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Toward creating an environment of cooperation between water, energy, and food stakeholders in San Antonio

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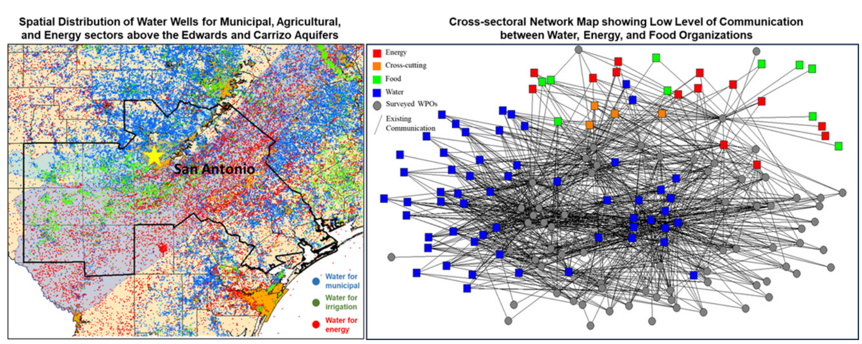
HIGHLIGHTS

- 101 responses to survey, out of 257 water stakeholders; response rate of 39.3%
- Low levels of communication between water, energy, and food stakeholders
- Positive correlation; attending stakeholder events and communication among water officials
- Insufficient evidence; communication and concern for water availability
- Insufficient evidence; communication and higher scale of governance authority

GRAPHICAL ABSTRACT



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ABSTRACT

The San Antonio Region is home to a rapidly growing population with developing energy and agricultural sectors competing for water, land, and financial resources. Despite the tight interconnectedness between water, energy, and food challenges, little is known about the levels of communication and coordination among the various officials responsible for making the decisions that affect the management and planning of the three resource systems. It has been postulated that efficient communication is a prerequisite to developing resource allocation strategies that avoid potential unintended negative consequences that could result from inefficient allocation of natural resources and competing demands. Factors that may impact communication are identified and their potential roles are considered in improving existing levels of communication between San Antonio's water officials and those at other energy, food, and water institutions in the San Antonio Region. A questionnaire designed to gather information on stakeholder concerns, frequency of communication, and participation in engagement forums was sent to public water officials in the Region. Using social network analysis and bivariate Ordinary Least Square regression analysis, the authors conclude that while modest levels of communication exist among water institutions, a very low level of communication exists between water institutions and those responsible for food and energy. It was further concluded that the frequency of communication among officials at different water institutions is higher among those that participated in stakeholder engagement activities. However, there is insufficient evidence to suggest that participation in stakeholder engagement activities improves communication frequency between water stakeholders and those in the food and energy sectors. There is also

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insufficient evidence to conclude that people at water institutions in San Antonio would have a higher frequency of communication with other water, energy, and food stakeholder in correlation with a higher level of concern about future water availability in the Region.

1. Introduction

Demand for resources is projected to increase as populations and economies around the world continue to grow (Bazilian et al., 2011; Hoff, 2011; World Economic Forum, 2011; Mohtar and Daher, 2012): by 2050, populations around the world will need 55% more water, 60% more food, and 80% more energy (IRENA, 2015). The pressures facing the resource systems and the extent of their interdependence, vary from one location to another, often emerging as hotspots (Mohtar and Daher, 2016) of varying characteristics and requiring unique sets of solutions to address them. Our growing understanding of these interlinkages, and the development of different methods for their quantification (Howells et al., 2013; Giampietro et al., 2013; FAO, 2014; Daher and Mohtar, 2015; Khalkhali et al., 2018), is an initial step in reducing stresses on these resource systems and their interdependence (Mohtar and Daher, 2017). While methods in WEF nexus research have focused to a large extent on quantifying the interlinkages between physical resource systems and trade-offs evaluation (Webber, 2016), the literature is still lacking in incorporating the political and institutional context to water, energy and food sector (Albrecht et al., 2018; Hagemann and Kirschke, 2017). Despite our growing understanding of the level of interconnectedness between resource challenges, we know little about the level of communication and coordination between those making decisions within the different resource domains (Hoolohan et al., 2018; Portney et al., 2017a). Without sufficient communication, inefficient and competing resource allocation strategies and policies could be developed, resulting in unintended negative consequences to the sustainability of the resource systems. White et al. (2017) cite lack of communication and collaboration as one of four main barriers to making decisions to address water-energy-food shocks. Pittock et al. (2013) and Pahl-Wostl (2017) further attribute policy incoherence across different sectors to lack of communication, and divergent targets and institutional frameworks. Harris and Lyon (2014) additionally identify communication and collaboration across disciplines as one of the major practical challenges facing nexus-oriented research (Kurian, 2017).

Building on this body of literature, this article quantifies the level of communication between cross-sectoral stakeholders, considering it a precursor, for their cooperation on addressing interconnected resource challenges. The article specifically focuses on the water-energy-food hotspot in the San Antonio Region in Texas, USA, by first, understanding physical resource competition resulting of its growing municipal, agricultural, and energy sectors. Then it tests hypotheses related to **1)** the current **levels of communication** between decision makers within the water, energy, and food domains; **2)** the impact of water officials' perception of future water challenges, **3)** their participation in stakeholder forums related to resource planning, and **4)** the impact of the scale at which they govern, **on that level of communication.**

2. Common pool resources and collective action

Stakeholders within various resource domains have authority to make decisions that impact the way in which resources are allocated, supplied, used, consumed, and reused (Daher et al., 2018). Resources are finite and often common to multiple groups. The term "Social Dilemma" refers to situations in which individuals make independent choices about inter-dependent situations (Hardin, 1971). Social dilemmas occur when "individuals in interdependent situations face choices in which the maximization of short-term self-interest yields outcomes leaving all participants worse off than feasible alternatives" (Ostrom, 1998). According to Collective Action Problem, when people act independently of each other, this often results in a worse outcome than if they coordinate their actions. Individuals tend to maximize their own utility, which results in everyone, including the individual, becoming worse off when compared to a coordinated action (Feiock, 2013). The theory of collective action, first published by Mancur Olson, argues that any group of individuals attempting to provide a public good has difficulty in efficiently doing so (Olson, 1965). The example below illustrates a set of possible actions by water, energy, and food stakeholders and potential implications of that action on the same resources (Fig. 1).

- **Water (W)** resources are finite, and under increasing pressure as a result of decisions made by a stakeholder, within or outside of, the water domain (including energy and food).
- **Energy (E)** is required for pumping, treating, and conveying water, and for food production. The choice of energy portfolio also impacts how much water, land, and financial resources are required.
- **Land (L)** is also limited, and is mainly shared between agriculture, energy, cities, recreational areas, forests and other public areas.
- **Financial (Fi)** resources are needed to subsidize, invest in, operate, and maintain different activities within water, energy, or food systems. These finances come from public or private sources; the focus here is on public budgets, which have limitations and must be prioritized in relation to various sets of competing expenditures.
- **Carbon emissions (C)** are produced or reduced depending on the decisions made by stakeholders within the three domains.

Decision makers within the public sector, with the authority to develop policies related to governing water, energy, and food resources, also have an important role to play in incentivizing different actions that could, potentially, result in reducing pressures on the resource systems (Portney et al., 2017a). An example of that could be through the implementation of subsidies, decisions to invest in different technologies, or changing trade policies, among others. In carrying out this role, decision makers must be aware of the extent to which the policies they develop might conflict with other stakeholders managing the same common resources. There is a need to provide a better understanding of the *potential* of translating solutions developed across resource domains into coordinated policies that are consistent with the degree of resource interconnectedness and the manner in which they affect the long-term sustainability of the resource systems. However, this must done with an understanding of the public policy process and its potential role in ensuring effective implementation of proposed policies and for a given environment with identified biophysical conditions, community attributes, rules, and action situations (Ostrom, 2011). The analysis that follows will build on common pool resource and collective action theory to explore ways that highlight the added value of communication and coordination among public policy officials within water, energy, and food domains.

