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Toward understanding the convergence of researcher and stakeholder perspectives related to water-energy-food (WEF) challenges: The case of San Antonio, Texas

Bassel Daher[a,b,c], Bryce Hannibal[c], Rabi H. Mohtar[a,d,e,*], Kent Portney[c]

[a] Department of Biological and Agricultural Engineering, Texas A&M University, College Station, TX 77843, United States
[b] Texas A&M Energy Institute, Texas A&M University, United States
[c] Bush School of Government and Public Service, Texas A&M University, United States
[d] Zachry Department of Civil Engineering, Texas A&M University, United States
[e] Faculty of Agricultural and Food Sciences, American University of Beirut, Beirut 1107 2020, Lebanon

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ABSTRACT

In the past decade, research on interconnected resource challenges has primarily focused on quantifying physical resource interconnections, and there is a growing focus on the social, economic, and policy dimensions of these interconnections. While the nature of the complexity of interconnected resource challenges resulted in emphasizing the need for inter- and trans-disciplinary research and in increased collaboration between research groups, little work has examined the convergence of perspectives between the research groups and their respective stakeholders. This paper focuses on the San Antonio Region of Texas: a resource hotspot characterized by rapid urbanization, increased energy production in the Eagle Ford Shale Play, and growing agricultural activity. The paper reports on a survey sent to 370 researchers and regional stakeholders from governmental, non-governmental/non-profit, and business organizations in the Region's water, energy, or food sectors. The study goals were to 1) evaluate *levels of convergence* in perspectives regarding the water, energy, and food challenges in the Region; 2) quantify existing *levels of communication* of both researchers and regional stakeholders with identified WEF organizations in the region; and 3)identify *barriers to and opportunities for improving communication* between the WEF organizations and the researchers involved. The authors found aspects of convergence between surveyed regional stakeholders and researchers. Aspects of convergence exist between both groups regarding the potential of different Texas Development Water Board strategies to address future water challenges. Modest levels of communication were reported between surveyed researchers and regional stakeholders with other identified WEF organizations. Both groups converge on the potential roles of "increased communication" and "sharing information between agencies" as a means to improve cooperation to address interconnected resource challenges. To make this possible, institutional mechanisms and resource allocations for such activities must be revisited.

1. Introduction

In the past decade, the scientific community witnessed growth in water-energy-food nexus related literature (Albrecht et al., 2018; Dai et al., 2018; Zhang et al., 2018; Kaddoura and El Khatib, 2017; Mohtar, 2017; Mohtar and Daher, 2019). This was primarily focused on quantification of the bio-physical interconnections and trade-offs between the three resources systems (Bazilian et al., 2011; Giampietro et al., 2013; Howells et al., 2013; FAO, 2014; Daher and Mohtar, 2015; IRENA, 2015). There is also growing interest in employing social sciences research to better understand policy processes and implications for resource allocation pathways (Kurian, 2017; Portney et al., 2017a; Pahl-Wostl, 2017; Artioli et al., 2017; Daher et al., 2019a, 2019b, White et al., 2017; Bunakov et al., 2017; Hannibal and Vedlitz, 2018). While much of this scientific literature comes from within cross-disciplinary research groups (Mohtar and Daher, 2019; Endo et al., 2018) that build on interconnected resource system frameworks and theories, little is known about the extent to which that research reflects the actual stakeholder perspectives in the region studied.

Water, energy, and food resource systems are multi-dimensional

* Corresponding author: Department of Biological and Agricultural Engineering, Texas A&M University, College Station, TX 77843, United States.
E-mail addresses: mohtar@tamu.edu, mohtar@aub.edu.lb (R.H. Mohtar).

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and interconnected (Fig. 1a). The systems do not exist in a vacuum, but are governed, managed, and consumed by various, interacting actors who have differing value systems and preferences that impact their decisions and actions (Daher et al., 2018) (Fig. 1b). To more fully understand the research methodologies in the nexus, Albrecht et al. (2018) review and categorize 73 WEF nexus methods from the literature, including methods focused on the biophysical resources and their interconnections. These categories include: footprinting (Cottee et al., 2016; Rulli et al., 2016; Talozi et al., 2015), systems analysis (Al-Ansari et al., 2015; Li et al., 2016), spatial analysis (Daccache et al., 2014; Giupponi and Gain, 2016; Scott and Sugg, 2015), and material flows analysis (Villarroel Walker et al., 2012). *Social Science methods* categorized include: institutional analysis (de Strasser et al., 2016d; Sharma et al., 2010), questionnaires, surveys and interviews (Portney et al., 2017a; Cottee et al., 2016; Endo et al., 2015), and stakeholder analysis (Halbe et al., 2015; Karlberg et al., 2015). Additional categories focused on bridging the biophysical and social dimensions through scenario analysis (Walsh et al., 2016; Ringler et al., 2013; Daher and Mohtar, 2015; Scott, 2011), trade-off analysis (Bonsch et al., 2016; Mayor et al., 2015), and integrated assessment models (van Vuuren et al., 2015; Yang et al., 2016a). Similar work by Galaitsi et al. (2018) categorized 63 studies from the literature into those focused on modelling physical systems, analysis of governance and management systems, and direct support of decision or policy making.

Despite recent academic research developments emphasizing the biophysical and social sciences, relatively little is known about the extent to which researcher and stakeholder perspectives converge over resource related issues (Fig. 1). As researchers continue to work toward a better understanding of interconnected resource challenges, and toward supporting stakeholders in addressing them, it is important to ensure high levels of communication and engagement between both groups at different stages of a project. This is especially useful when rapid recommendations to address timely resource challenges are needed. Reducing the length of the feedback cycle between researchers and stakeholders who are making decisions, through ensuring a level of convergence between their perspectives exist, would allow for the development of informed policy incentives, technologies, and management practices that appropriately respond to the resource challenges facing societies. This paper uses the water-energy-food nexus hotspot in the region of San Antonio, Texas, USA, and researchers at Texas A&M's Water Energy Food Nexus Initiative (WEFNI, 2018), to develop a better understanding of the gap between researchers and stakeholders, and identify areas of convergence, or lack thereof. The paper: 1) evaluates *levels of convergence* in perspectives regarding the water, energy, and food challenges in the Region; 2) quantifies existing *levels of communication* of both researchers and regional stakeholders with identified WEF organizations in the region; and 3)identifies *barriers to and opportunities for improving communication* between the WEF organizations and the researchers involved.

Throughout this study, "*Researchers*" are those affiliated with the WEF Nexus Initiative and involved in the study of the San Antonio resource hotspot and other academics on the WEFNI mailing list from institutions in Texas. A "*Regional Stakeholder*" is one whose work focuses on water, energy, food, or any combination of those sectors; water and energy, water and food, energy and food, or water, energy and food[1] . There is an overlap between "Regional Stakeholders" and "WEF Organizations". "WEF Organizations" are similar to "Regional Stakeholders" in their sectoral focus. In addition to individual institutions or actors, identified as "Regional Stakeholders", "WEF organizations" include stakeholder categories, including Groundwater Conservation Districts, River Authorities, for example (Appendix 2). While Ground water districts (GCDs) is one of the WEF Organizations, identified Regional stakeholders contacted for this study came from multiple GCDs within the San Antonio Region.

2. Convergence theory

Convergence theory originated in the 1960's. It suggests that as societies industrialize and grow, common societal patterns emerge, and eventually result in a uniform global culture (Rostow, 1959). Bergendahl et al. (2018) emphasize the importance of convergence of actions taken by engineering, science, and business partners to yield Food-Energy-Water technological innovations to address complex resource problems of the 21st century. Michaud-Létourneau and Pelletier (2017) considered convergence a prerequisite for coordination between multi-sectoral partners. Cronley and Kilgore (2016) use a survey sent to students and faculty to examine convergence of perspectives on issues related to student writing abilities. They then quantify the statistical significance of the differences in answers of the two groups to identify areas where gaps in perspectives exist. Convergence has a temporal dimension, reflecting movement from different positions to a common point over time (Bennett, 2018), although Bennett acknowledges that convergence is also a synonym for similarity or uniformity in comparative policy literature.

This paper uses a static reflection of the difference between perspectives at a given point in time to identify areas of non-convergence between researchers and regional stakeholders, as reflected in a survey about their perspectives and preferences related to managing WEF resources in the San Antonio Region. This would be a chance to identify areas over which greater levels of dialogue and communication need to happen between researchers and stakeholders. We do not investigate the level of convergence within each of the groups separately, but between them. As researchers work to operationalize WEF nexus concepts and frameworks into technical and policy recommendations, the multi-sectoral stakeholders must be engaged to ensure that those recommendations being made are consistent with the nature of the challenges faced. Stakeholders must understand, and be aware of, the areas in which convergence of perspectives (or lack thereof) exist with researchers as they make decisions about future resource allocations. Such information would contribute to providing insight for both groups.

3. Resource hotspot: San Antonio Region, Texas

The San Antonio Region (Region L) is one of 16 Texas water-planning regions (TWDB, 2017). Region L is home to a growing, rapidly urbanizing population (Zhao et al., 2016), has major agricultural activity (Odintz, 2010), and lies over the Eagle Ford shale play - with its growing production of oil and natural gas (Mohtar et al., 2019). Region L is a resource hotspot whose cross-sectoral stakeholders compete for limited water, land, and financial resources (Daher et al., 2019a, 2019b) in a region whose projected trends indicate continued growth across those sectors (Portney et al., 2017b). A "resource nexus hotspot", can be considered a "vulnerable sector or region at a defined scale, facing stresses in one or more of its resource systems due to resource allocation at odds with the interconnected nature of food, energy, and water resources" (Mohtar and Daher, 2016).

