programs and policies over time. Counter to our expectations, however, organizations from the *same* sector (e.g., local government, non-profit, private, etc.) tend to implement IUWM policies and programs together.

Keywords: Implementation; Integrated urban water management; Networks

Highlights

- Institutional setting may explain who leads and the extent of sectoral integration in IUWM implementation over time.
- Non-IUWM implementation networks are comparatively stable and homogeneous, likely reflecting obligations in regular water and wastewater service provision.

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Introduction

Many urban centers worldwide are transitioning to integrated urban water management (IUWM) to deal with increasing complexity and uncertainty of pressures in water governance, and to promote social, economic, and ecological sustainability (Larsen *et al*., 2016; Hess & Brown, 2018). The IUWM paradigm views water supply, drainage, and wastewater conveyance as part of an integrated system (Fletcher *et al*., 2015). IUWM also emphasizes the need for new models of governance that promote coordination and collaboration among diverse water management stakeholders, and that move away from traditional, fragmented approaches to water management (Mukheibir *et al*., 2014).

Despite the importance of coordination and collaboration in IUWM, it is still largely unclear when and why governance stakeholders coordinate to implement integrated (or non-integrated) policies and programs. Examining coordination in policy implementation, or the carrying out of policy decisions (Pressman & Wildavsky, 1973; Mazmanian & Sabatier, 1983; O'Toole, 2000), is one way to address this gap. While water management literature suggests that diverse stakeholder participation and leadership are cornerstones of transitioning to IUWM (Brown *et al*., 2013), other work has indicated that factors such as professional protocols, limited time, budgetary constraints, and fear of losing constituent support could limit such action (Brown, 2005; Stoker *et al*., 2018).

This paper asks: How do sectoral affiliation of governance stakeholder organizations (e.g., local government, businesses, etc.) and leadership (which entails mobilizing others and their resources) influence patterns of joint implementation of programs and policies over time? Current research examines IUWM from a variety of angles, including barriers to implementation (Brown & Farrelly, 2009; O'Donnell *et al*., 2017) and the role of water stress, heightened public attention, leadership, and venues as catalysts for transitioning to more sustainable water management practices (Gliedt *et al*., 2018; Garcia *et al*., 2019). Other work presents more applied considerations including decision-support tools and cost-benefit analyses (Makropoulos *et al*., 2008; Fattahi & Fayyaz, 2010). Together, these studies offer valuable insight and strategies relating to sustainability transition processes. Yet, there is limited inferential analysis examining how leadership and sectoral heterogeneity affect patterns of joint policy implementation. Systematic examination of these factors can improve understanding of implementation dynamics across different transitioning urban water systems.

Leveraging data from 358 gray literature documents published online, we use exponential random graph models (ERGMs) to estimate the effects of leadership and sectoral affiliation on joint policy implementation for IUWM and non-IUWM water management practices in Tucson, Arizona, USA, in 2007 and 2017. Through this study, we build on current policy implementation research and sustainability transitions literature.

In what follows, we introduce the background for our study. Next, we discuss drivers of joint implementation in the governance networks and introduce our hypotheses. Following a discussion of data, methods, and model results, we descriptively evaluate the network structures. We conclude with the implications and limitations of our work, and considerations for future research.

Background

This study focuses on joint implementation of water management programs and policies in Tucson, Arizona. Tucson is a growing urban center located in the semi-arid Sonoran Desert, which receives about 11 inches of rainfall per year (NOAA, 2019). Water security concerns in Tucson are salient at present because of current climate-related and regulatory conditions. Tucson – like most of Arizona – has endured a drought now for more than two decades (AMWUA, 2020). The drought has also impacted Lake Mead, which supplies a portion of Tucson's annual water resources. Over time, water supply has declined in the reservoir, nearing a level at which the Bureau of Reclamation would declare a shortage in the Colorado River Lower Basin (USDOI, 2007). Should this occur, Tucson would lose its annual allocation to California (Pitzer *et al*., 2007).

Tucson's water security concerns are rooted in a long history of rapid growth and extensive water consumption. Starting in the early 20th century, Arizona experienced rapid agricultural growth, and later urbanization – both which relied on groundwater resources (Larson *et al*., 2009; Megdal *et al*., 2014). Groundwater over-extraction soon became problematic, so Congress approved the construction of the Central Arizona Project (CAP), which would import water over 300 miles uphill to central Arizona, including Tucson. The intent of the CAP was to deliver new water resources to offset groundwater (August & Gammage, 2007). Nonetheless, many consumers instead used CAP to supplement groundwater use.

To address continued over-extraction, the state passed the Groundwater Management Act (GMA) in 1980, which would designate much of the Arizona – Tucson included – as active management areas (AMAs). The Arizona Department of Water Resources (ADWR) designed five consecutive management plans that would introduce increasingly rigorous conservation and management requirements for AMAs to decrease groundwater withdrawals over the next 45 years (ADWR, 2016a). Under these plans, the Tucson AMA must implement conservation measures to achieve 'safe yield' standards by 2025, where annual groundwater withdrawals will not exceed the amount recharged (ADWR, 2016a).