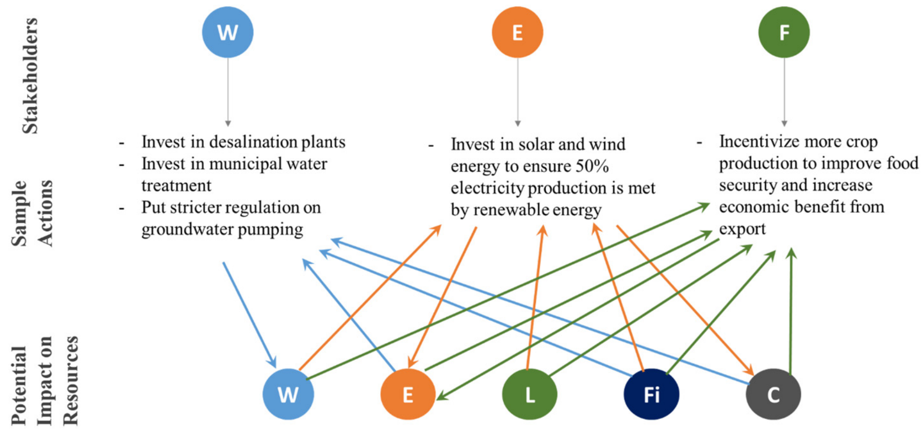

Fig. 1. Example demonstrating the implications of different actions made by water, energy, and food stakeholders on water (W), energy (E), land (L), finances (Fi), and carbon emissions (C) (Source: Authors).

3. San Antonio Region Case Study: resource trends

3.1. Overview of population, water, energy, and food production trends in the San Antonio Region

The San Antonio Region, for this study, includes the city plus those counties comprising Planning Region L (Fig. 2), as defined by the Texas Water Development Board (TWDB) in the Texas State Water Plan. San Antonio is one of the fastest growing cities in the U.S. (Forbes, 2017), and the Region has a rapidly developing energy industry, particularly hydraulic fracturing in the Eagle Ford Shale, and a burgeoning irrigated agriculture sector. The competition for water between the agricultural, energy, and municipal sectors can be exacerbated by climate change, which further threatens the availability and distribution of water resources.

The economy and environment of southeast Texas were transformed when the Eagle Ford shale play became a major producer of shale oil and gas, much of which production occurs above the Carrizo Aquifer. Texas accounts for nearly 23% of the total natural gas production of the United States (USEIA, 2017). While the Texas Railroad Commission, the regulatory agency for this production, does not require companies to report the quantity or sources of water used for production, based on voluntary reporting, the average amount of water used per fractured well in the Eagle Ford Shale is 13.7 million L (Kondash and Vengosh, 2015). As more wells are permitted, and as technology continues to advance toward greater lateral length per well, it is projected that more water will be consumed in energy production. Agriculture is most present in the Wintergarden area, west of Region L, and includes LaSalle, Frio, Dimmit, and Zavala counties. The Texas Water Development Board (2017) predicts that water used for irrigation will

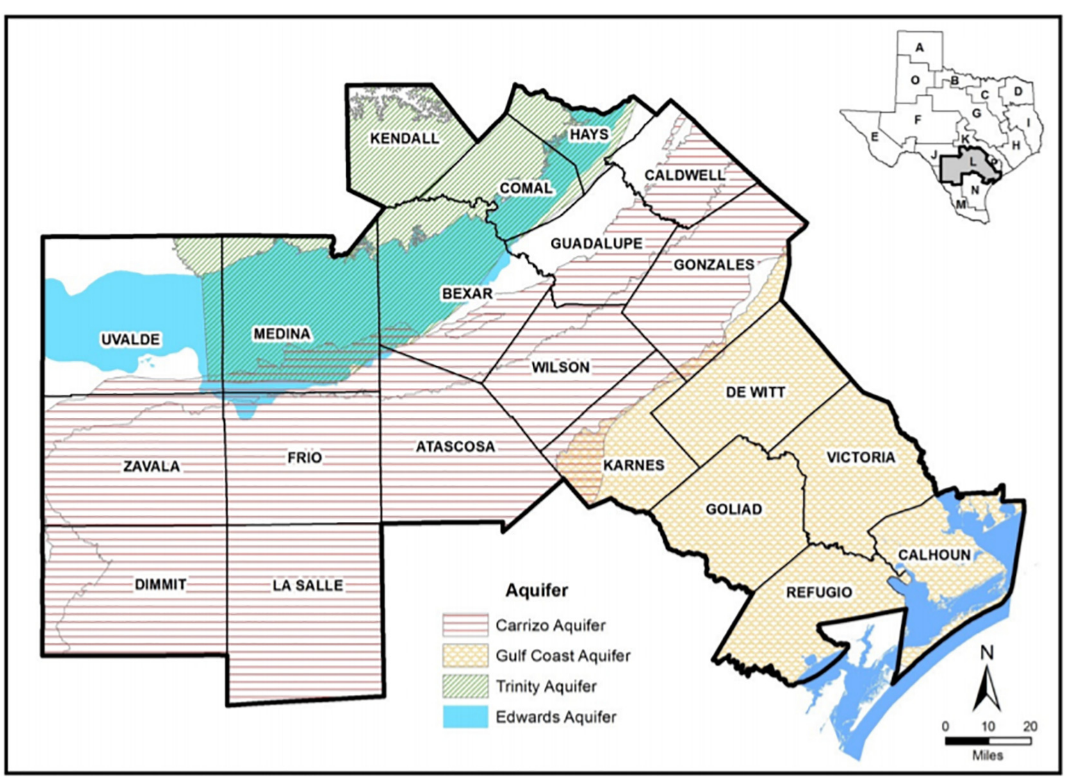

Fig. 2. Texas Water Planning Region L (TWDB, 2017).

increase by 47% between 2015 and 2020. However, water stress from irrigation is projected to decline by 8% in the period 2020–2070 as a result of the anticipated increase in irrigation technology efficiency. The Eagle Ford shale play, located under the vegetable growing Wintergarden area, means direct competition for water between the agriculture and energy sectors.

3.2. San Antonio region: a water-energy-food hotspot

The growth trends of the municipal, industrial, and agricultural sectors are expected to continue to exert increasing pressure on the limited water resources in the Edwards and Carrizo-Wilcox aquifers. As population grows and climate uncertainty continues, the water system faces increasing stresses. Water, energy and food are highly interconnected resource systems: planning future management pathways to allow their mutual development and limit competition that infringes a single sector makes it important to better understand and quantify those interlinkages. Fig. 3 shows the groundwater wells of the San Antonio region: the green, red, and blue dots respectively represent groundwater wells whose water is used for agriculture, oil & gas, or municipal purposes. The figure also illustrates the "nexus hotspot" (Mohtar and Daher, 2016) created by the competition between these sectors for the water. Addressing such hotspot requires holistic, yet localized, transdisciplinary, multi-stakeholder approaches. While plans for strategic water reserves exist, these are very costly (TWDB, 2017): solutions for better resource allocation requires that we build on our understanding of the interconnections of these resource systems, and strive to reducing projected resource gaps through cooperative, synergistic solutions that cost less and have a greater likelihood of implementation.

4. Hypotheses & rationale

This section introduces several hypotheses being tested in this paper and the rationale behind each.

Hypothesis 1. Individuals at water institutions in the San Antonio Region engage in higher levels of communication with individuals at other water institutions, than with individuals at food or energy institutions.