The Texas A&M Water-Energy-Food Nexus Initiative (WEFNI), established in 2015 with the goal of better understanding the complexities of the regional resource hotspot (Mohtar and Daher, 2019), identified and developed six interdisciplinary sub-groups: data and modeling, trade-off analysis, water for food, water for energy, energy for water, and governance and financing. Following their research activity and building on a series of research-based workshops, WEFNI convened a Stakeholder Engagement Meeting, at which WEF stakeholders representing governmental, non-governmental/non-profit, and business organizations from the Region received the preliminary findings and recommendations from the research (Rosen et al., 2018). Prior to the meeting, a survey was distributed to researchers and invited

[1] We do not consider these categories to be mutually exclusive.

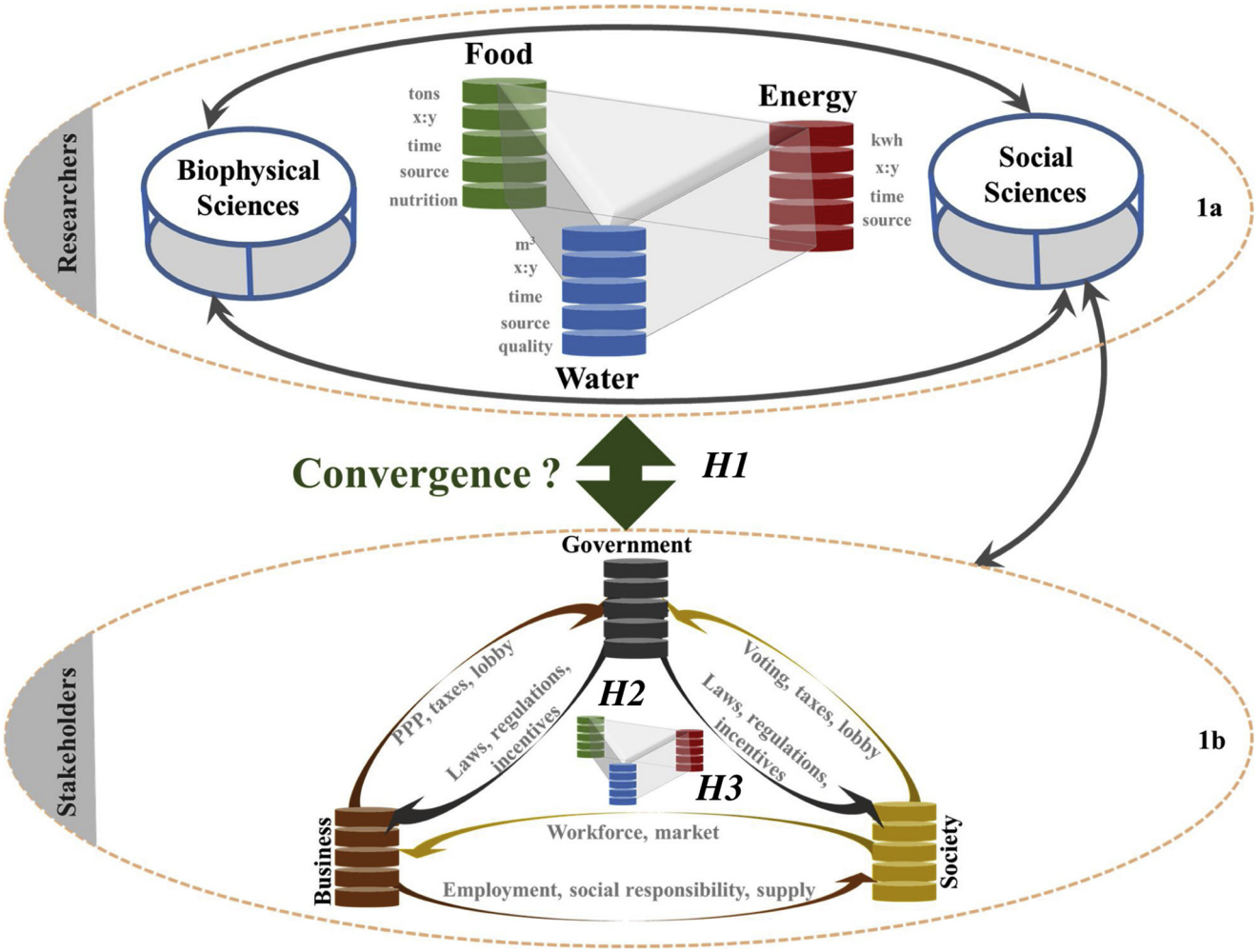

Fig. 1. Gap in studies on difference in perspectives between academics and stakeholders on issues related to water, energy and food issues. Adapted from (Daher et al., 2019a, 2019b).

regional stakeholders, in order to learn their perspectives regarding issues related to WEF security in the region.

Effectively addressing future resource challenges and ensuring sustainable urbanization demands that stakeholders understand the interdependence of their decisions and are able to evaluate the extent to which technological, policy, or social interventions may reduce stresses and address the complex resource challenges faced. Each sector needs to better understand the interlinkages and tradeoffs as they relate to their own sector, but also contribute to the initiation of dialogue among stakeholder from other sectors (Mohtar and Daher, 2016). Such dialogue promotes holistic, sustainable allocation decisions, while potentially reducing unintended consequences and sectoral competition.

4. Hypotheses and rationale

To address various levels of convergence on WEF related issues, several hypotheses were examined.

HYPOTHESIS 1. The perspectives of researchers and regional stakeholders from San Antonio converge over issues related to water, energy, and food resources in the region.

The first hypothesis examines convergence in perspectives between researchers and regional stakeholders over ***six elements***:

1 extent of interconnectedness between water, energy, and food in the region;
2 the perception of the level to which local agencies need to cooperate across issues of water, energy, and food;
3 current and future relative priorities for action for water, food, and energy in the San Antonio region;
4 level of concern toward future water availability, energy security, and food security in the region;
5 level of familiarity with the Texas Water Development Board's (TWDB) water supply strategies for the San Antonio Region (2017 State Water Plan); and
6 potential of proposed TWDB strategies in meeting the Region's water needs in the coming 10 years.

This hypothesis and the sub-hypotheses are drawn from public policy literature on the theory of convergence (Drezner, 2001; Knill, 2005; Heichel et al., 2005). It assumes that researchers studying different resource challenges in the region have an understanding of those challenges and a degree of convergence due to input from different stakeholders through various formal and/or informal participatory and engagement processes. The hypothesis also assumes that stakeholders in the region are aware of research being developed within the academic sphere through information exchange that contributes to greater convergence over time.

HYPOTHESIS 2. Hypothesis H2(a–c) examines the frequency of communication of researchers and regional stakeholders at different types of organizations *(academic vs. non-academic; governmental vs. businesses or non-governmental/non-profit organizations)* or sectoral

focus *(single or multiple focus areas),* with the identified WEF organizations.

H2a. Respondents who reported working at *non-academic organizations* have a higher level of communication with WEF organizations in San Antonio than those who reported working at *academic institutions*.

H2b. Respondents who reported working at *organizations with a single sectoral focus* (water, energy, or food) have a lower level of communication than respondents who reported working at *organization with focus on a combination of two or three of those sectors.*

H2c. Respondents who reported working at *governmental organizations* have a higher level of communication with stakeholders from San Antonio than those working at *businesses* or non-governmental/*non-profit organizations* in the region.

Hypothesis 2. draws on the theory of homophily (McPherson and Smith-Lovin, 1987; McPherson et al., 2001) and its relation to communication (Rogers and Bhowmik, 1970), suggesting that people working at similar types of organizations are likely to communicate among each other at a higher rate than with those from different types organizations.

HYPOTHESIS 3. Researchers and regional stakeholders' perspectives converge regarding ways in which greater cooperation might be achieved between WEF organizations in San Antonio Region.

While stakeholders within different cross-sectoral organizations might realize the need for better communication as they plan for future allocation and management of regional resources, barriers may exist that challenge such interaction. These barriers could be financial, legal, or the lack of proper institutional mechanisms facilitating or improving cooperation (Daher et al., 2019a, 2019b). As in Hypothesis 1, H3 builds on the theory of convergence, exploring the extent to which researchers and regional stakeholders converge over what they view as the main barriers to better cooperation and its improvement.

5. Methodology

5.1. Stakeholder identification, classification, and relationships

Different methods exist for stakeholder identification, classification, and analysis: this study uses ***survey, snowball sampling,*** and ***scoping studies*** to identify, classify, and seek input from stakeholders. ***Social network analysis*** was used to understand stakeholder relations. The methods by which each was done (Fig. 2) are outlined.

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

Freeman et al. (2010) offer several definitions of stakeholder. For this study, a **stakeholder** is a person at an entity/organization/institution who is involved in the decision making process that may impact water, energy, and/or food/agriculture in the San Antonio Region. These can be governmental, business, or non-governmental/non-profit organizations. Throughout this paper "regional stakeholders" refers to respondents to the survey, and the 97 water, energy, and food organizations in the San Antonio Region are "WEF Organizations" (Appendix 2).