ADWR supplemented the management plans with the Assured Water Supply Program, requiring new commercial and residential subdivisions to either demonstrate the availability of 100-year water supply (Arizona State Senate, 2007), or for their AWS-designated, municipal providers (e.g., Tucson) to present a written commitment of service (ADWR, 2016a). Pursuant to the GMA, municipal providers with an AWS designation must also participate in the Total Gallons Per Capita per Day (GPCD) Program, which sets annual municipal use targets (ADWR, 2016b). In 1989, Tucson Water, the City's water department, failed to comply with GPCD standards, so ADWR required the utility to adopt a base conservation program to reduce groundwater consumption. Tucson Water has since introduced price- and incentive-based strategies, regulatory measures, and programs promoting public awareness and compliance, together superseding requirements (City of Tucson & Pima County, 2009). Arizona's experience with long-term drought and recent concerns about future shortages on the Lower Colorado River make these efforts especially timely (Castle & Fleck, 2019).

Coordination and leadership in water management

IUWM networks

Translating vision into action. A key strategy in Tucson's adaptation to long-term drought has entailed adoption and implementation of IUWM. This management paradigm conceptualizes traditional, siloed water management (i.e., supply, stormwater, and wastewater) as an integrated whole (Furlong *et al*., 2017). The goal of this approach is to improve water-use efficiency and to reduce reliance on potable resources (Mitchell, 2006). There is a wide array of means to implement IUWM, such as demand-based incentives or pricing structures (Sharvelle *et al.*, 2017), passive infrastructure to strategically channel water flows, and technology to promote wastewater reuse (Sharma *et al.*, 2019).

Nonetheless, a key challenge to IUWM is translating vision into action. Such barriers to implementation can be multifaceted. Capacity to carry out a new program, for example, may be limited due to budgetary constraints, lack of expertise with new technology, or unclear responsibilities, or for fear of losing constituent support (Brown, 2005; Stoker *et al.*, 2018).

Coordinated IUWM implementation. One way to understand barriers to IUWM implementation is to examine this in the context of the policy process. According to the Advocacy Coalition Framework (ACF), a policy issue relating to a specific geographic area, or a 'policy subsystem', tends to remain fairly stable over time (Sabatier & Jenkins-Smith, 1993). Policy stakeholders within the subsystem are hypothesized to engage in non-trivial degrees of coordination to translate policy goals into action (Sabatier & Weible, 2007). While this coordination is often examined in the agenda-setting stage of the policy process, this can also occur in policy implementation.

Over the past several decades, the policy literature has examined implementation from several theoretical points of departure (DeLeon & DeLeon, 2002). Areas of focus have included (i) why implementation fails following adoption (Pressman & Wildavsky, 1973); (ii) whether it is best to conceptualize variation in implementation through a top-down (i.e., mandated processes) or bottom-up lens (i.e., focusing on actors at the operational level) (Hjern & Hull, 1982; Mazmanian & Sabatier, 1983); and (iii) how to reconcile theoretical gaps of earlier generations of study and employ rigor in scientific research design (Sabatier, 1986; Goggin, 1990; Winter, 2012; Saetren, 2014).

More recent work has shifted focus away from unilateral, hierarchical structures, to governance networks to carry out policy objectives (Nilsen *et al.*, 2013). Within these structures, autonomous stakeholders interact to share financial resources, as well as unique ideas, knowledge, and experience to identify solutions that address outstanding problems (Hartley *et al.*, 2013; Torfing, 2016). Nonetheless, this may include some top-down practices if joint implementation occurs within broader governmental regimes or involves public actors linked to institutional requirements (Koontz *et al.*, 2004; Koontz & Newig, 2014).

Assuming policy stakeholders are not required to coordinate in the implementation of policy (Chisholm, 1992), they may form strategic relationships with others who have complementary resources or capacities, such as unique information, influence, or financial resources (Pfeffer & Salancik, 2003). This resource dependence is a common theme among policy stakeholders that depend on one another to achieve shared management and policy goals (Milward & Provan, 1995; van de Meene *et al.*, 2011; Henry & Vollan, 2014).

Research on the implementation of IUWM points to the importance of coordination between organizations from different sectors to access novel resources and other contributions. For example, it is shown that through these types of relationships, public actors can provide funding to those with expertise to carry out public goals (Mitchell, 2006). In other instances, organizations might rely on one another for unique capacities, such as legal authority, flexibility outside of institutional constraints, or diverse, specialized knowledge or skills (Henry, 2009, 2017; van de Meene *et al.*, 2011).

As a municipal water service provider, Tucson Water is required by ADWR regulations to implement local initiatives for efficient water use, conservation, and use of renewable resources (ADWR, 1999). While the utility is not functionally interdependent with other organizations, its implementation of IUWM has involved a broad range of diverse stakeholders. A key strategy that Tucson Water has leveraged to promote water-use efficiency is the implementation of green infrastructure technologies, which refers to an interconnected system of greenspace (e.g., waterways, wetlands, greenways, natural areas, green streets, swales, etc.), that is designed for sustaining social and ecological health and well-being (Benedict & McMahon, 2012). Green infrastructure, a stormwater management strategy central to IUWM (Brumley *et al*., 2018), is depicted in empirical research as utilizing cross-sectoral interaction for different dimensions of implementation, such as planning, siting (Meerow & Newell, 2017), and leveraging diverse expertise or skills (Shifflett *et al*., 2019). In practice, such coordination may be useful for the implementation of a variety of strategies, such as regulation (Fricano & Grass, 2014), market-based approaches (Gómez & Teixeira, 2017), or educational programs (Newell *et al*., 2013). With new policies and programs, we expect increased operational complexities and needs, and utility reliance on organizations from other sectors.