Rationale 1: Drawing from the theory of homophily (Katz et al., 2004; McPherson and Smith-Lovin, 1987; McPherson et al., 2001), Hypothesis 1 suggests that people at water institutions with public authority are more likely to communicate with people at other water institutions, compared to others from energy or food institutions, regarding addressing similar goals or challenges facing water resources in the San Antonio region. The rationale underlying this hypothesis is linked to the opportunity of people at those water institutions to communicate at water planning meetings at which representatives from different water institutions are present, or through different correspondence to coordinate and establish common regional goals, perhaps within the same water planning region, such as Region L. Such communication might be less present with other food and energy institutions. Testing Hypothesis 1 will provide an indication of the level of communication between water institutions, and the way in which it compares to those with energy and food institutions.

Hypothesis 2. The frequency of communication of people at water institutions with people from water, energy, and food institutions is improved as a result of their participation at stakeholder cooperative planning efforts.

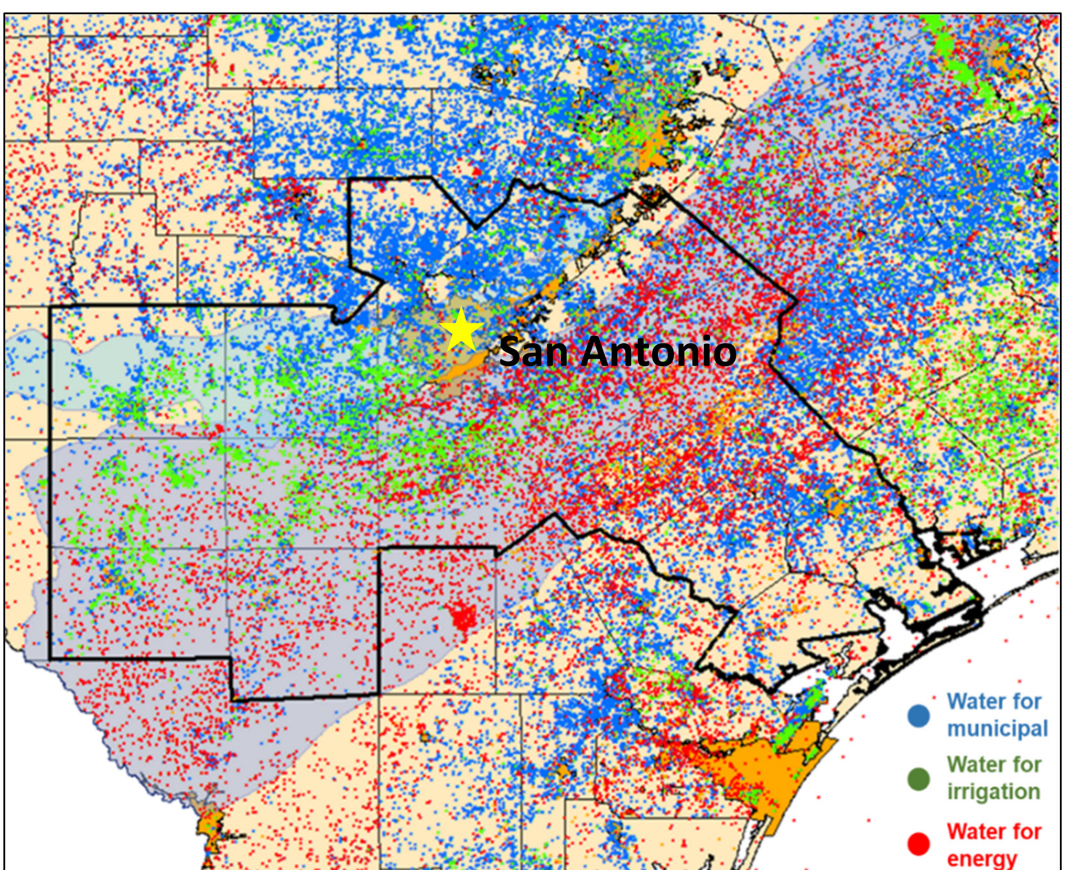

Fig. 3. Map showing water wells for agriculture, oil & gas, and municipal use in the San Antonio Region. Source: Figure developed by authors using Geographic Information System (GIS) and TWDB (2017) data.

Rationale 2: The rationale behind this hypothesis is that people who attend such meetings have a greater chance to meet people from other institutions in the water domain, and/or from the food and, or energy domains (Hamilton et al., 2018). The assumption is that people who are exposed to and trained on the importance of integrative planning while dealing with water issues are likely to see increased value in having such communication. This could result in them being more likely to reach out to those from other water, energy, and food institutions when attempting to address the challenges within the mandate of their own water centric institutions. Integrative planning is referred to as the process of coordination with other stakeholders regarding setting priorities and developing resource allocation plans for the region.

Hypothesis 3. People at water institutions who are less concerned about water future availability are less likely to communicate with people from different water, energy, and food institutions.

Rationale 3: According to Portney et al. (2017b), the potential to coordinate across domains could be viewed as a function of the perception of existing public policy and management officials regarding the urgency of the resource challenges and of resource interconnectedness. The rationale underlying this hypothesis is that people with a higher sense of urgency toward future water availability are more aware of the need to communicate and coordinate with other water institutions. They are more likely to be aware that solutions to water challenges will not come exclusively from within the water sector itself, but will come through coordination with others interconnected with the sector.

Hypothesis 4. People at water institutions having authority at a larger scale are more likely to communicate with people from other water, food and energy organizations.

Rationale 4: The underlying rationale for this hypothesis is that people working at institutions with a broader governance authority (geographical, institutional) are more likely to intersect with a greater number of other institutions, thereby increasing the likelihood of communications with these institutions (Mullin, 2009; Newig and Fritsch, 2009). The standard orthodoxy from administrative theory is that higher level organizations in the "hierarchy" should perform coordinating functions among lower level organizations. The practical implication is that if there is greater contact with these higher level organizations, in this case state agencies, then perhaps some level of coordination is actually taking place. If there is not, then the standard view of public administration isn't working and changes need to be prescribed (Kok and Veldkamp, 2011).

5. Methodology

5.1. Stakeholder definition, identification, classification, and investigating relationships

5.1.1. Stakeholder definition: who are the "Stakeholders"?

It is important to clearly define who is meant by "stakeholder". A wide body of literature proposes different ways for defining stakeholders. Some approaches are more pragmatic, attempting to classify stakeholders according to a set of attributes: those who affect an action, and those who are affected by an action (Freeman, 1984), or those whose involvement is a "pragmatic requirement" to achieving a successful outcome (Miles, 2015), or whoever causes a problem needs to be considered as a stakeholder and co-owner in the process of addressing that problem (Checkland, 1991). Others promote greater inclusiveness of all types of stakeholders, whether closely or remotely connected with the given issue (Bryson, 2004; Grimble and Wellard, 1997; Nutt and Backoff, 1992; Johnson and Scholes, 2002; Lebacqz, 1986; Lewis, 1991). In addition to these methods of identifying stakeholders, expert opinion is also recognized as important tool for achieving the same goal (Kumar et al., 2016; Schiller et al., 2013). In this study, a stakeholder is defined as a person at an entity, organization, or institution, who makes decisions that impact the water, energy, and food sectors of the San Antonio Region; stakeholders may be employed at units working centrally on related water, energy, or food issues. The survey was distributed to those stakeholders who are public officials with legal authority, and who work at water organizations in the San Antonio Region. The survey sent to the stakeholders gave them the chance to self-identify (Crane and Ruebottom, 2010) as "water stakeholders" through asking the following question: "Do you currently work for an agency or department that deals with water issues in the San Antonio Region?"

5.1.2. Stakeholder identification and classification

A list of water institutions with legal authority and other major energy and food stakeholders in the San Antonio Region has been identified extant research (Portney et al., 2017a). This document formed a base from which to identify key stakeholders. Additional literature and web searches were used to identify different organizations and key personnel actively working in areas related to water, energy, and food. In the end, the survey was distributed to 257 identified people who work at water organizations in Region L. Stakeholders in this study were classified by the domain in which they were employed at the time; namely water, energy, food, and "cross cutting". The category of "cross-cutting" includes offices with mandates that likely extend beyond water management, such as state representatives, senators, the Railroad Commission of Texas, and others. The identified sample cosists of 57 water, 14 energy, 10 food, and 12 cross-cutting organizations in the San Antonio Region from Portney et al. (2017a), in addition to research on the scope of the different organizations to identify their category. The list of water, energy, and cross-cutting stakeholder organizations is presented in Appendix I.