5.1.2. Stakeholder identification

Stakeholders were identified through input by the Organizing Committee of the WEFNI workshop, snowball sampling, and scoping.

5.1.2.1. WEFNI workshop organizing committee contacts. The Texas A&M University Water-Energy-Food-Nexus Initiative (WEFNI, 2018), with National Science Foundation sponsorship, organized the *Water-Energy-Food Nexus (WEF) Stakeholder Information and Engagement Workshop* (Jan 10, 2018). The workshop included invited WEF sector leaders of diverse technical, academic, research, and business backgrounds from the San Antonio Region. The organizing committee included WEFNI leadership team members actively engaged in the San Antonio Region. A total of 370 names from WEF institutions from government, business, non-government/non-profit, and academia, were suggested. Researchers were those actively involved in the different WEFNI research subgroups, and those subscribed to the WEFNI mailing list from different departments at the Texas A&M San Antonio, College Station, Kingsville, and Corpus Christi campuses and University Texas San Antonio and Austin.

- **Web search for organizations and contacts–scoping:** Additional WEF stakeholders from the region were identified by the Organizing Committee through a web search of organizations and key personnel actively working in related WEF areas. The list of 97 WEF Organizations in the survey (Appendix 2) builds on a list developed by Portney et al. (2017) to identify major WEF stakeholders in the Region.
- **Suggested stakeholders from survey respondents–snowball sampling** technique seeks suggestions from existing study subjects to recruit future subjects (Goodman, 1961), insuring sample inclusivity by not missing unidentified stakeholders who should be included. Those who attended the stakeholder engagement workshop were requested to complete a post workshop questionnaire with a question about identifying other stakeholders, not at the workshop, who should be included. The 12 responses to the post workshop survey (response rate 13.6%) included names of organizations already on the initial list of invitees, thus, no additional invitations were sent.

5.2. Survey

A survey sent to WEFNI workshop invitees received 71 responses (19.2% response rate); 88 attended the workshop (24% attendance rate). To avoid stakeholders responding to the survey after being influenced with the workshop discussions, those who attended the workshop without responding to the survey were not included in further reminders.

5.2.1. Stakeholder classification

The stakeholders and their affiliated institutions were categorized as *researchers* and *regional stakeholders*. Regional stakeholders were asked, in the survey, to self-identify their type of institution (governmental, non-governmental/ non-profit/, or business) and its focus (on water, energy, or food) (Table 1). Stakeholders at organizations with a focus across multiple resource systems, such as the office of the mayor, were classified as *cross-cutting*. Author judgment was used to initially classify which category best represents each organization. Stakeholders self-identified the type of their organization and areas of primary focus through responding to questions asking about the same in the survey (Fig. 2).

5.2.2. Measuring convergence

A method similar to Cronley and Kilgore (2016) was used to examine the level of convergence between both groups. The difference in means of answers from researchers and regional stakeholders to each of the six questions (Q1-a to Q1-e) is quantified and compared (Table 2). An independent samples *t*-test was conducted representing both sets of responses. If the difference in means is statistically significant for a specific question, we conclude there is no convergence on that issue. If the difference between means is not statistically significant, we fail to reject the null hypothesis (i.e. that both perspectives converge). The answers to each question were first recoded, i.e., in Q1-a: Very Low, Low, Moderate, High and Very High were recoded into 1, 2, 3, 4, and 5, respectively. Q1-b and Q1-e were similarly recoded. As Q1-d and Q2 carried 0–10 and 1–5 scales, respectively, no recoding was necessary.

$$\textbf{Gap} = \Delta \text{ means} = \left| \mu_{\text{Researchers}} - \mu_{\text{Regional Stakeholder}} \right|$$

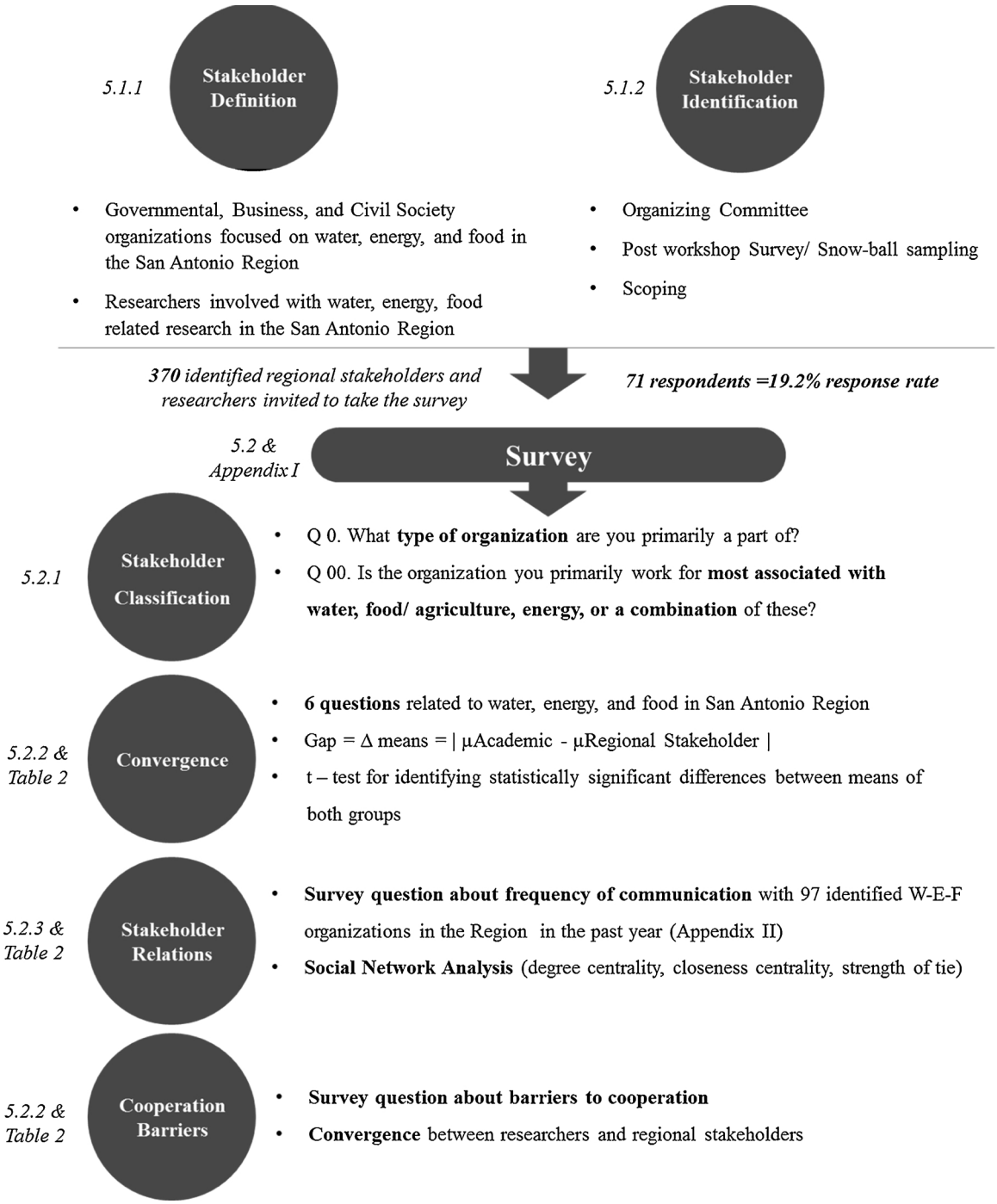

Fig. 2. Methodology summary.

5.2.3. Social network analysis metrics: measuring degree, closeness and strength of tie

Social network analysis was used to examine and visualize aspects of the relationship between stakeholders. We focus primarily on degree and closeness centrality of different stakeholders. The responses on frequency of communication from the aforementioned survey were entered into a bipartite network used for the analysis in this study. The network analysis was done using UCINET 6.665 (Borgatti et al., 2002). *Centrality* provides information on stakeholders most connected with others and distinct aspects of connectiviety within the network. A highly centralized network is characterized by a few stakeholders with the majority of ties with others in the network (Prell et al., 2009; Zhu et al., 2010). Bavelas (1948) introduced the idea of centrality as it applies to human communication. According to Prell et al (2009), stakeholders with high *degree centrality* can be considered key players to mobilize the network by bringing other stakeholders together (Proctor and Loomis, 1951; Freeman, 1978). Degree centrality is the sum of ego's, or the focal actor's direct ties to other actors in the network, and defined as:

$$\text{degree}_i = \sum_j x_{ij}$$

where i represents the actor and x_{ij} is the (i, j) entry in the adjacency matrix, or value of the tie between i and j.

Closeness centrality, another measure for centrality in a network, is calculated as the sum of the shortest paths between a given node and all

Table 1
Summary of self-identified categories for type of institution of survey respondents and workshop attendees.