> *H_{1a}: In the implementation of IUWM programs and policies, organizations from different sectoral affiliations will tend to work together over time.*

Leadership in coordinated IUWM implementation. The policy literature also points to skilled leadership as having a central role in coordination. Such leaders, which the ACF refers to as 'policy entrepreneurs', are described as investing time and energy to promote new relationships and mobilize other stakeholders (Sabatier & Weible, 2007). Being centrally embedded in coordination networks is suggested to afford these actors strategic capabilities to access novel information and finances, and to identify opportunities for those in the coordination network to achieve collective goals (Sabatier & Weible, 2007; Christopoulos & Ingold, 2015; Grigg *et al*., 2018).

Although policy entrepreneurs often receive attention in the policy literature in the agenda-setting process, they may also be instrumental through the implementation phase to ensure the success of a policy innovation (Mintrom & Norman, 2009; Arnold, 2015). In the context of the water management literature, leaders are depicted as necessary for establishing priorities and for visioning after policy adoption (Brown, 2005; Bos & Brown, 2012). They may also support others in implementation by providing needed information, through consultation, or in leading by example (van de Meene *et al*., 2011).

Empirical research on IUWM has shown that leaders are integral to implementation processes. Leaders are described as persistent and committed, adept in strategic networking, and engaged in directing and motivating others to implement sustainable water management innovations (Taylor, 2009). Prospects for the success of integrated management approaches are also credited to the presence of leadership (Grigg *et al*., 2018). With this central role of leaders in sustainability transitions – and IUWM implementation more specifically – we propose:

> *H_{1b}: Leaders will have a clear role over time in driving patterns of joint implementation of IUWM policies and programs.*

Non-IUWM networks

Coordination in non-IUWM networks. Policy subsystems that adopt and implement IUWM may also continue traditional strategies for treatment, water supply, wastewater conveyance, and stormwater management (Daigger & Crawford, 2007; Wong & Brown, 2009). Traditional water management systems, unlike IUWM, use large-scale, mechanized approaches and well-established institutional structures such as administrative processes and rules (Brown *et al*., 2009; Farrelly & Brown, 2011).

Within institutional frameworks, administrators and bureaucrats hold formal responsibility over service provision, with clearly designated responsibilities (Dobbie *et al*., 2016). One way that government actors may maximize efficiency and responsiveness in implementation is through coordination with one another (Provan & Milward, 2001). Nonetheless, assuming these actors have comparatively narrow professional incentives and responsibilities, they may be more inclined to minimize risk, as well as the potential for liabilities and loss of public support (Farrelly & Brown, 2011; Feiock, 2013; Mullin & Rubado, 2017). Given the predefined roles of responsible actors and the stability of their behavior, we expect that the non-IUWM implementation network might manifest as a relatively stable, homogeneous network over time.

> H_{2a}: *In implementation of non-IUWM programs and policies, organizations with the same sectoral affiliation tend to work together.*

The role of leadership in non-IUWM networks. Compared to an IUWM network, provision of essential public services in traditional water management likely requires less entrepreneurial leadership. Although water professionals may be adept in promoting innovations that address complex problems, routine operations and reliability may remain top priorities (Termeer, 2009). The ACF proposes that, within the policy subsystem, actors seeking to maintain the *status quo* participate in stable coordination networks over time (Sabatier & Jenkins-Smith, 1993). In the absence of a shared goal to advance policy innovation, entrepreneurial leaders may not be needed to support these groups of actors.

> H_{2b}: *Leadership will not have a significant effect in driving patterns of joint implementation in traditional water management.*

Methods

Data

We derived network data from gray literature content to test our hypotheses. Here, gray literature refers to literature resources including news articles, websites, government reports, ordinances, meeting minutes, manuals, presentations, and white papers. These data were most appropriate for the longitudinal nature of our study. Key challenges that come with collecting longitudinal data include high costs and limited availability (Sabatier & Jenkins-Smith, 1993; Macnamara, 2005). While survey respondents may have difficulty with recall (Henry *et al*., 2012), gray literature can yield resources produced at the time of the event of interest. Data from gray literature may also produce a comparatively holistic rendering of the true network because it is not affected by low response rates.

Our data come from a corpus of gray literature documents sampled with a systematized online search protocol. By combining search terms of topic and location (e.g., 'stormwater' and 'Tucson'), we identified stakeholders and their shared ties through the events they implemented together (i.e., policies and programs) in content published online from 2007 to 2017[1]. Selecting this time range was motivated both by the limited availability of content prior to 2007 and by the theoretical expectation that a decade or more is required for experience with implementation and policy change to occur (Sabatier & Weible,

[1] See Supplementary Material, Appendix A for a list of search terms.

2007). This does not link change to any major event that would be expected to cause change but provides better information in the transition process that occurs over time.

We selected the first ten unique query results for each search term combination and year. Our heuristic for the ten-result limit was motivated by a preliminary inspection of search results – after the first page (approximately ten results), document content relevance decreased, and redundancy of query results increased. Lastly, with snowball sampling, we also read hyperlinks found in our initial corpus, together yielding 840 gray literature documents. With our interest in examining the governance networks in 2007 and 2017, however, we only relied on 358 of those documents.