5.1.3. Stakeholder relationships – social network analysis

In this study, Social Network Analysis (SNA) is used to provide an understanding of the relations between stakeholders (Scott, 2000; Wasserman and Faust, 1994). Rogers (1986) characterizes a communication network as consisting of "interconnected individuals who are linked by patterned communication flows". The strength of the tie between different stakeholders, according to Prell et al. (2009), is representative of the influence one has upon another in comparison to those who share weaker ties. It also can be an indication of similar views, effective communication of complex information and tasks, and a higher likelihood of trust between stakeholders (Coleman, 1994; Crona and Bodin, 2006; Cross and Parker, 2010; Friedkin, 1998; Kadushin, 1966; Newman and Dale, 2007; Wellman and Frank, 2001).

In the context of resource management, Crona and Bodin (2006) refer to stakeholders with strong ties as those more likely to influence one another and for whom there is a greater likelihood of mutual learning and resource sharing. On the other hand, weaker ties[1] are indicative of less frequent communication, and might imply a lower likelihood of resource sharing or influencing one another's decisions. In Prell et al. (2009), the tightness of the links between a network of stakeholders was identified with the question: "Do you communicate with anyone from [stakeholder category named here] on upland management issues in the Peak District National Park?" If the respondent answered "yes," the follow-up "How often do you communicate with this person? (Daily, Weekly, Monthly, 1–2 times = year)" was asked. In this study, the level of communication between water, energy, and food organizations in the San Antonio Region is measured through a survey which included a roster of other organizations involved with resource management. The results from the network question were organized into a communication network matrix which is used to test hypotheses listed below.

[1] Here, weaker ties are characterized by infrequent communication. We are not referring to a bridging tie as elaborated in Granovetter (1973).

5.2. The survey and questionnaire

Of the 257 surveys distributed, 28% of recipients work at Groundwater Conservation Districts, 16% work at River Authorities, 9% work at state agencies, 10.4% work at municipal service providers and 36.6% work at other water related organization. The questionnaire displayed a web address that the respondents could use to answer the questions on a computer or handheld device. A total of 101 responses were received by mail or online, yielding a response rate of 39.3%. Table 1 identifies the specific questions used to test these hypotheses. The detailed list of questions is available in Appendix II.

The 101 respondents indicated the frequency of their communication with individuals from other water (W), energy (E), food (F), or "cross-cutting" (C) institutions in the San Antonio Region (Fig. 4).

Table 1
Methodology summary.

	Methodology summary
Population	Public officials with legal authority, who work at water organizations in the San Antonio Region.
Methods for Stakeholder Identification and classification	- Portney et al. (2017a) list of water institutions with legal authority in San Antonio Regions - Scoping – Literature and web searches - Self-identification: ***Q1.*** *Do you currently work for an agency or department that deals with water issues in the San Antonio Region?*
Methods for Stakeholder Relations	Social Network Analysis
Hypothesis 1: *Individuals at water institutions in the San Antonio Region engage in higher levels of communication with individuals at other water institutions, than with individuals at food or energy institutions.*	***Q9, 10, 11, 15.*** *Over the last year, as part of your job,* ***how often have you communicated*** *with any of these organizations, or decision makers from these organizations,* ***about water issues affecting the San Antonio Region?***
Hypothesis 2: *The frequency of communication of people at water institutions with others from water, energy, and food institutions is improved as a result of their participation at stakeholder cooperative planning efforts in San Antonio.*	***Q12.*** *Over the last year, as part of your job, have you* ***personally participated in any kind of stakeholder forum*** *or* ***cooperative planning*** *effort with organizations or agencies other than your own?* with Q 9, 10, 11, and 15
Hypothesis 3: *People at water institutions who are less concerned about water future availability are less likely to communicate with others from different water, energy, and food institutions in San Antonio.*	***Q13.*** *Overall, how concerned are you about* ***future water availability*** *in the San Antonio Region?* with Q 9, 10, 11, and 15
Hypothesis 4: *People at water institutions having authority at a larger scale are more likely to communicate with people from other water, food and energy organizations.*	***Q2.*** *What* ***agency or department*** *do you work for?* with Q 9, 10, 11, and 15
Methods for Statistical Analysis to examine significance of results	Hypothesis 1: t-tests; Hypothesis 2, Hypothesis 3, Hypothesis 4: Bivariate regression analysis (OLS Regression)
Outcomes	- Identify level of communication between governmental water stakeholders and other water, energy, food, and "crosscutting" C stakeholders in San Antonio - Identify potential correlation between attending stakeholder engagement meetings and level of communication - Identify potential correlation between perception toward the urgency of water scarcity challenges in the region and the level of communication with other stakeholders - Identify potential correlation between the scale at which stakeholders operate and the level of communication

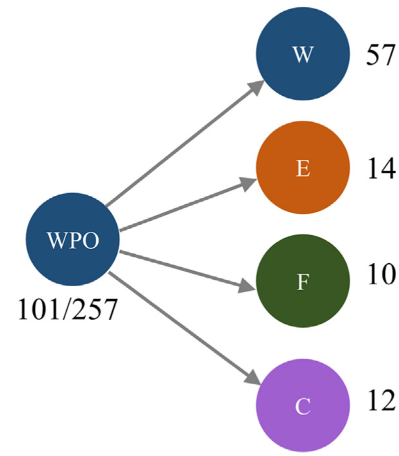

Fig. 4. The distribution of the number of water, energy, food, and cross-cutting stakeholders.

Respondents indicated the frequencies with which they communicated with each of the institutions:

4 = Once a week or more; **3** = Monthly; **2** = Once every 3 months; 1 = Once a year; **0** = Not at all.

Throughout this discussion, the responses to the questions addressing frequency of communication are shown as percentages indicating: "no communication" (0's) or "some communication" (sum of 1, 2, 3, and 4's). More details on these questions in the conducted surveys are elaborated in the following sections. The operationalization of "low levels of communication" generally consists of contacting behavior "once a year" or "not at all."

Throughout the analysis, the level of communication indicated by a given respondent in the questionnaire is represented by the **average** of the responses to their frequency of communication with the different institutions. A larger number of 0's (meaning, no communication at all) indicates a lower level of communication with other institutions. The average value representing that level of communication can be between 0 and 4. The closer that number is to 0, the less communication that respondent has with others from different institutions. Conversely, the higher that average, the greater the communication.

Other measures are included as predictor variables. The first, forum attendance, asked about their participation in stakeholder forums or cooperative planning efforts. Respondents were asked if they attended a forum or cooperative planning effort and were given the answer options "**yes**", "**no**", or "**not sure**". We also asked about the stakeholder's level of concern about future water availability. When asked about their level of concern about future water availability in San Antonio, respondents were asked to rate their level of concern about future water availability and give a 0 to 10 point range as answer options, where 0 is not concerned at all, and 10 is extremely concerned.

6. Results and analysis

Hypothesis 1 aims at obtaining two main pieces of information about the communication levels of the different stakeholders: 1) the overall level of communication existing between the 101 surveyed water officials and other water, energy, and food institutions in San Antonio, and 2) the likelihood of higher levels of communication between water officials among themselves, than with those from energy or food domains. Throughout the remainder of the analysis, communications by the 101 surveyed people from water institutions with the other water institutions are referred to as WW. WE, WF, WC refer to the communication of those water officials (W), with other identified energy (E), food (F), and cross-cutting institutions (C), respectively.