		SURVEY RESPONDENTS	WORKSHOP ATTENDED BY
By type of organization	Governmental (G)	14	19
	Non-Gov./ Non-Profit (N)	11	13
	Business (B)	14	15
	Researchers	32	41
By area of focus	Water	21	33
	Energy	4	6
	Food	5	13
	Cross-cutting	41	36
	Total	**71** /370 (19.2%)	**88** /370 (24%)

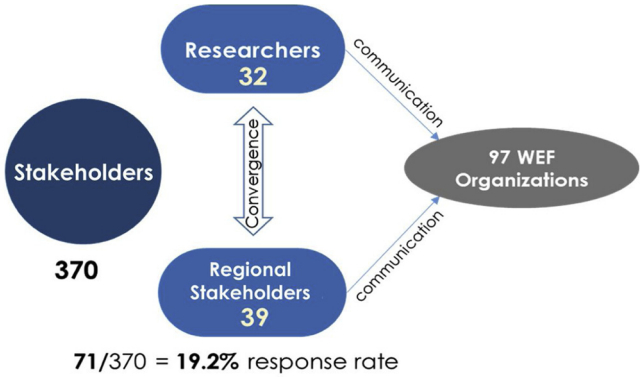

Fig. 3. Summary of researcher and regional stakeholder responses and response rate.

other nodes in the network (Bavelas, 1948). It examines how "close" an actor is to all other actors in the network by summing the total number of shortest paths from a focal node and all other nodes. Close actors may be influential in transmitting information (Borgatti et al., 2013), as closeness is frequently interpreted as an amount of time until information flowing through the network arrives at the focal node (Borgatti 2005). Nodes that are closer (lower scores) have shorter distances from others and may be well-positioned to obtain the information earlier than those on the network periphery.

$$C_c(i) = \sum_{j=1}^{n} d_{ij}$$

where d_{ij} is the distance to connect actors i and j. Closeness assumes that whatever flows through the network does so along the shortest path.

Strength of tie is measured in the networks and represents the frequency of communication between nodes (Sheng et al., 2013). Strength of tie is important: it allows gauging the level of connectedness in the network; it varies for a number of reasons. Very infrequent information sharing represents a weak tie and more frequent sharing a stronger tie. Strength of tie is represented as valued degree centrality: the total number of connections for each actor in a given network. Frequency of communication, indicated by responses to Q3, is represented by the average frequency of communication with different institutions. A larger number of 0′s (no communication) indicates a lower level of communication. The average values for that level of communication ranges between 0 and 5; closer to 0 represents less communication with others from different institutions. Conversely, higher average score indicates greater communication. (Daily-5, Weekly-4, Monthly-3, Once in three months-2, Annually-1). Statistical tests (*t*-test for two samples with unequal variances) were conducted to identify the sigificance of differences in results between responding researchers and regional stakeholder.

6. Results and analysis

6.1. Level of convergence in perspectives between researchers and regional stakeholders

One of the main aims of Hypothesis 1 is to learn whether researchers and regional stakeholders converge over a series of issues related to water, energy, and food resources in the region. We are also interested in learning whether convergence exists within each of the groups: researchers and regional stakeholders. In order to do that, we investigate whether responses from both groups are statistically different. At first glance, there are no significant gaps in answers to the given questions (Fig. 3). Researchers and regional stakeholders seem to agree over the extent of interconnection between WEF resources (Q1a), and the extent to which organizations in the region need to cooperate over related WEF issues (Q1b). Both groups agree about the current relative priorities, with water first, followed by energy, then food (Q1c). There is

Table 2
Hypotheses and respective survey questions.

Hypothesis 1: The perspectives of researchers and regional stakeholders from San Antonio converge over issues related to water, energy, and food in the region.	Q 1-a. ***To what extent*** *do you think water, energy, and food* ***resources are connected*** *to each other?* Q 1-b. *In general,* ***to what extent*** *do you think that agencies and* ***organizations should collaborate, coordinate, or cooperate*** *across issues of water, energy, and food?* Q 1-c. *What do you see as the* ***current relative priorities*** *of water, food, and energy in the San Antonio region? What do you think the* ***relative priorities*** *of water, food, and energy should be for the San Antonio region* ***in the future****?* Q 1-d. *Overall, how concerned are you about* ***future water availability*** *in the San Antonio Region? Overall, how concerned are you about* ***energy security*** *in the San Antonio Region?* *Overall, how concerned are you about* ***food security*** *in the San Antonio Region?* Q 1-e. *How* ***familiar*** *are you with the* ***TWDB's water supply strategies*** *for the San Antonio Region in the 2017 State Water Plan?* Q 1f. *Please indicate* ***how much potential*** *you think each* ***listed strategy has*** *for managing water to help the San Antonio Region meet its water needs over the next ten years?*
Hypothesis 2: Researchers have a lower level of communication with water, energy, and food stakeholders from San Antonio than that of stakeholders among each other.	*Q 2. Over the last year, about* ***how often have you communicated*** *with any of these organizations, or decision makers from these organizations,* ***on issues related to water, energy, and food/agriculture planning*** *in the* ***San Antonio region****? and Q4. and Q5. (Appendix 1)*
Hypothesis 3: Researchers and regional stakeholders' perspectives converge regarding ways in which greater cooperation might be achieved between WEF organizations in San Antonio Region.	*Q 3. In your view,* ***how could cooperation*** *across issues of water, energy, and food best* ***be accomplished****?*

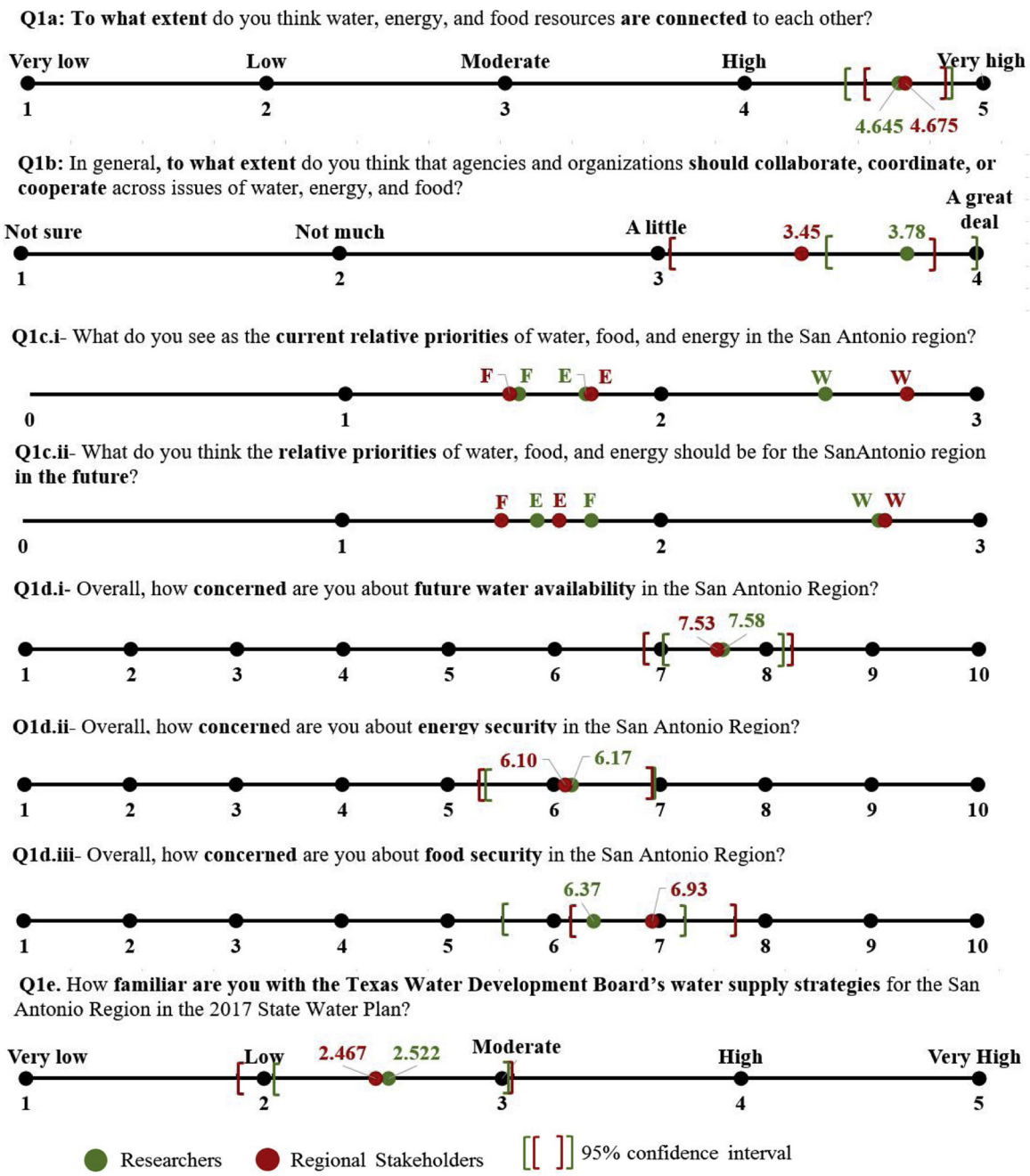

Fig. 4. Summary of academic and regional stakeholder respondents to the survey questions.

some disagreement on future priorities: while both groups agree that water must remain the first priority in the future, reserchers rank food before energy and regional stakeholders rank energy before food.

The authors initially included the confidence intervals to Q1c in Fig. 4. Since there are six observations, their inclusion was visually confusing. The fact that it does not detract from where respondents priorities are, led us to the decision of leaving them out of the figure.