Constructing implementation networks

We used network structures to operationalize joint implementation in the policy system. Social networks are mathematical abstractions of the real world (Henry, 2011), comprising actors or 'nodes', and the relationships, or 'ties' they share. These structures can demonstrate a variety of aspects about joint implementation, such as its prevalence among water governance stakeholders, and whether this mostly occurs among smaller groups.

An event-based approach allowed us to identify relevant network actors and joint implementation (Laumann *et al.*, 1989). This means that, in the absence of survey data (with direct responses about shared ties), we identified ties between two or more actors if they implemented the same policies or programs (i.e., 'events'). Specifically, we found evidence of joint implementation in the documents either with phrases indicating that two actors had some role in the implementation of a common event or by explicit mentions of collaborative or coordinated efforts in relation to that event. We operationalized implementation as enacting policy, using technology, or carrying out management activity central to IUWM. Collectively, these joint implementation ties comprised unipartite (i.e., actor-actor) networks.

The networks we constructed (Figure 1) represented joint implementation between stakeholder organizations in 2007 and 2017 to evaluate how patterns of actor involvement changed over time. Some organizations only implemented one common program or policy and only shared ties with one another, whereas others were involved in multiple programs or policies and thus shared implementation ties with a broader range of organizations. We further divided the network into two subgraphs (i.e., smaller networks) of organizations involved in IUWM and non-IUWM implementation, respectively[2]. We conceptualized IUWM as relating to wastewater reuse, demand management, stormwater management (including GI and green building practices), infrastructure management, and reduction of pollution and erosion/sedimentation (Mitchell, 2006; World Bank, 2012).

Prior to modeling, we assessed descriptive statistics of the IUWM network and of the non-IUWM network. By counting nodes and ties, we observed growth and attrition over time. Other statistics we calculated in the network included *density*, or the proportion of observed ties to all possible ties in the network (Wasserman & Faust, 1994), and the number of transitive triads, where two actors are tied through a direct and indirect path of length two. These triads form when actor *A* creates ties with actors *B* and *C*, increasing the likelihood that *B* and *C* also form a tie (Holland & Leinhardt, 1971).

Table 1 shows changes in the network statistics for the IUWM and non-IUWM networks in 2007 and 2017. Membership of the IUWM network increased by 141% and the number of ties more than

[2] In this case, there were actors that were active in both IUWM and non-IUWM implementation networks.

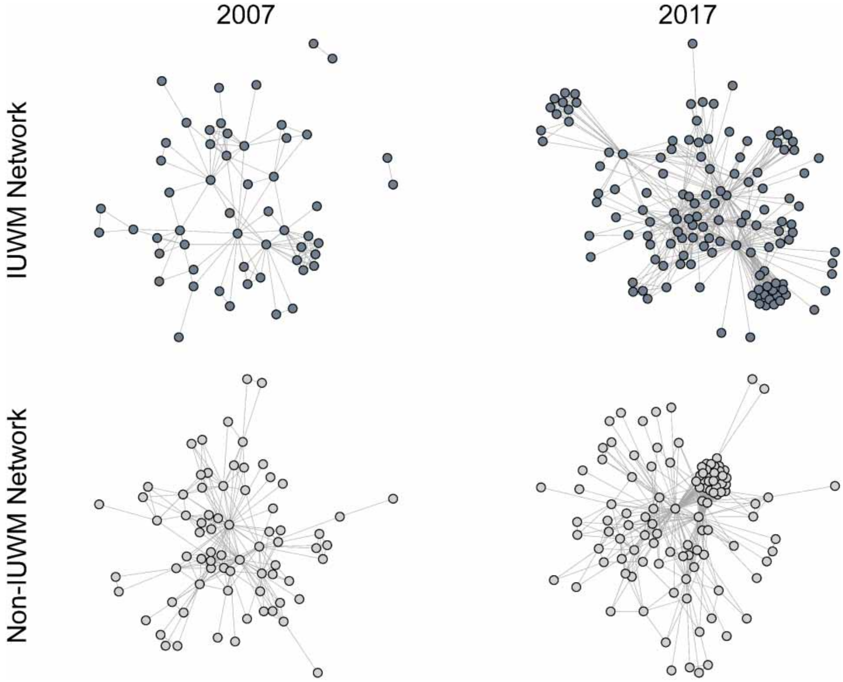

Fig. 1. IUWM and non-IUWM joint implementation networks for 2007 and 2017.

quadrupled. There was also a slight increase in the triadic closure, but a slight decrease in density. This potentially indicates growth in the number of new policies and programs, and involvement of new actors not necessarily linked to those present in the 2007 network.

The non-IUWM implementation network showed comparatively less growth – the number of participants increased, but only by 52%. The number of joint implementation ties grew more in the IUWM network, as did the network density and triadic closure. These increases potentially indicate more stability both in organizations and their patterns of joint implementation over time.

Model

We used ERGMs to test our hypotheses. ERGMs estimate the likelihood that a simulated network structure would approximate the observed network we have measured with our selected parameters

Table 1. Descriptive statistics of the implementation networks, 2007–2017.