Using social network analysis techniques, we create a visual representation of the information described above. Fig. 5 illustrates the

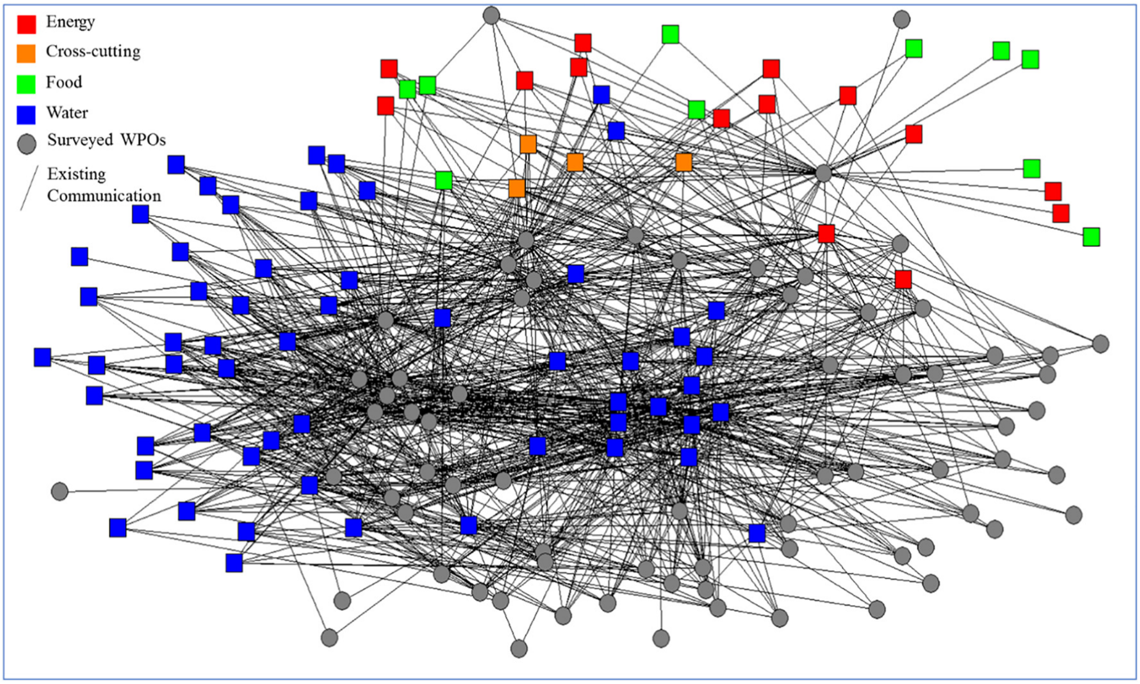

Fig. 5. Network map depicting any level of communication between water, energy, food, and crosscutting organizations in the San Antonio Region.

communication network between the 4 categories of organizations. The tie represents any level of communication, or if the organizations communicated at least once per year. The grey circles are those who received and responded to the aforementioned survey of San Antonio water organizations. The blue squares represent water organizations, the red squares are energy organizations, the green squares are food organizations and the orange squares are crosscutting institutions.

It is fairly clear to see that the majority of the ties in the figure are to water organizations. The cluster of water organizations in the center portion of the map as well as the numerous ties to the water organizations on the left of the figure demonstrate that there is more connectivity to those groupings of water organizations. The presence of connectivity to water organizations is also highlighted by the sparseness of connections to other types of organizations. Again, it is notable from the figure that, on average, there are fewer connections to both energy and food organizations. A number of those organizations are pendants (only one connection) or have a small number of ties to other water organizations.

Fig. 6 illustrates weekly communication between survey respondents and other organizations. This figure provides good visual evidence of what is being examined in Hypothesis 1. As frequency of communication increases, many of the food, energy, and crosscutting organizations drop from the network because of the very infrequent communication. In fact, only one energy organization (CPS Energy, the San Antonio city-owned utility) remains in the weekly communication network.

The results about communication, displayed in Table 2, show low levels of communication are reported between water officials and other stakeholders in San Antonio Region. Only 4% of the responses indicate some communication with food institutions, 7% with energy institutions, and 17% with cross-cutting institutions. The highest level of communication was reported with other water institutions: 20% of responses indicate some communication. Fig. 7 shows a breakdown of the different levels of communications reported.

Even among those who reported "some level of communication", most indicated a low frequency (once a year). Only 8% communicated with other water institutions yearly, 7% every 3 months, 4% monthly,

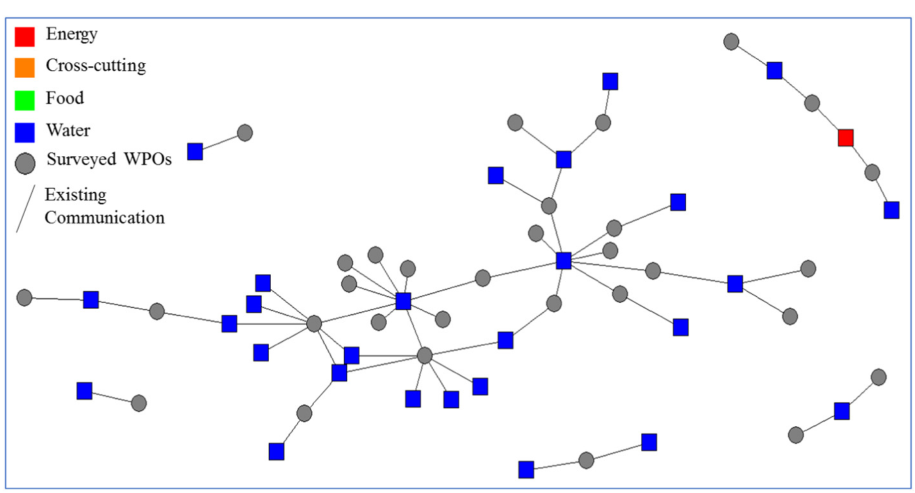

Fig. 6. Network map depicting weekly communication between water, energy, food, and crosscutting organizations in the San Antonio Region.

Table 2
Communication between the 101 officials at water institutions with other water, energy, and food institutions.

	WW	WE	WF	WC
No communication	80.3%	93.2%	95.8%	83.2%
Some communication	19.7%	6.8%	4.2%	16.8%

and only 1% communicated at a frequency of once a week or more often. These percentages are lower for communication with people from energy and food institutions. A similar higher level of communication is reported between WW and WC (19.7% and 16.8%), compared to those with WE and WF (6.8% and 4.2% respectively).

While the percentages displayed in Table 2 provide basic information about level communication, they do not suggest whether communication within one sector is statistically different from another. To address this, we examine the results from a paired sample, or dependent, *t*-test. The paired sample t-test is used to determine whether the means of two variables are not independent from each other. Table 3 summarizes the *p*-values from the respective *t*-tests.

As seen in Table 3, we find mixed support for Hypothesis 1. Specifically, we find that water managers have more communication with other water managers than individuals from energy institutions. This result is statistically significant at the $p < 0.001$ level. The results for WF and WC do not support Hypothesis 1, meaning that the levels of communication between WF and WC are not statistically different from WW.

Hypothesis 2 investigates the relation between participation in stakeholder forums and cooperative planning efforts, and the effect of such participation on frequency of communication (Table 4). The results for whether or not an individual attended a forum are split nearly identically between "yes" and "no," with **50.6% attending a forum and 46.4%** not attending a forum. Out of the 46 people who answered "yes," **77%** of their possible interactions with different water, energy, and food stakeholders, showed no communication at all. This number was higher among those who indicated not participating in any stakeholder forum or cooperative planning effort as part of their job (total 36 who answered "no").

Table 4
Percentages of frequency of communication between water officials who have or have not participated in integrative planning workshops, with all stakeholders from San Antonio.

	No participation	Participation
No communication	91%	77%
Some communication	9%	23%

Table 5
Results from bivariate regression predicting the influence of stakeholder forum participation on communication.