Researchers and regional stakeholders also indicate higher levels of concern about future water availability, followed by food security, then energy security (Q1d). Both groups indicate low-moderate familiarity with the TWDB water supply strategies (Q1e). After conducting t-tests for each of the questions, no statistical signifiance in the difference of perspectives was found: indicating that aspects of convergance do exist between both groups' perspectives about the six topics. In addition to mapping the means of the responses of each researcher and regional stakeholder, we calculated and mapped the 95% confidence interval for each (Fig. 3). The confidence interval gives a range of most likey values for each group's responses, both aiding in identification of areas of convergence between both groups of respondents, and providing an indication of the level of convergence within each group. A wider confidence interval indicates lack of convergence within the same group over a specific topic. For example, there seems to be more convergence within each group regarding concern about future water availability (compared with future energy/food securities). This could be observed through the shorter confidence interval range when asked about water availability. Overall, given the ranges of confidence interval overlaps between both groups, and since those ranges are within one answer difference (between 4 and 5 in Q1a), we conclude the presence of aspects of convergence within and between both groups in the Region regarding the six WEF resource topics.

The 2016 TWDB Report outlines a list of water management strategies to meet projected water demands by 2070, including strategies to

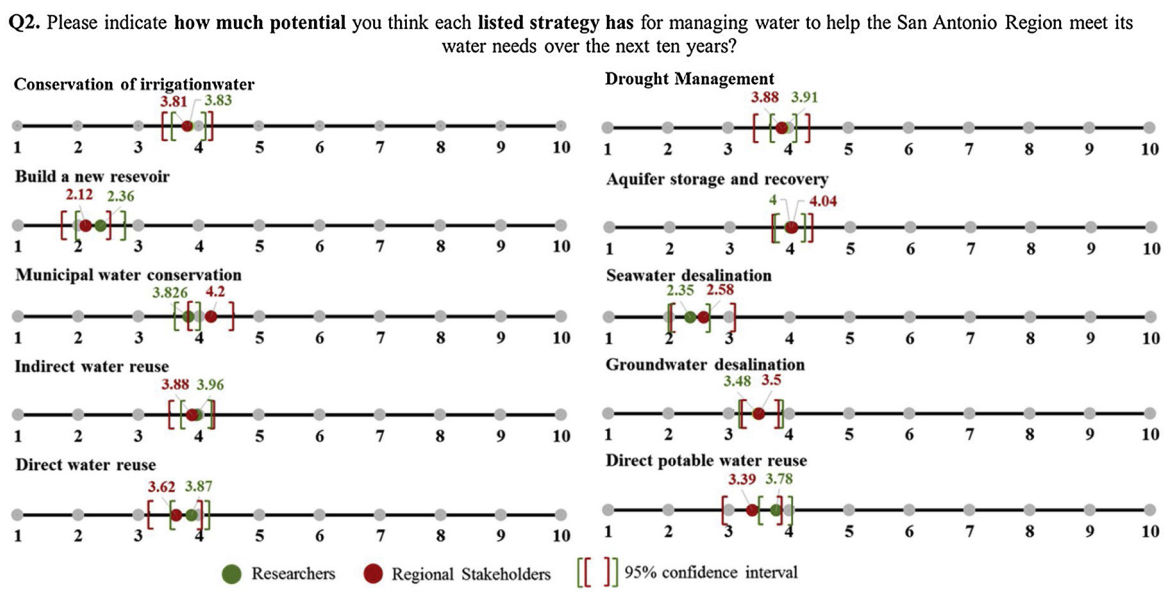

Fig. 5. Summary of responses: potential of different TWDB strategies.

increase supply and reduce demand in order to address projected water system challenges in the coming decades. In response, both groups indicated similar views about the potential of the different strategies (Fig. 5). Researchers indicated, as management strategies with greatest potential, *aquifer storage and recovery,* followed by *indirect water reuse*. Regional stakeholders indicated *municipal water conservation,* followed by *aquifer storage and recovery*. Both groups agree that *building a new reservoir*, has the least potential for meeting San Antonio's water needs in the next 10 years. We similarly conduct two-sample t-tests to identify whether the differences in responses from both groups are statistically significant. For all strategies, we fail to reject the null hypothesis for equal means, at 95% confidence level. Accordingly, there is insufficient evidence to conclude lack of convergence between researcher and regional stakeholder groups regarding the potential of TWDB's regional water strategies.

6.2. Level of communication

Of the 71 survey responses, 55 completed the network question (Q3) about frequency of the respondents' communication with the 97 identified WEF organizations from the Region. We used responses to this question and network analysis metrics to identify central players and communications. In Fig. 5, "communication" includes any frequency of communication (daily, weekly, monthly, once in 3 months, annual). Overall, there was a modest level of communication between categories of respondents with WEF organizations from the region. Twenty five (25) researchers and thirty (30) regional stakeholders answered the network question. A higher level of communication between regional stakeholders, compared to that between researchers, and the 97 WEF organizations was reported. This was confirmed after conducting a *t*-test showing a statistically significant difference between both ($p = 0.0461 < 0.05$). The 20 respondents who self-identified in their answer to Q00 (Appendix 1) as working for an organization with either a water, energy, or food focus were considered "silo" focused. The other 34 respondents, who identified as doing a combination of water, energy, and food, were considered as "inter-sector/discipline" focused. Similar frequencies of communication are reported by both groups (Fig. 6), and confirmed by the *t*-test, which indicated no statistically significant difference between both groups ($p > 0.05$). In Q0 (Appendix 1), respondents self-identify their organization type. Here, we found that those working at business organizations have lower communication levels with San Antonio WEF organizations, compared to governmental and non-governmental/non-profit organizations. After conducting pair-wise t-tests between the three groups, we fail to reject the null hypothesis for equal means, and conclude no statistically significant difference between responses.

6.2.1. Network mapping and metrics

Responses to Q3 were used to identify central actors and visualize their frequency of communication with the 97 WEF organizations from the region. The visualizations below represents a bipartite network matrix of communication among involved organizations. Each survey respondent is represented by a colored circle, according to their respective category, and the 97 WEF organizations by grey squares. Each line connecting two nodes represents some level of communication, whose frequencies are reflected in line thicknesses (Fig. 7). The size of the node (circle or square) indicates stakeholder centrality: larger size signifies a higher number of connections (higher centrality).

Fig. 6 appears to reflect a higher number of regional stakeholders (red) central to the network; similar results are demonstrated in Table 3. Researchers show lower levels of monthly and weekly communication by both network measures (degree and closeness). San Antonio River Authority appears to be the most central/connected stakeholder and Eco Centro-San Antonio College the most central research/academic player in the networks. Some of the major stakeholders emerging from the network are Texas Commission of Environmental Quality and other River Authorities. We limit the network map to monthly, weekly, and daily communications to identify the most frequent communicators.

Table 3 presents some descriptive characteristics from the network measures. The primary takeaway is that: as frequency of communication increases, network structure dissipates or may begin to break down. This is supported by the total number of ties in the communication network, where the total number decreases from 422 to 112 in monthly verses weekly communication, and which may be expected, as there is no assumption or expectation that network actors should communicate weekly or daily. The frequency of communication omits details of the quality of discussion. Fig. 8 examines the communication network of organizations who identified as a single disciplinary focus (silo) or a multiple disciplinary focus (Inter) with other regional WEF stakeholders. There does not appear to be a centralized group in the network, as is reflected in monthly communication (Table 3), where very little difference exists between monthly metrics. Weekly communication indicates that siloed organizations communicate with a larger

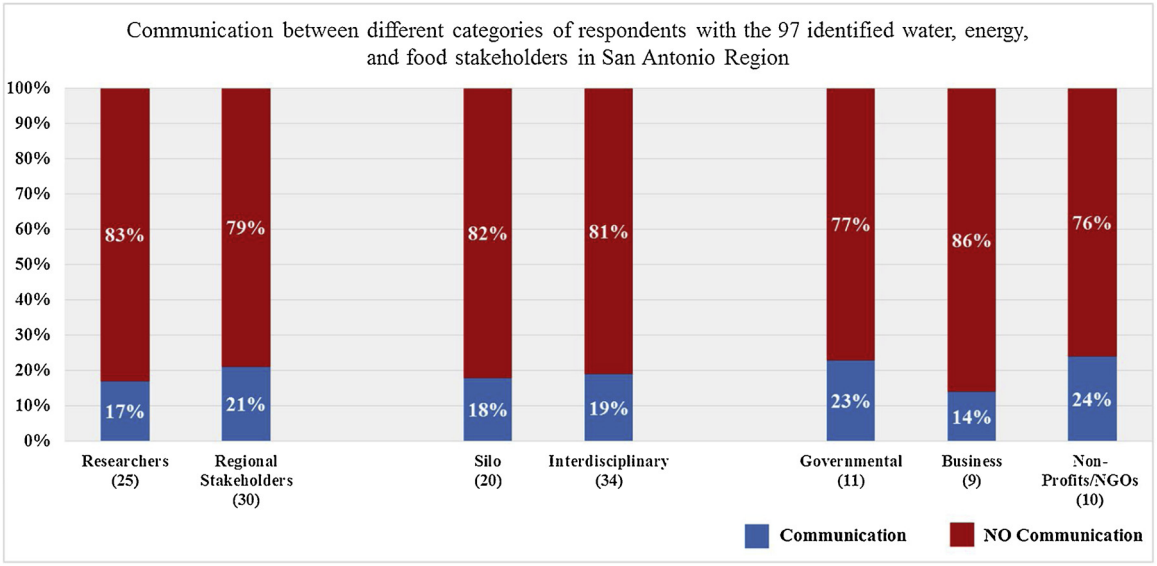

Fig. 6. Communication between categories of respondents with 97 identified WEF organizations.

number of other organizations (higher degree centrality). It is unclear whether these siloed organizations communicate with other siloed organizations or reach out to a broader pool of natural resource managers.