	IUWM network		Non-IUWM network	
Statistic	2007	2017	2007	2017
Number of nodes	54	130	73	111
Number of ties	128	653	229	822
Density	0.089	0.078	0.087	0.135
Triads	0.528	0.536	0.414	0.804

(Lusher *et al*., 2013). This network model is preferable to linear regression models because dyadic independent variables of interest violate the assumption of independence (Robins *et al*., 2012). We fit four models total to estimate the effects of our specified parameters for the IUWM and non-IUWM networks in 2007 and 2017, respectively.

Model parameters

Our model specified two covariates. First, we fit an exogenous nodal covariate that was the sum of media-reported 'leadership' roles in the governance network (i.e., *not* inferred from network position). Specifically, we operationalized this variable as the sum of occupying at least one of three roles mentioned in gray literature reports of brokerage, entrepreneurship, and leadership (with a score ranging from 0 to 3 to account for each reported role occupied). Our coding scheme required only one mention of having occupied a role to receive designation as leader, broker, or entrepreneur.

Brokerage reports were detected as the mention of any intermediary organizations engaged between two or more other organizations. For example, one online report described how a non-profit organization – the identified broker – worked on behalf of the Tucson City Council with the Pima County Regional Flood Control District to address localized flooding and water quality issues (WMG & PCRFCD, 2015). We coded organizations as policy entrepreneurs if they were reported to have championed adoption or implementation of a program, event, or policy. Lastly, we recorded verbatim reports of organizations as 'leaders'.

The model also fit an edge covariate – the tendency for organizations to form ties with organizations from other sectors. We coded each organization as one of the following: an interest group, or organization from the public, non-profit, private, or academic sectors. Using the nodematch term from the *ergm* package (Hunter *et al*., 2008) in R, a statistical computing program (R Core Team, 2014), we estimated the effects of homophily, or preference for similar others in our model (McPherson *et al*., 2001); a negative coefficient reflected preference for forming ties with organizations from sectors different from their own.

We then included baseline structural terms to help explain the observed network. Density and clustering are two common parameters that are considered baseline features of networks. Given the structure of our data, we fit a Metropolis-Hastings constraint on density to avoid model degeneracy. We did, however, include a parameter for the likelihood of transitive triad formation, discussed earlier.

Results and discussion

This section covers the model results and interpretation. While we find support for some of our hypotheses, we also observe coefficients with significance and directions that are counter to our expectations. Here, we discuss these outcomes in greater detail and potential empirical drivers for we observe.

Transitive triads

Table 2 shows us the ERGM coefficients for transitive triads, shared sector, and the presence of leadership. The positive, significant transitive triad coefficient suggests that the log likelihood of tie formation between two actors that share ties with a mutual connection is greater than would happen by chance. This means that in both the IUWM and non-IUWM networks, organizations directly

Table 2. ERGM results[a]

Parameters	IUWM network 2007	IUWM network 2017	Non-IUWM network 2007	Non-IUWM network 2017
Transitive triads	2.113*** (0.290)	7.023*** (0.442)	3.887*** (0.373)	7.427*** (0.571)
Shared sector	0.260 (0.135)	0.241*** (0.063)	0.055 (0.082)	−0.028 (0.056)
Leadership role	0.221*** (0.064)	0.061* (0.028)	0.065 (0.048)	−0.001 (0.034)

[a]Goodness of fit simulations in Supplementary Material, Appendix B.
***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; standard errors in parentheses.

linked to one another also have multiple shared partners. This coefficient may be inflated by the event-based coding (i.e., assuming all implementers of a common policy or program share a tie), but it also potentially suggests that some organizations were involved in the implementation of more than one policy or program in 2007 and 2017, respectively.

In practice, triadic closure can be beneficial to joint implementation. These structures have been theoretically linked to social dynamics such as trust, norms of reciprocity, cooperation (Simmel, 1950; Krackhardt, 1999), and lower risk of defection in collective action scenarios (Berardo & Scholz, 2010). Triads can also improve access and distribution of resources network-wide (Henry & Vollan, 2014).

Leadership

The IUWM network. We also see a positive coefficient for leadership in the IUWM network over time. This lends support to Hypothesis 1b that leaders shape patterns of joint implementation in IUWM policies and programs. This finding suggests that leaders attract new ties – and increase their own centrality in the network structure – through actions such as initiating programs, garnering resources, and mobilizing others. Without organizations in leadership roles, these ties may have not otherwise formed. The effect of leadership on the network structure decreases over time, however, potentially indicating that new actors not reported in the gray literature as 'leaders' also began to introduce new IUWM approaches. Such shifts might reflect how organizations other than key actors like Tucson Water were taking the initiative to champion integrated approaches to urban water management.

In the non-IUWM network, we see – as proposed in Hypothesis 2b – no significant effect of reported leaders on joint implementation. This may indicate the relative stability of traditional water management approaches over time. In this case, both leaders and non-leaders may be less active in activities such as gaining support and resources, or mobilizing others into action.

Given these results, we consider (i) the validity of the gray literature reports, (ii) the types of organizations that assume leadership roles, and (iii) why we might observe change over time. We informally validate leadership by assessing degree centrality[3], extent of program or policy participation, and how these statistics corresponded to gray literature reports of occupying at least one leadership role (i.e., 'broker', 'entrepreneur', and/or 'leader'). Figure 2 shows these three metrics for 2007 and 2017. Organizations with more leadership nominations in the gray literature ('Leadership') also tend to have higher degree centrality ('Centrality') and participate in more policies and programs ('Participation Frequency').