	Model 1: WW	Model 2: WE	Model 3: WF	Model 4: WC
Participation in stakeholder Forum	0.283**	0.050	−0.392	−0.061
	(0.089)	(0.043)	(0.450)	(0.364)
Constant	0.270***	0.082**	0.830*	0.821**
	(0.063)	(0.030)	(0.320)	(0.259)
R-squared	0.099	0.015	0.008	0.000

$N = 95$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

To investigate whether this change is statistically significant, we examine the relationship between forum participation and communication in a bivariate regression. We estimate and ordinary least squares (OLS) regression where the dependent variable measures levels of communication between water, energy, food, and crosscutting. The bivariate regression results are presented in Table 5.

These results offer partial support for Hypothesis 2. We find that attending a stakeholder forum is positively related to the levels of communication between water organizations; however there is no relationship with attending a forum and communication between water and any other groups. Based on these results, it is probable that the forums attended were directed at water managers. If this is the case then forums directed at a broader audience may influence breaking down institutional silos and promote communication across areas of specialty. Further research on this topic is important and warranted.

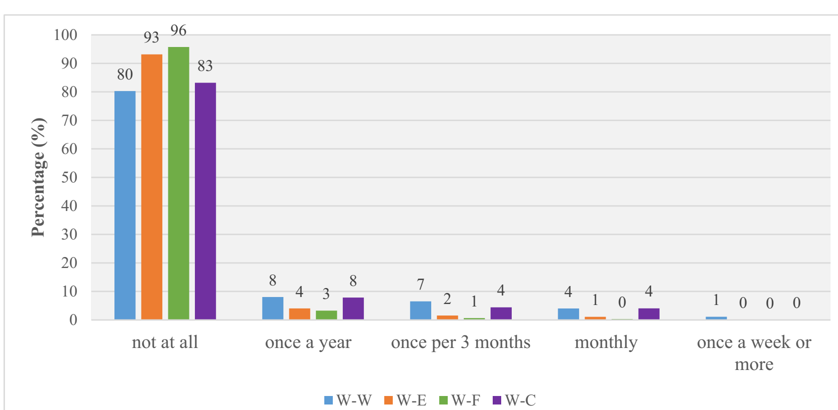

Fig. 7. Breakdown frequency of communication with other water, energy, food and cross-cutting institutions in San Antonio.

Table 3
P-value results for t-test for WW *vs* WF, WW *vs* WE, WW *vs* WC averages.

Comparisons	Hypothesis	P-value (*t*-test)	Decision
WW vs WF	Hypothesis 1: $\mu(\text{ww}) > \mu(\text{wf})$	$p < 0.967$	No Support for Hypothesis 1
WW vs WE	Hypothesis 1: $\mu(\text{ww}) > \mu(\text{we})$	$p < 0.001$	Support for Hypothesis 1
WW vs WC	Hypothesis 1: $\mu(\text{ww}) > \mu(\text{wc})$	$p < 0.998$	No support for Hypothesis 1

Table 6
Results from bivariate regression predicting the influence of concern about water availability on communication.

	Model 1: WW	Model 2: WE	Model 3: WF	Model 4: WC
Concern for future water Availability	−0.014	−0.002	0.010	−0.013
	(0.019)	(0.008)	(0.064)	(0.060)
Constant	0.501***	0.125***	0.307	0.699
	(0.137)	(0.061)	(0.470)	(0.442)
R-squared	0.007	0.001	0.000	0.001

$N = 88$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

As stated above, Hypothesis 3 examines levels of communication in relation to concern about future water availability. Specifically, the question asked, "…on a scale of 0–10, with 0 being not concerned at all, 10 being extremely concerned, how concerned are you about the water availability in the future." We estimate an OLS regression for this variable as well, similar to Hypothesis 2. Results are shown in Table 6.

As with Hypothesis 2, we looked for a relation between levels of concern about water availability and the frequency of communication between water-water, water-energy, water-food, water-crosscutting. As our results do not show support for the hypothesis, we learn that there is insufficient evidence to conclude that people at water institutions in San Antonio Region have a higher frequency of communication with other water, energy, and food stakeholders, as a result of being more concerned about future water availability.

Hypothesis 4 examines the influence of "scale" or region of governance on the level of communication among stakeholder groups. We measure scale by geographic governance responsibilities or area of jurisdiction. We divide organizations into 2 categories which seek to capture horizontal and vertical communication. There are different levels of governance being addressed by this hypothesis. Specifically, this hypothesis captures horizontal communication among regional institutions such as cities, counties, groundwater conservation districts, river authorities, and utilities as well as vertical communication between these institutions and state governing bodies (including Texas Water Development Board, Texas Commission on Environmental Quality, and Texas Water Resources Institute). Certainly, there may be other classifications of scale that researchers could define and our measurement provides a baseline level of communication.

The results for Hypothesis 4 are presented in Table 7. Again, we estimate OLS regressions to determine the impact of "scale" on levels of communication. The results in suggest that geographic scale may have little influence on levels of communication among the stakeholder groups. Further investigation into different treatments of scale categories yielded similarly insignificant results.

7. Discussion

In this paper, we investigated the level of communication that exists among different water institutions, and between water, energy, food, and cross-cutting institutions in San Antonio. We also investigated the potential role concern about future water challenges, participation in engagement activities, and the scale of organization, play in improving those levels of communication. Results from the statistical analysis offer several conclusion and offer useful insights into further examination of stakeholder an polycentric governance studies (Berardo and Lubell, 2016; Mewhirter et al., 2018).

7.1. On the overall level of communication

We conclude that the overall level of communication of water institutions with other water, energy, food, and crosscutting institutions is low. However, we also notice and conclude that people at water institutions in San Antonio have a higher frequency of communication with people at other water institutions, than with people at energy and food institutions. Low communication could be attributed to institutional or financial constraints, as well as time limitations. Without specific agreements or contractual obligations toward cooperation or coordination with the different institutions in place, water officials might find themselves unable to take steps toward improving levels of communication with other institutions. The various responsibilities water officials at different institutions have as part of their mandate, may leave little time to effectively engage with others through cooperative planning workshops, for example. This low level of communication might also be a result of the officials' perception toward the limited role or value of increased communication in addressing the resource challenges faced, lack of common goals and collaborative projects, a lack of incentives to collaborate, and a lack of institutional mechanisms to cooperate (Rosen et al., 2018). Even though our study results showed higher levels communication between people at different water organizations, compared to their communication with people at food and cross-cutting organizations, that difference was not statistically significant. This could mean that people at water organizations communicate more with people at food and cross cutting organizations, compared to energy. Additional effort needs to focus on addressing the barriers resulting in low overall levels of communications, particularly with energy.

7.2. On the role of stakeholder forums in increasing communication

We conclude that the frequency of communication among water officials who attended stakeholder forums is higher than that of those who have never attended such a forum with other water, energy, food or crosscutting institutions in San Antonio. To clarify, representatives from water institutions who attend forums have a higher level of communication with other water institutions than those who do not attend the forum. We also find that there is insufficient evidence to suggest that attending stakeholder engagement activities improves the frequency of communication by water stakeholders with stakeholders at food, energy, and crosscutting organizations. One reason behind the increased communication among officials from water institutions but not others, might simply be the fact that such meetings are largely attended by people from water-centric institutions, or the forums are oriented toward water managers. Even though such forums promote integrative planning, they largely remain to be done within the same "silo", with weaker agriculture or energy presence. Therefore, assuring food/agriculture and energy are represented at such meetings could play a role in improving current levels of communication, potentially contributing to an improved environment for cross-sectoral cooperation.