Fig. 9 represents the communication network for government, non-government/non-profit, and business organizations. As in Table 3, there appears to be no significantly higher level of communication for any category of organization. While some network measures are low, a few organizations are involved in frequent communication with each other. For example, the food distribution service company (Fig. 7) communicates weekly with aquifer authorities and with state land and public utility offices. Weekly communication occurs between respondents and large engineering firms, the San Antonio Office of Sustainability, regional planning authorities, river authorities, groundwater conservation districts, and A&M extension services, among others. While the quality of the communication is unknown and overall levels of communication are relatively low, we suggest that some of the region's WEF governance organizations are in frequent communication.

6.3. Identification of barriers to improved cooperation

As part of the WEF Stakeholder Information and Engagement Workshop (WEFNI, 2018), participants were asked: *In your view, how could cooperation across issues of water, energy, and food best be*

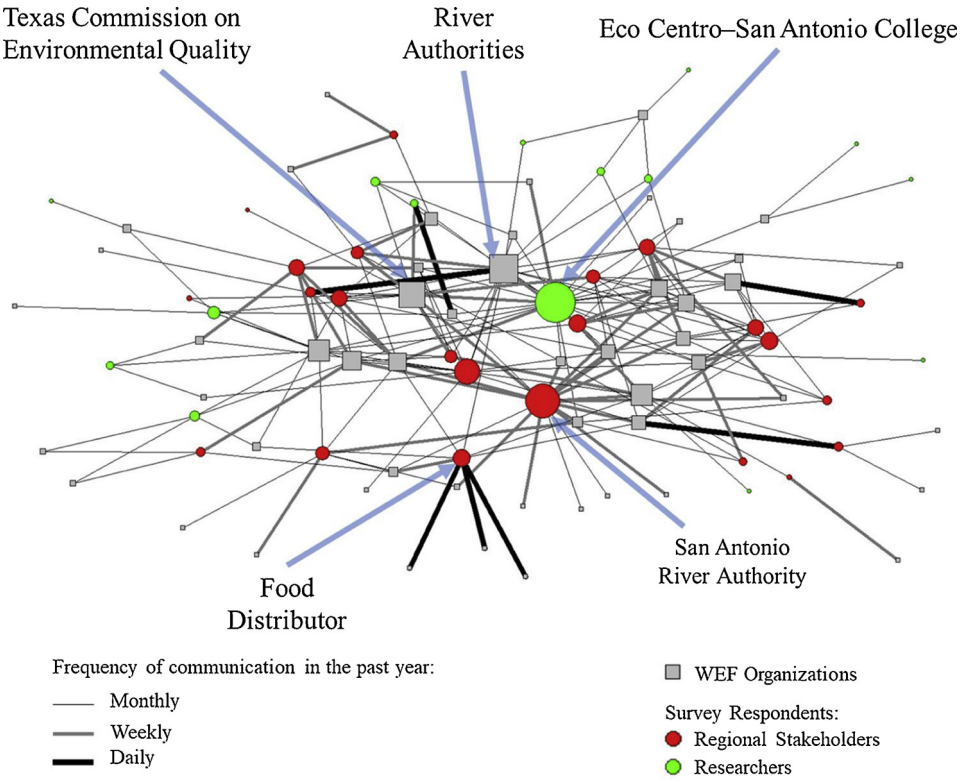

Fig. 7. Network map of daily/weekly/monthly communication of researchers and regional stakeholders with regional WEF organizations.

Table 3
Mean Frequency of Monthly and Weekly Communication*.

	Degree		Closeness	
	Monthly	Weekly	Monthly	Weekly
Researchers	2.48	0.2	982	1208
Regional stakeholders	4.65	1.59	904	1146
-				
Silo	3.93	1.67	905	1137
Inter	3.62	0.74	951	1186
-				
Governmental	5.27	1.73	919	1131
Business	3.22	1.11	938	1168
Non-Gov./ Non-Profit	5.13	1.8	839	1150

* values represent connectivity of all organizations, including those that are disconnect from the main component including isolates.

accomplished? 71 responses were recorded. Respondents were given the option of selecting multiple responses, and these tied between "sharing information" and "improving communication among existing agencies" (Fig. 10). Aspects of convergence were observed between researchers and regional stakeholders regarding perspectives on ways to cooperate across sectors. Participants were asked to identify 2–3 most important impediments collaborating on WEF issues, answers included: lack of understanding across the topic, lack of understanding the organization's current or potential role, bureaucratic silos, time and focus, lack of communication, lack of common language, silo mentality, organizational hierarchies, lack of shared information and lack of incentives, territorialism, lack of incentives to collaborate; lack of institutional mechanisms to cooperate, competing goals between agencies.

7. Discussion

It may be of value, in discussing the results of the analysis, to emphasize that the analysis and conclusions about convergence and communication are context-specific to this case study, and not necessarily representative of broader trends of convergence and communication within/across other research and regional stakeholder groups (Advisory Committee for Environmental Research and Education, 2018). The methods used here could be replicated and customized to learn about similar trends in other resource hotspots.

7.1. Level of convergence between researchers and regional stakeholders

Survey results show aspects of convergence between researchers and regional stakeholder perspectives regarding the 6 investigated elements related to WEF in San Antonio. The responding researchers do not differ from the responding regional stakeholders about current and future priorities of the region. Both groups agree that water is, currently and in the future, a top priority. This may be attributable to a larger number of researchers with a water/agriculture focus; it could also reflect stakeholder views regarding the importance of the energy sector and its contribution to the state's economy (making it a higher priority than agriculture and food security). While a difference appears between the second and third priority (energy or food), that difference is not statistically significant. Regarding TWDB strategies, both groups converged over the high potential of aquifer storage and recovery as one that addresses San Antonio's water challenges in the coming decade. Both groups also agreed that building new reservoirs has the least potential to address those challenges. As researchers work to model and assess the sustainability of alternatives for bridging the Texas water gap (Daher et al., 2019a, 2019b), these inputs from regional stakeholders need to be taken into account and may result in development of recommendations and analytics that support and catalyze stakeholder dialogues around trade-offs of alternative resource allocation pathways.

7.2. Level of convergence within researchers and regional stakeholder groups

While analyzing the survey results, we observed aspects of convergence, at varying levels, in the responses from within researchers and within regional stakeholders. That was represented by the 95% confidence interval that varied in range across issues. Given the complexity and interconnectedness of resource challenges facing the region, the diverse sets of goals and priorities, and the diversity within researcher groups and regional stakeholders, some level of divergence is expected, even within the same group. Inter-group convergence within researchers could be improved by supporting further interdisciplinary projects and developing teams of researchers across faculties and disciplines to allow debate and discussion toward a consensus on ways to develop solutions to address the complex, interconnected resource challenges (Mountford et al., 2019; Werder et al., 2018). Inter-group

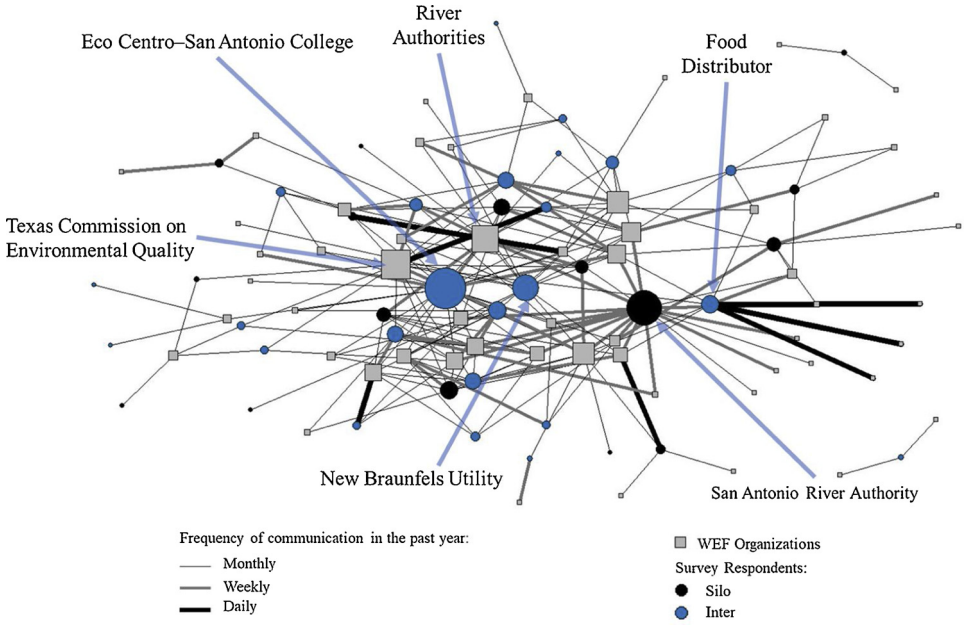

Fig. 8. Network map: daily, weekly, monthly communication with regional WEF stakeholders of respondents (self-identifying as within a single disciplinary focus versus interdisciplinary focus).