[3] Degree centrality is a common statistic in social network analysis to identify leadership. All 'leader' organizations selected from the 2007 and 2017 networks had a centrality score at least two standard deviations above the mean.

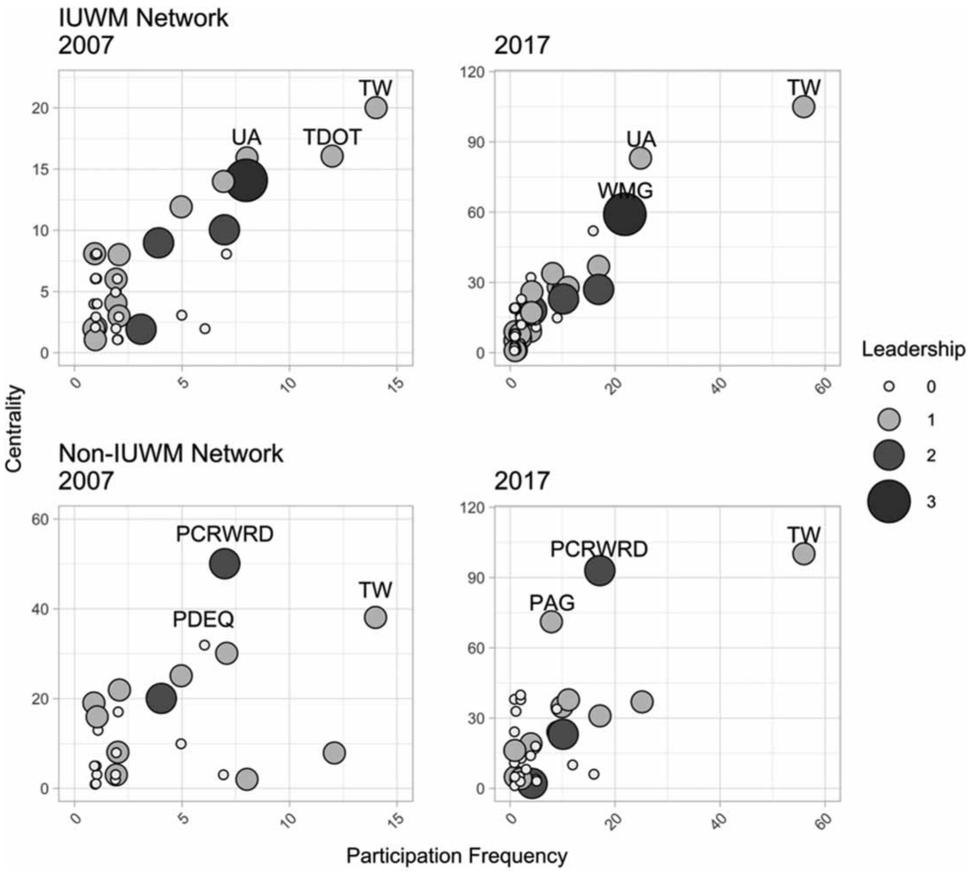

Fig. 2. Leadership in the IUWM and non-IUWM networks, measured by degree centrality, gray literature nominations, and frequency of project participation.

Tucson Water – the city's main water utility – was the top leader in the implementation of IUWM in both 2007 and 2017. Tucson Water's prominence may have stemmed from efforts to fulfill water conservation and reuse goals to meet GMA safe yield goals by 2025 (discussed previously). The utility pioneered, for example, a program to support residential installation of passive and active rainwater harvesting systems and an ordinance requiring commercial facilities constructed after 2010 to install rainwater harvesting features to capture 50% of the estimated annual irrigation needs for the property (Huckelberry & Letcher, 2009). Tucson Water also began promoting conservation through home water audits and by providing water-saving fixtures to customers (Tucson Water, 2013). Around this time, the utility also began offering incentives and support for retrofits and installation of high-efficiency appliances, rainwater harvesting, and residential graywater use (Tucson Water, 2013).

The University of Arizona also maintained a top leadership role over the study period. Since 2007, the University has both implemented a workshop with the Pima County Cooperative Extension and has pioneered multiple education- and information-based initiatives. By 2017, the University participated in 24 different IUWM programs and policies. Continuing an emphasis on water management education, the University introduced an instructional program and an online tool to inform consumers and aid in decision-making relating to rainwater harvesting and conservation strategies (WRRC & CALS, 2017; WRRC, 2019). It also partnered with local government to reduce stormwater pollution and wetlands restoration (PAG, 2016).

In 2007, the Tucson Department of Transportation was a leading organization, institutionalizing curb cut standards, allowing streetside capture of stormwater runoff for trees and shrubs (Kraker, 2014). This action was one of the several codified implementation strategies included in the Department's Stormwater Management Program, which provided a framework for city staff to work in 'an effort to reduce discharge of pollutants to the municipal storm sewer system and into the navigable waters' (TDOT, 2014).