7.3. On the role of concern regarding future water availability in the region

We conclude that there is insufficient evidence to allow us to conclude that people at water institutions in the San Antonio Region would have a higher frequency of communication with other water, energy, and food stakeholders as a result of being more concerned about

Table 7
Results from bivariate regression predicting the influence of scale on communication.*

	Model 1: WW	Model 2: WE	Model 3: WF	Model 4: WC
Scale	−0.059	0.081	1.311	1.237
	(0.163)	(0.071)	(0.890)	(0.769)
Constant	0.411***	0.094***	0.745**	0.920***
	(0.049)	(0.021)	(0.266)	(0.229)
R-squared	0.001	0.013	0.021	0.025

$N = 101$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

future water availability. One potential factor contributing to this result is not perceiving the resource systems and their challenges to be as interconnected as they are. Viewing these resource systems as siloed could potentially cause officials to not realize the need for greater communication across resource domains, regardless of their concern toward future water availability. Raising awareness and building institutional capacity toward the importance of cross-institutional and cross-sectoral cooperation and coordination on resource allocation challenges could play a positive role in improving those levels of communication.

7.4. On the differing scales of organizations

From the data presented in this study, we conclude that the frequency of communication among organizations charged with differing governance scales does not vary significantly. Future research could delve deeper into analyzing specific strategies and tasks in natural resource governance among these organizations and develop theory about levels of communication. Given the conflicting ideal or optimal level of communication, it is unclear what research might expect to uncover regarding communication among these categories of organizations. Future research in the areas of nexus governance may focus on this area of research.

7.5. Limitations and future research

This first hypothesis gave us an overall indication of the low level of communication among people from different institutions in San Antonio, and the relatively higher level of communication among water institutions, compared to that with other food, energy, and cross-cutting institutions. In reality, these 101 water officials come from different types of organizations with differing scopes and scales of authority. Further, this study does not identify the quality of communication being surveyed. This study only scratches the surface of the research possibilities in the communication between organizations across interconnected resource domains. It is important to note that the results presented here should be taken as preliminary to a more thorough and robust analysis which would be worthwhile. A comparative study, done at a region with similar resource stresses, could investigate trends in cross-sectoral levels of communication, and reasons behind similar or different results, compared to those reported by this case study in San Antonio. Further research also needs to be done on the type and quality of communication that might result in cooperation or coordination between institutions. Also capturing the perspective of energy and food officials from San Antonio, would increase the sample size and type, and could yield new insights to better describe the network and levels of communication.

8. Conclusions

Given the tight interconnectedness between resource challenges facing the San Antonio Region, a certain level of communication, coordination, and cooperation is needed between officials across these resource domains. Collective action dilemmas and issues must be confronted by polycentric, or network governance systems (Feiock, 2013). The social relations and dense connectivity among stakeholders can reduce transaction costs that may impede collective and effective governance of common pool resources. If a siloed mentality and governance system progresses, the region may be subject to competing resource allocation strategies and policies that result in unintended consequences. An environment that incentivizes increased levels of communication, coordination, and cooperation is needed. This could be partly be achieved through investing in cross-institutional mechanisms which promote higher levels of cooperation, and that work toward improving the compatibility of differing planning horizons, and common goal setting activities across sectors. This could also be facilitated through the organization of integrative planning workshops, forums, and moderated dialogues which bring officials representing institutions from different resource domains to discuss future resource strategies. Such dialogue and exposure to different viewpoints would facilitate better understanding the reality of the resource challenges facing the region, and of the innovative cross-disciplinary and cross-institutional solutions necessary to effectively allocate and distribute resources to society.

Acknowledgements

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Appendix I. List of water, energy, food and cross-cutting stakeholders

Water stakeholders (57)

Edwards Aquifer Authority	Bandera County River Authority & Groundwater Conservation District
Any Irrigation District	Barton Springs/Edwards Aquifer & Groundwater Conservation District
A TCEQ Office in Austin	Blanco-Pedernales Groundwater Conservation District
Any TCEQ Freshwater Supply District	Comal Trinity Groundwater Conservation District
Texas Water Development Board in Austin	Cow Creek Groundwater Conservation District
Texas Water Development Board Region K Office	Evergreen Groundwater Conservation District
Texas Water Development Board Region L Office	Gonzales County Underground Water Conservation District
San Antonio Water System (SAWS)	Hays Trinity Groundwater Conservation District
Live Oak Municipal Utility	Headwaters Groundwater Conservation District
Canyon Regional Water Authority	Kinney County Groundwater Conservation District
Any Storm water Management or Control District	McMullen Groundwater Conservation District
Texas Water Resources Institute in College Station	Medina County Groundwater Conservation District
Texas State Public Utility Commission	Pecan Valley Groundwater Conservation District
Texas General Land Office	Plum Creek Groundwater Conservation District
Texas State Soil and Water Conservation Board, Region 2 Office	Post Oak Savannah Groundwater Conservation District
South Texas Watermaster	Uvalde County Underground Water Conservation District
Edwards Aquifer Association	Alamo Soil & Water Conservation District #330
Texas Alliance of Groundwater Districts	Comal-Guadalupe Soil & Water Conservation District #306
Any Drainage District	Wilson County Soil & Water Conservation District #301
Bexar County Heritage & Parks Department	Trinity River Authority
Brazos River Authority	Trinity River Vision Authority
Central Colorado River Authority	San Antonio River Authority
Guadalupe-Blanco River Authority	Upper Colorado River Authority
Lavaca-Navidad River Authority	Upper Guadalupe River Authority
Lower Colorado River Authority	Groundwater Management Area #9 Office

(*continued*)

Edwards Aquifer Authority	Bandera County River Authority & Groundwater Conservation District
Nueces River Authority	Groundwater Management Area #10 Office
Hill Country Priority Area Office	Ozarka Spring Water Company
Trinity Aquifer Priority Area Office	Any Professional Hydrologist or Geologist

Energy stakeholders

ExxonMobil	EOG Resources
Shell Oil	Texas Comptroller, Office of Energy Conservation
Valero	Texas Public Utility Commission
City Public Service (CPS) Energy	GE Power and Water
Duke Energy	Halliburton
Marathon Oil	Association for Electric Companies of Texas
Pioneer Natural Resources/Reliance Joint Venture	Blue Wing Solar, Inc.

Food stakeholders

San Antonio Food Policy Council	Sysco Central Texas, Inc.
San Antonio Food Bank	Labatt Food Services
H.E.B.	Del Norte Foods, Inc.
Kroger	Cargill Food Distributors
NatureSweet Company	Texas Farm Bureau

Cross-cutting stakeholders

Office of Texas House Speaker Joe Strauss
Joint Base San Antonio
Office of State Representative Lyle Larson
Office of Texas State Senator Carlos Uresti
San Antonio City Office of Sustainability
Texas Railroad Commission
San Antonio Mayor's Office
San Antonio City Manager's Office
Bexar County Commissioners or County Manager
San Antonio Metro Health District
San Antonio Parks & Recreation Department
San Antonio Greenspace Alliance

Appendix II. Questionnaire

Water Management in the San Antonio Region

Q9. Over the last year, as part of your job, how often have you communicated with any of these organizations, or decision makers from these organizations, about water issues affecting the San Antonio Region?