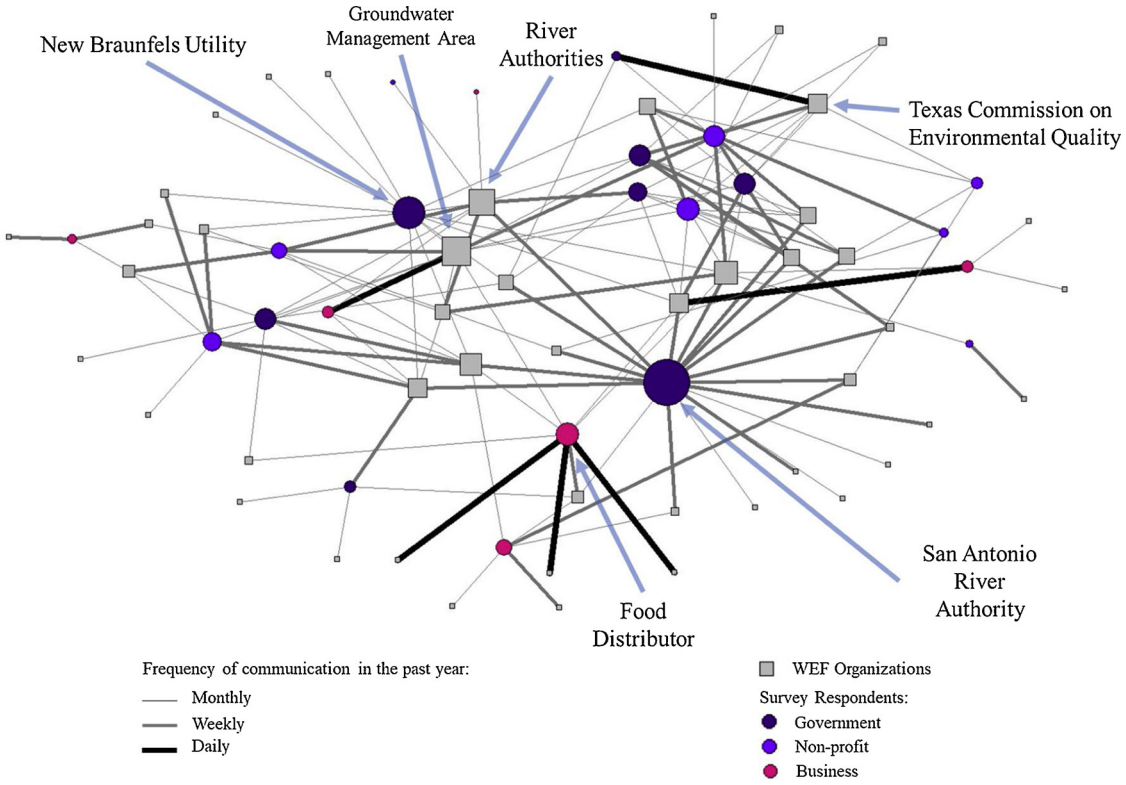

Fig. 9. Network map: communication with regional WEF stakeholders by governmental, non-governmental/non-profit, and business respondents to the survey.

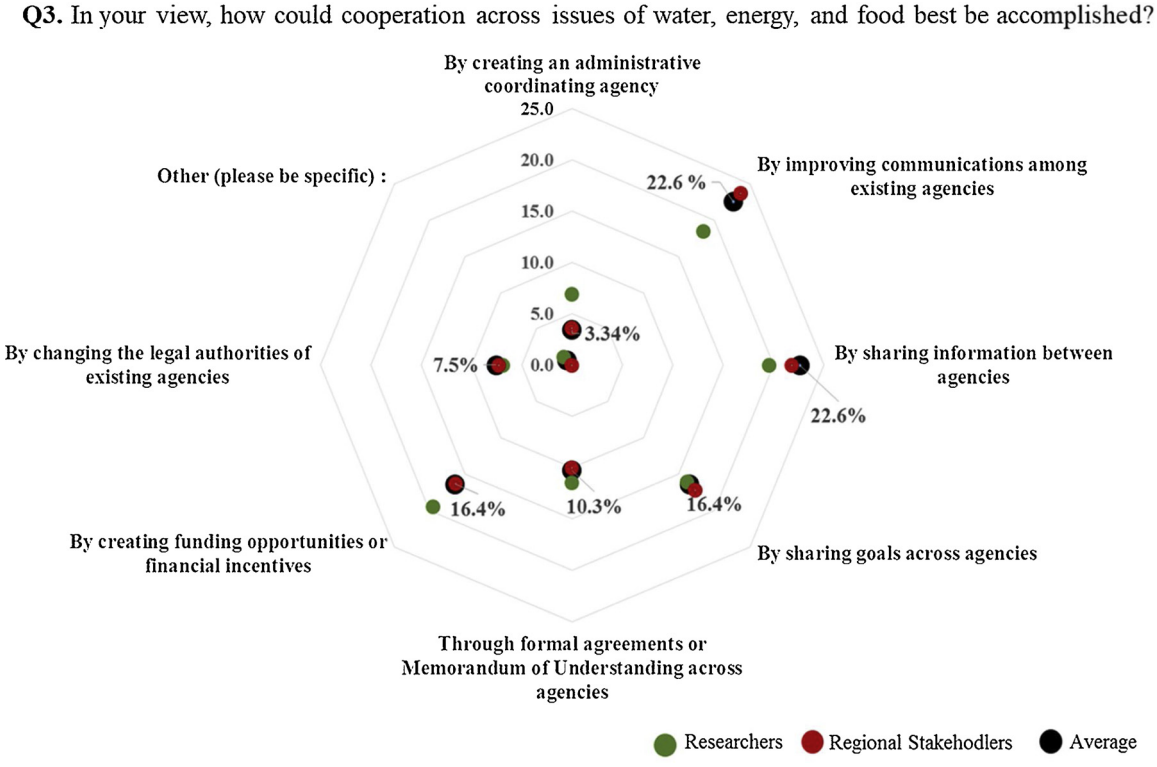

Fig. 10. How cooperation could across regional issues of water, energy, and food best be accomplished.

convergence among regional stakeholders could be improved by ensuring cross-sectoral representation at resource planning meetings and stakeholder engagement activities; this could be facilitated and supported by researcher groups (Rosen et al., 2019).

7.3. Level of communication of researchers and regional stakeholders

- ***Overall, modest levels of communication exist between respondents and regional WEF organizations***. The low levels of communication could be attributed to the lack of appropriate institutional

mechanisms and resources for improving those levels. The implications of not improving levels of communication include incoherence within research and regional stakeholder environments; either may lead to the development of incoherent policies and strategies for managing resources.

- ***A higher frequency of communication among stakeholder groups is statistically significant, compared to that of researchers with stakeholders***. This result was expected and could be attributed to the fact that different governmental, business, or non-governmental/non-profit organizations have more opportunities to meet and engage, compared with those at academic/research institutions. Level of communication between researchers and stakeholder groups could be improved by ensuring active engagement and outreach plans, including capacity building seminars and dialogue forums (Rosen et al., 2018). Dedicating sufficient time and resources would contribute to increased potential usability and significance of developed research and improve continuity, feedback, and engagement between researchers and stakeholders. That is in addition to ensuring incentives and reward mechanisms, which encourage researchers' engagement with stakeholders.
- ***Insufficient evidence of significant difference in the frequency of communication exists between respondents working at organizations with a silo focus, compared to organizations with interdisciplinary focus:*** This could be the result of institutional barriers that bar communication. People in different organizations may desire more communication, or realize its importance, but it is not part of their organization's mandate, or resources are not allocated for formal, meaningful communication.
- ***No statistically significant difference exists between the frequency of communication of businesses, governmental, and non-governmental/non-profit organizations with the regional stakeholders.*** We notice a limited link between type of organization and level of communication. This could indicate that institutional and financial challenges cut across types of organizations and are not limited to governmental institutions and gives rise to additional research questions: With whom are specific organizations communicating and in what context? Institutional boundaries may exist that impede communication: what institutional mechanisms could facilitate communication?

7.4. Perspectives on ways to overcome barriers to improved cross-sectoral communication

Convergence exists between both groups regarding their perspective about the role of "sharing information" and "improving communication between agencies" in improving cross-sectoral cooperation. In order to allow greater information sharing and improved communication, financial resources, human capital, and appropriate institutional mechanisms and incentives need to be in place. This might require introducing specific sections in the mandates of the cross-sectoral institutions that requires them to do so. Kurian et al. (2019) also emphasize the role of tools such as place-based observatories and composite indices in fostering cooperation among networks.

7.5. Societal impacts

As researchers evolve in their knowledge in understanding resource interconnections and quantifying trade-offs associated with alternative pathways forward, and as regional stakeholder evolve with their experience of facing these challenge and addressing them, it is important to ensure that both are converging in terms of understanding and addressing them. It is important to ensure proper levels of communication and exchange between both groups to allow research to be relevant and consistent with the challenges facing them. Stakeholders also need access to properly communicated information that supports their decision making processes. Particularly in the context of interconnected resource challenges, high levels of convergence can, potentially avoid tragedy of the commons situations within local communities, and ensuring taxpayer-funded research is addressing the correct questions.