By 2017, the Watershed Management Group surpassed Tucson Department of Transportation in both project involvement and its connectedness in the network. The Watershed Management Group has supported Tucson Water's incentives and financial support for residential rainwater harvesting by leading installation and maintenance workshops (WMG, 2019). The Group also promotes rainwater harvesting in Tucson through group job training and by hosting demonstration sites (WMG, 2018).

The non-IUWM network. As proposed in Hypothesis 2b, we find no significant effect of leadership on joint implementation in the non-IUWM network. Just as the descriptive network statistics suggest stability in network members over time (Table 2), we also see stability in the leading public organizations.

The two top leading organizations – Tucson Water and the Pima County Regional Wastewater Reclamation Department – are both obligated to provide water and wastewater services. Tucson Water is responsible for supply in the core metropolitan area and has led siting and maintenance of major infrastructure to store and distribute potable resources through traditional, piped systems. Examples of the utility's programs to ensure quality service provision include its lead pipe detection programs and water dye testing program for potable and reclaimed resources (Tucson Water, 2010, 2014).

The Pima County Regional Wastewater Reclamation Department was the second most central leader involved in the most non-IUWM programs and policies over time. The Wastewater Reclamation Department is responsible for Tucson's wastewater conveyance system and reclamation facilities (PCRWRD, 2014). Examples of its other tasks include a subsidy program offering low-income support with rising sewer fees, and its grease collection campaign to reduce drain blockage (PCRWRD, 2019).

Although the Pima Association of Governments and the Pima County Department of Environmental Quality do not carry out the core water and wastewater service provision obligations, they were more involved with other organizations and programs than most in the non-IUWM network. Nonetheless, the Department of Environmental Quality was not a reported leader in the gray literature, and the Pima Association of Government's reported leadership was related to a stormwater management program. These findings suggest that the gray literature sufficiently detects outstanding leaders with high involvement but that this approach is not always accurate.

Sectoral affiliation

We observe mixed results for sectoral heterogeneity as a driver of joint policy or program implementation. In the IUWM network, there is no significant effect in 2007, but there exists a significant, positive effect for *shared* sectoral affiliation in 2017. While the latter result aligns with our expectations that sector indeed plays a role in joint implementation patterns, it is counter to our proposition in

Hypothesis 1a, that organizations with different sectoral affiliations tend to work together to implement IUWM policies and programs.

The patterns of sectoral growth offer potential clues to help us understand these findings. In the IUWM network, there was a 500% increase in the number of private organizations, a 118% increase in the number of non-profit organizations, and a 73% increase in the number of public organizations partaking from 2007 to 2017 (Figure 3). Assuming public organizations – comprising the largest sectoral proportion in the network – also worked with Tucson Water to meet GMA requirements, there may have been relatively fewer connections with organizations not obligated to achieve regulatory benchmarks. Nonetheless, the extensive growth in the number of new ties, decrease in density, and clear emergence of more auxiliary network actors (Figure 2) suggest new emerging programs not associated with the public sector.

Lastly, coefficients for non-IUWM joint implementation among organizations from the same sector are insignificant. Thus, our model findings do not support Hypothesis 2a, which proposes that organizations tend to form ties with others from the same sector. The coefficients also show us that the effect is positive in 2007, but negative in 2017. This indicates that organizations in the non-IUWM implementation network tended to form fewer ties with others from the same sector over time. One possible explanation may be that there was a core of stable ties for ongoing water management approaches (especially among governmental organizations), but also new programs that increased the sectoral diversity. Initiatives such as the Pima County's Dispose-A-Med, for example (introduced in 2009), involves 33 partners, including the City, as well as local organizations from the non-profit, private, and academic sectors.

Data limitations

Our study illustrates how the joint implementation of policy innovations does not always rely on heterogeneous networks of policy stakeholders and that – in this case – leadership roles remain fairly stable,

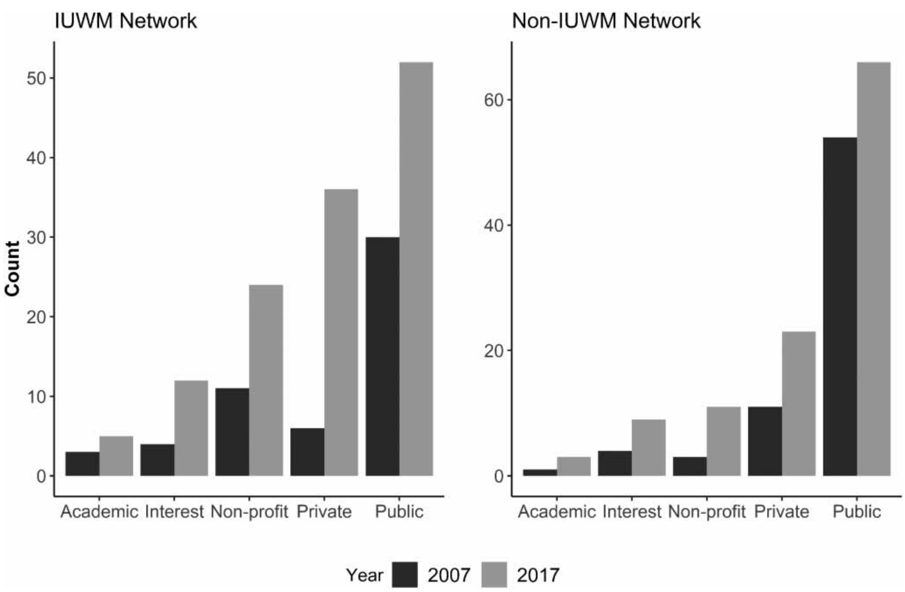

Fig. 3. Sectoral distribution of organizations in the IUWM and non-IUWM networks.

despite having a decreasing effect on patterns of join implementation over time. Yet, these findings should be interpreted with some caution because of data collection and coding challenges.