	Once a week or more (1)	Monthly (2)	Once every 3 months (3)	Once a year (4)	Not at all (5)	This is my own organization (6)
a. Edwards Aquifer Authority	○	○	○	○	○	○
b. Any Irrigation District	○	○	○	○	○	○
c. A TCEQ Office in Austin	○	○	○	○	○	○
d. Any TCEQ Freshwater Supply District	○	○	○	○	○	○
e. Texas Water Development Board in Austin	○	○	○	○	○	○
f. Texas Water Development Board Region K Office	○	○	○	○	○	○
g. Texas Water Development Board Region L Office	○	○	○	○	○	○
h. San Antonio Water System (SAWS)	○	○	○	○	○	○
i. Live Oak Municipal Utility	○	○	○	○	○	○
j. Canyon Regional Water Authority	○	○	○	○	○	○
k. Any Stormwater Management or Control District	○	○	○	○	○	○
l. Texas Water Resources Institute in College Station	○	○	○	○	○	○
m. Texas State Public Utility Commission	○	○	○	○	○	○

(*continued on next page*)

(*continued*)

	Once a week or more (1)	Monthly (2)	Once every 3 months (3)	Once a year (4)	Not at all (5)	This is my own organization (6)
n. Texas General Land Office	◯	◯	◯	◯	◯	◯
o. Texas State Soil and Water Conservation Board, Region 2 Office	◯	◯	◯	◯	◯	◯
p. South Texas Watermaster	◯	◯	◯	◯	◯	◯
q. Edwards Aquifer Association	◯	◯	◯	◯	◯	◯
r. Texas Alliance of Groundwater Districts	◯	◯	◯	◯	◯	◯
s. Any Drainage District	◯	◯	◯	◯	◯	◯
t. Bexar County Heritage & Parks Department	◯	◯	◯	◯	◯	◯

Q10. Over the last year, as part of your job, how often have you communicated with any of these specific organizations, or decision makers from these organizations, about water issues affecting the San Antonio Region?

	Once a week or more (1)	Monthly (2)	Once every 3 months (3)	Once a year (4)	Not at all (5)	This is my own organization (6)
a. Bandera County River Authority & Groundwater Conservation District	◯	◯	◯	◯	◯	◯
b. Barton Springs/Edwards Aquifer & Groundwater Conservation District	◯	◯	◯	◯	◯	◯
c. Blanco-Pedernales Groundwater Conservation District	◯	◯	◯	◯	◯	◯
d. Comal Trinity Groundwater Conservation District	◯	◯	◯	◯	◯	◯
e. Cow Creek Groundwater Conservation District	◯	◯	◯	◯	◯	◯
f. Evergreen Groundwater Conservation District	◯	◯	◯	◯	◯	◯
g. Gonzales County Underground Water Conservation District	◯	◯	◯	◯	◯	◯
h. Hays Trinity Groundwater Conservation District	◯	◯	◯	◯	◯	◯
i. Headwaters Groundwater Conservation District	◯	◯	◯	◯	◯	◯
j. Kinney County Groundwater Conservation District	◯	◯	◯	◯	◯	◯
k. McMullen Groundwater Conservation District	◯	◯	◯	◯	◯	◯
l. Medina County Groundwater Conservation District	◯	◯	◯	◯	◯	◯
m. Pecan Valley Groundwater Conservation District	◯	◯	◯	◯	◯	◯
n. Plum Creek Groundwater Conservation District	◯	◯	◯	◯	◯	◯
o. Post Oak Savannah Groundwater Conservation District	◯	◯	◯	◯	◯	◯
p. Uvalde County Underground Water Conservation District	◯	◯	◯	◯	◯	◯
q. Alamo Soil & Water Conservation District #330	◯	◯	◯	◯	◯	◯
r. Comal-Guadalupe Soil & Water Conservation District #306	◯	◯	◯	◯	◯	◯
s. Wilson County Soil & Water Conservation District #301	◯	◯	◯	◯	◯	◯

Q11. Over the last year, as part of your job, how often have you communicated with any of these specific organizations, or decision makers from these organizations, about water issues affecting the San Antonio Region?

	Once a week or more (1)	Monthly (2)	Once every 3 months (3)	Once a year (4)	Not at all (5)	This is my own organization (6)
a. Brazos River Authority	◯	◯	◯	◯	◯	◯
b. Central Colorado River Authority	◯	◯	◯	◯	◯	◯
c. Guadalupe-Blanco River Authority	◯	◯	◯	◯	◯	◯
d. Lavaca-Navidad River Authority	◯	◯	◯	◯	◯	◯
e. Lower Colorado River Authority	◯	◯	◯	◯	◯	◯
f. Nueces River Authority	◯	◯	◯	◯	◯	◯
g. Trinity River Authority	◯	◯	◯	◯	◯	◯
h. Trinity River Vision Authority	◯	◯	◯	◯	◯	◯
i. San Antonio River Authority	◯	◯	◯	◯	◯	◯
j. Upper Colorado River Authority	◯	◯	◯	◯	◯	◯
k. Upper Guadalupe River Authority	◯	◯	◯	◯	◯	◯
l. Groundwater Management Area #9 Office	◯	◯	◯	◯	◯	◯
m. Groundwater Management Area #10 Office	◯	◯	◯	◯	◯	◯
n. Hill Country Priority Area Office	◯	◯	◯	◯	◯	◯
o. Trinity Aquifer Priority Area Office	◯	◯	◯	◯	◯	◯
p. Ozarka Spring Water Company	◯	◯	◯	◯	◯	◯
q. ExxonMobil	◯	◯	◯	◯	◯	◯
r. Shell Oil	◯	◯	◯	◯	◯	◯
s. Office of Texas House Speaker Joe Strauss	◯	◯	◯	◯	◯	◯
t. Joint Base San Antonio	◯	◯	◯	◯	◯	◯
u. Valero	◯	◯	◯	◯	◯	◯
v. Any Professional Hydrologist or Geologist	◯	◯	◯	◯	◯	◯
w. Office of State Representative Lyle Larson	◯	◯	◯	◯	◯	◯
x. Office of Texas State Senator Carlos Uresti	◯	◯	◯	◯	◯	◯

Q12. Over the last year, as part of your job, have you personally participated in any kind of stakeholder forum or cooperative planning effort with organizations or agencies other than your own?

○	Yes	○	No	○	Not sure

Q13. Overall, how concerned are you about future water availability in the San Antonio Region?

0 Not Concerned at all	1	2	3	4	5	6	7	8	9	10 extremely concerned
○	○	○	○	○	○	○	○	○	○	○

Q15. Over the last year, as part of your job, about how often have you communicated with organizations, or decision makers from these organizations, about any issues affecting the San Antonio Region?

	Once a week or more (1)	Monthly (2)	Once every 3 months (3)	Once a year(4)	Not at all (5)
a. City Public Service (CPS) Energy	○	○	○	○	○
b. Duke Energy	○	○	○	○	○
c. Marathon Oil	○	○	○	○	○
d. Pioneer Natural Resources/Reliance Joint Venture	○	○	○	○	○
e. EOG Resources	○	○	○	○	○
f. San Antonio City Office of Sustainability	○	○	○	○	○
g. Texas Railroad Commission	○	○	○	○	○
h. Texas Comptroller, Office of Energy Conservation	○	○	○	○	○
i. Texas Public Utility Commission	○	○	○	○	○
j. Texas Farm Bureau	○	○	○	○	○
k. San Antonio Mayor's Office	○	○	○	○	○
l. San Antonio City Manager's Office	○	○	○	○	○
m. Bexar County Commissioners or County Manager	○	○	○	○	○
n. San Antonio Metro Health District	○	○	○	○	○
o. San Antonio Parks & Recreation Department	○	○	○	○	○
p. San Antonio Food Policy Council	○	○	○	○	○
q. San Antonio Food Bank	○	○	○	○	○
r. H.E.B.	○	○	○	○	○
s. Kroger	○	○	○	○	○
t. NatureSweet Company	○	○	○	○	○
u. Sysco Central Texas, Inc.	○	○	○	○	○
v. Labatt Food Services	○	○	○	○	○
w. Del Norte Foods, Inc.	○	○	○	○	○
x. Cargill Food Distributors	○	○	○	○	○
y. Blue Wing Solar, Inc.	○	○	○	○	○
z. San Antonio Greenspace Alliance	○	○	○	○	○
aa. GE Power and Water	○	○	○	○	○
bb. Halliburton	○	○	○	○	○
cc. Association for Electric Companies of Texas	○	○	○	○	○

Again, thanks for taking the time to answer these questions. When completed, please return this questionnaire in the self-addressed stamped envelope and return the postcard separately to:
Prof. Kent Portney, Director
Institute for Science, Technology and Public Policy
Texas A&M University
TAMU 4350
College Station, Texas 77843-4350

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