7.6. Limitations and future work

One limitation of this study is the small number of responses: while the response rate approached 20%, a larger number of responses might have resulted in identifying areas where convergence might not exist and where further attention is needed. Among the respondents, fewer identified as non-governmental/non-profit/governmental stakeholders from the energy and food sectors (compared with those from other categories). Generally, more responses were reported from stakeholders within the water sectors than from the food or energy sectors. A more even distribution of responses across stakeholder categories would contribute to more representative results. Future studies could include type of impact on resources by regional stakeholders: for example, food distributors and retailers are not necessarily involved in decisions regarding increased agricultural growth or technologies, and the case is similar with water and electricity utilities. Regarding the methodology outlined for measuring convergence and communication between different groups: future work could build on this methodology to include different contexts of consensus building where convergence between different actors is a goal. Examples include transboundary water conflict settings or competition over common resource pools. There would be value in including elements that measure quality of communication, not only its frequency: such information would provide additional insights about the potential of communication resulting in collaboration and coordination across institutions. Future work could also be strengthened to include additional understanding and quantification of convergence within each of the researchers and stakeholder groups.

8. Conclusions

The resource challenges we face today will require the development of creative solutions that are consistent with our understanding of their complexities and interdependencies. Arriving at such solutions will require innovative thinking in the way we research and manage resources systems. There is also a need to be innovative in catalyzing a dialogue that fosters the essential communication within each of the research and stakeholder communities, and between them both. As resource challenges continue to intensify, there is a growing need for research that is able to offer rapid solutions. This requires reducing the length of the feedback cycle between researchers and stakeholders who are making decisions, whether by introducing policy incentives, technology, and or management practices that respond to different resource challenges. Based in system's thinking, and through the use of science-based mechanisms that support the quantification of interconnections between resource systems, researchers could play an important role in communicating the trade-offs associated with different scenarios. Early stakeholder involvement in the process of developing new research is particularly important to ensure convergence of perspectives and relevance of the research. Potentially, both increased communication between cross-sectoral stakeholders and increased exchange of information allow greater coherence in strategies for managing the future of these interconnected resources.

Aspects of convergence were identified between the perspectives of researchers and regional stakeholders regarding issues related to water, energy, and food in the San Antonio Region. Aspects of convergence were also found in the perspectives of both groups toward Texas Water Development Board strategies with the most or least potential. Both groups converge regarding the direction of future regional priorities: with water as a first priority of focus. We learned that modest levels of communication exist between respondents and regional WEF organizations; stakeholder groups do have a higher frequency of communication with other stakeholders, compared to researchers. We could

not conclude a relation between the organizations scope (silo vs interdisciplinary) or type (businesses, governmental, and non-governmental/non-profit) and the frequency of communication. The study also indicated that both groups converge regarding the potential roles of "increased communication" and "sharing information between agencies" as a means to improve cooperation and address interconnected resource challenges. For those potentials to become realities, institutional mechanisms and resource allocations for such activities should be revisited. Both groups converged regarding the high potential of aquifer storage and recovery and the low potential of building new reservoirs to address San Antonio's water challenges in the coming decade.

In an effort to ensure that issues are addressed early on and to create research and solutions of greater value to society, the survey developed in this study allows the identification of possible areas of convergence or divergence between researchers and regional stakeholders. Such a survey could be considered a 'spot check' in the life time of a project: one that would allow evaluating the research progress, as well as the level of stakeholder engagement and the level of convergence between them. This would help to identify potential gaps in communication or perceptions towards the different issues facing a resource stressed region. The convergence identified through this survey provides an encouraging foundation towards increased cooperation between researchers and cross-sectoral stakeholders regarding future planning and decision making.

While this study examines convergence between stakeholders and researchers in the context of the San Antonio resource hotspot, a similar methodology could be used to address hotspots elsewhere. Building on the methods used in the study to understand the level of convergence between researchers and water, energy, and food stakeholders in San Antonio, future work could include contexts in which consensus-building among the different stakeholders is a goal.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1 Survey Questions

Q 1-a. To what extent do you think water, energy, and food resources are connected to each other?

Very Low ○ Low ○ Moderate ○ High ○ Very High ○

Q 1-b. In general, to what extent do you think that agencies and organizations should collaborate, coordinate, or cooperate across issues of water, energy, and food?

Agencies should coordinate, cooperate, or collaborate:

A great deal ○ A little ○ Not much ○ Not sure ◉

Q 1-c-i. What do you see as the current relative priorities for action for water, food, and energy in the San Antonio region:

- Water resources
- Food and agricultural resources
- Energy resources

Q 1-c-ii. What do you think the relative priorities of water, food, and energy should be for the San Antonio region in the future?

- Water resources
- Food and agricultural resources
- Energy resources

Q 1d.i- 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
○	○	○	○	○	○	○	○	○	○	○

Q 1d.ii- Overall, how concerned are you about **energy security** in the San Antonio Region?

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

Q 1d.iii- Overall, how concerned are you about **food security** in the San Antonio Region?

0	1	2	3	4	5	6	7	8	9	10
Not concerned at all										Extremely concerned

Q 1e. How familiar are you with the Texas Water Development Board's **water supply strategies** for the San Antonio Region in the 2017 State Water Plan?

0 Not concerned at all	1	2	3	4	5	6	7	8	9	10 Extremely concerned

Not at all familiar ◯ Not at all familiarSlightly familiar ◯ Slightly familiarModerately familiar
◯ Moderately familiarVery familiar ◯ Very familiarExtremely familiar

Q 1f. Please indicate **how much potential** you think each listed strategy has for managing water to help the San Antonio Region meet its water needs over the next ten years?

◯ Extremely familiar

Q 2. Over the last year, about **how often have you communicated** with any of these organizations, or decision makers from these organizations, **on issues related to water, energy, and food/agriculture planning** in the **San Antonio region**?

Daily (1)	Weekly (2)	Monthly (3)	Once every 3 months (4)	Once a year (5)	Not at all (6)	This is my own organization (7)

Q 3. In your view, **how could cooperation** across issues of water, energy, and food best **be accomplished**?

- By creating an administrative coordinating agency
- By improving communication among existing agencies
- By sharing information between agencies
- By sharing goals across agencies
- Through formal agreements or Memorandums of Understanding across agencies
- By creating funding opportunities or financial incentives
- By changing the legal authorities of existing agencies
- Other

Q4. What **type of organization** are you primarily a part of?

- Academic
- Government
- Business/ Private sector (including consulting)
- Non-governmental/ Non-profit
- Other

Q5. Is the organization you primarily work for most associated with water, food/agriculture, energy, or a combination of these?

- Water
- Energy
- Food/Agriculture
- Water AND energy
- Water AND food/agriculture
- Energy AND food/agriculture
- Water, energy, AND food/agriculture
- My organization is not primarily associated with the above options.

Appendix 2 97 WEF Organizations

Ground Conservation Districts (GCDs)	Texas Public Utility Commission
Underground management areas	Texas General Land Office
River Authorities	San Antonio Office of Sustainability
TCEQ	Texas Railroad Commission

Regional Planning Areas
Texas State Public Utility
Texas General Land Office
Edwards Aquifer Authority
Texas Irrigation Districts
Texas Groundwater Protection Committee
Texas Alliance Groundwater Districts
San Antonio Water System (SAWS)
Drainage Districts
Texas Water Resources Institute (TWRI)
Water Conservation Districts
Texas Water Development Board (TWDB)
US Army Corps of Engineers
Texas Floodplain Management Association
San Antonio Office of Sustainability
Texas Railroad Commission
Texas Comptroller, Office of Energy Conservation
CDM Smith
Layne
Ozarka Spring Water Company
ExxonMobil
Shell Oil
Valero
Blue Wing Solar, Inc.
GE Power and Water
Haliburton
Association for Electric Companies of Texas
City Public Service (CPS) Energy
Duke Energy
Marathon Oil
Pioneer Natural Resources/Reliance Joint Venture
EOG Resources, Inc.
NOV-National Oilwell Varco
Exelon Corporation
Anadarko Petroleum
Schlumberger
STAR Park
Aramco Services Company
Hunt Oil Co.
The Texas Sustainable Energy Research Institute at UTSA
Schertz-Seguin Local Government Corporation
Forbes Environmental
Green Spaces Alliance
HMM Risk Group
Texas Parks and Wildlife
USDA-Natural Resources Conservation Service
Hahn Public
City of San Antonio (OOS)
Texas Center for Applied Technology
South Texas Program Office Chief, San Antonio
Bexar County, Environmental Engineer
Environmental Defense Fund
Southwest Research Institute
Texas Farm Bureau
Guadalupe County Farm Bureau
USDA
Texas Department for Agriculture
San Antonio Parks and Recreation
RSAH2O, LLC
Accelerate H20
Xylem Inc
El Paso Water Utilities
Blue Tech Research
Texas Alliance of Groundwater Districts
Water Reuse Research Foundation
H20 Midstream, LLC
Alan Plummer Associates, Inc.
Carollo Engineers
RWL Water

San Antonio Food Policy Council
San Antonio Food Bank
H.E.B.
Kroger
NatureSweet Company
Sysco Central Texas, Inc.
Labatt Food Services
Del Norte Foods, Inc.
Cargill Food Distributors
Ranches
Texas Water Foundwation
Texas Rural Water Association
Association of Water Board Directors
Mission Verde Alliance, SA Clean Tech
Texas A&M University-Global Petroleum Re Inst
Association of Electric Companies of Texas
The Nature Conservancy
Sustainable SA
Youth and Food Program
Berkeley Research Group

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