Data collection. As mentioned previously, we collected data by systematically searching key terms that reflect different dimensions of water governance. However, we realized *post hoc* that by not searching Google in a private browsing session (i.e., 'incognito mode'), the search engine may have biased results. In 2005, Google personalized searches for all users with Google accounts, such that the search results would be tailored based on previous searches (Google, 2018). A private search would likely reduce the extent with which the browser dynamically updated results, as previous work has found that Google Chrome searches in private mode do not raise major concern for storage of web browser artifacts (Flowers *et al*., 2016).

Data coding and biases. Rendered social networks do not perfectly represent the real world. This principle also applies to our event-based approach to code network data. Namely, our assumption of direct engagement between all organizations participating in the same event likely led to overestimation of network density, degree centrality, and relatedly, modeled effect of leadership and heterogeneous ties in the implementation networks. Our cross-sectional analysis also likely limited our ability to detect attrition or new organizations over time.

Notwithstanding efforts to resolve biases from data collection and coding, the quality and availability of the gray literature information can still be uneven. For instance, gray literature produced regularly through government agencies may lead to better coverage of public programs and policies (Maclaren, 1996), whereas media reports may be comparatively sparse or have targeted focus on noteworthy events or well-known stakeholders (Yi & Scholz, 2016). This was evident in our study: the public sector published 49% and media sources (i.e., news and magazines) were responsible for 37% of the gray literature that reported on IUWM policies and programs in 2007 and 2017. In addition to reporting bias, our time frame of one decade likely provides but a narrow window of information regarding the policy process in Tucson's water governance system.

The validation of network measures with additional data sources would indubitably strengthen findings. Future data collection strategies to support such efforts might entail, for example, qualitative interviews of representatives from identified leader organizations. Accounts from organization representatives could offer deeper insight on social processes and on the relevance of the identified network leaders and patterns (Rice *et al*., 2014).

Extending systematic studies of implementation

Lastly, Tucson's strong role of the public sector brings into question the generalizability of our study's findings. Our models suggest that – unlike other systems – joint implementation of IUWM strategies is not significantly predicted by sectoral heterogeneity. This directs our attention to a related line of inquiry: how does implementation vary across systems with different natural and human features more broadly? Some systems have different governance regimes, where organizations such as corporatized water systems, private or competing public water utilities, or separate statutory authorities yield different processes or outcomes relating to IUWM implementation (Mukheibir *et al*., 2014; Furlong *et al*., 2016). Another area to consider is the nature of context-specific needs. Who leads implementation, for example, could depend on whether an urban system is responding to the needs of rapid peri-urban development, such as that occurring in developing countries (Díaz *et al*., 2016), or to climatic pressures such as extreme flooding and waterlogging (Wang *et al*., 2018). We thus encourage more work that applies network analytic techniques to build a broader, systematic understanding of implementation processes in sustainability transitions.

Conclusion

The body of the literature on policy implementation has made great strides over the past 30 years, but there is little systematic examination of what motivates joint implementation processes. This paper uses inferential social network analysis and content analysis to identify drivers of joint policy implementation in adaptive water governance systems. We focus on implementation in the context of system transition to IUWM. The sustainability transitions literature has cited factors such as administrative responsibilities, maintaining constituent support, and budgetary constraints as keeping organizations from undertaking new tasks associated with the IUWM approach. Yet, joint implementation efforts between organizations from different sectors (e.g., public, private, non-profit) and leadership have also been described as instrumental in advancing transitions to IUWM. We find that the institutional setting may play a key role in when, and the extent to which, leadership affects joint implementation and when sectoral integration occurs.

Our work offers theoretical contributions to the sustainability transitions and policy implementation literature. While we find that actors outside traditional public service provision increasingly participate in joint policy implementation over time (especially for GI), public organizations are highly involved through institutional and professional obligation. At the same time, we see that – counter to many sustainability transitions studies – government actors are leading niche innovations pursuant to regulatory structures. This potentially signals a need for more work to understand when and why stakeholders endogenous to a current regime may implement conscious or planned efforts to make transitions (Quitzau *et al*., 2013). Future work to address this area of focus may gain traction by examining how local governments spearhead and continue policy innovations when embedded in different state- and federal-level institutions. This, in conjunction with a systematic assessment of social, economic, and ecological capacities and vulnerabilities, can paint a better picture of how some cities are overcoming barriers to IUWM implementation.

Methodologically, this paper shows promise for future text analysis – much of which is already gaining traction in studies of policy and political science (e.g., Nowlin, 2016; Gao *et al*., 2018). Automated web scraping and rule-based extraction, for example, is a promising direction to improve the breadth and accuracy of content analysis (Valenzuela-Escárcega *et al*., 2015). Furthermore, this will enable large-scale, comparative analyses for theory building and to gather new, timely knowledge for understanding adaptation.

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Supplementary material

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