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# The Role of Communication in Managing Complex Water–Energy–Food Governance Systems

**Robert A. Greer *, Bryce Hannibal and Kent Portney**

Institute of Science, Technology, and Public Policy, Texas A&M University, College Station, TX 77843, USA; bryce.hannibal@tamu.edu (B.H.); kportney@tamu.edu (K.P.)

* Correspondence: rgreer1@tamu.edu

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**Abstract:** Managers of federal, state, local, and nonprofit organizations around the world are faced with the complex task of managing interconnected systems of scarce resources. One key example of this has been the recent research on the connections between water, energy, and food/agriculture, and the problem of managing these resources to be sustainable and reduce the likelihood of resource depletion. While engineering research has focused on achieving greater efficiencies in resource management, less attention has been given to issues of governance within the fragmented, decentralized, and polycentric systems that are responsible for resource delivery. The central question animating this paper is whether resource management decisions in water, energy, and food are siloed, and what theoretical frameworks can be leveraged to develop strategies to break down existing silos. Results from a survey of water agencies suggests that there is little communication between the water, energy, and food policy areas. If achieving greater nexus requires increased communication and repeated interactions, there is significant work to be done to re-think how policy and management are organized and conducted.

**Keywords:** governance; communication; collective action

## 1. Introduction

Managing natural common-pool resources within complex social-ecological systems with multiple users has long been a subject of social science research. One aspect of managing these collective action problems that has received increasing levels of attention has been the emphasis on and importance of communication across networks of stakeholders involved in decision-making processes [1,2]. While classical approaches to this research have focused on a single natural resource such as drinking water or fisheries, it is important to expand analytical approaches to include the interdependence and interconnectedness of various natural resource systems. One example of complex social-ecological systems research has been the work on water–energy–food (WEF) nexus systems. Scholars, particularly from hydrologic and physical sciences, have conducted extensive analyses in an effort to understand the connections between these three sectors [3–11]. However, research on governance efforts in the WEF nexus is limited. Indeed, there is insufficient empirical research devoted to issues of WEF governance [12–15].

This paper uses the Institutional Collective Action (ICA) framework to advance WEF nexus governance research by examining communication dynamics of the governance network, which includes various organizations involved in natural resource decision-making. The central question here is to what extent nexus governance and management decisions across water, energy, and food resources are siloed, meaning they are made in isolation without consideration of the other resource areas. We argue that communication between actors within each policy arena is an important component of nexus governance and that siloed communication in a fragmented and polycentric system can impede

and hamper efficient resource management and sustainability efforts. This paper examines the role of communication within collaborative governance to highlight the presence of intersectoral connections in the WEF nexus.

The Institutional Collective Action theory is one of several theoretical frameworks used to understand natural resource management efficiency among stakeholders in complex settings. ICA seeks to explicitly outline the conditions under which multiple governmental agencies involved in managing complex policies will or will not engage in cooperative and collaborative behaviors. ICA attempts to understand the willingness or unwillingness of agencies to cooperate by bringing together numerous rational choice and other theories. It outlines a variety of conditions that serve as impediments to inter-agency cooperation across policy areas, agencies, and levels of governance [16–23].

WEF nexus governance is rarely discussed in the context of managing common pool resources with externalities that extend beyond each individual policy area. The implications, however, are difficult to ignore. Nexus research offers explanations for why particular resources become depleted or are otherwise mismanaged by exploring the connections across resource areas. To illustrate, water depletion occurs, at least in part, because energy and food/agriculture decision-makers formulate policies or strategies that require significant amounts of water to be used in food production processes. Similarly, energy sources are developed and perhaps depleted because of demand from the water and food sectors. As a result, one of the underlying assumptions of extant nexus research is that sustainability requires greater efficiencies at the intersection of these sectors, and that extracting energy resources and generating electricity must be done in ways that use less water [15,24,25]. As Albrecht et al. [24] note, "by considering how water, energy, and food systems operate and interact, the nexus approach aims to maximize synergies (mutually beneficial outcomes), minimize trade-offs, improve resource-use efficiency, and internalize social and environmental impacts, particularly across a range of contexts and scales." In order to attain a sustainable economy and environment, nexus governance research must contend with breaking or loosening the linkages or connections across these sectors, and this is thought to be a desirable outcome. This creates a significant challenge as policymakers must step across natural resource lines and think broadly about the impact each resource is having on the sustaining, or depleting, of the others.

This study combines the parallel lines of research on WEF nexus governance and ICA. Specifically, we apply ICA to build on the idea of dynamic nexus governance by focusing on the level of communication between managers across the three natural resource sectors. This approach formalizes the interdependencies that exist across water, energy, and food sectors and focuses on the role of networks to govern complex systems. We then apply this networks-based approach to the San Antonio, Texas region, which is selected because it presents a particularly salient site for investigating governance complexity in a highly fragmented multi-level context. Using a survey of water agency managers, we demonstrate that there is little communication with agencies involved in energy and food management. We argue that these findings have implications for both individual agency management as well as policies regarding governmental structure and task centralization.

## 2. Institutional Collective Action and Nexus Governance

Smajgl et al. [25] suggest that there is a four-step process needed to understand nexus governance. The first step is to diagnose and document all intra-sectoral and inter-sectoral connections, especially communications. The second step is specifying potential trade-offs and synergies for the specified context. The third step is to derive effective measures of nexus connections that help mitigate or reconcile underlying trade-offs. The fourth step involves the ongoing monitoring and assessment of investment consequences on nexus dynamics. The first step—understanding the nature of existing communications and connections—is where we focus our attention in the San Antonio case presented below. Without an accurate understanding of the connections across sectors and the level of participation of various actors, it will be difficult to understand cross-sectoral interdependencies and trade-offs. In addition, the process of understanding sectoral connections is a parallel first step in the ecology of games framework.

Although attention to issues of WEF nexus governance is relatively new, the broader issue related to how the elements of nexus are governed is not. Extensive research has informed our understanding water governance, with perhaps less attention to energy and agriculture governance. For example, Gerlak [26] traces five historical streams of water policy in the United States and discusses the evolving nature of federal–state relations in water policy and management. Similarly, Rogers and Hall [27] take a global perspective on the concept of integrated water resources management (IWRM) to discuss governance arrangements in the water sector. Another line of research that has directly considered the use of water across a range of human consumption decisions has been the Water footprint literature that considers water sustainability and water resource management [28].

In recent years, WEF nexus research has grown in popularity, but it is not without criticism. One critique of the nexus framework has been its lack of formal conceptualization and lack of agreed upon definitions and praxis [29]. Another argument has been that the dominant conceptualizations are fundamentally depoliticized and do not adequately incorporate the social and political contexts necessary for understanding cross-sectoral negotiations [30]. To develop a more inclusive framework of WEF nexus governance research, a balanced approach to understanding the cross-sectoral connections and competing tradeoffs is needed. These nexus governance dilemmas are the same as the ICA dilemmas in which decisions by one government in one or more specific functional areas impact other governments and other government functions [17,31]. Therefore, we can apply the ICA approach to understand the barriers that prevent authorities from reaching coordinated decisions.

The ICA theory's central purpose is to address the fundamental dilemmas of policy design in complex, multi-scale, multi-function, and multi-level policy arenas, and to posit the conditions under which various governmental organizations choose to cooperate or not. It marshals theoretical and empirical elements from a variety of disciplines and makes explicit the impediments to collective action as well as the ways that these impediments might be overcome. For example, Feiock [17] describes the barriers that prevent coordinated decision-making through the lens of transaction costs and summarizes them into information costs, negotiation costs, external costs and enforcement costs. The ICA literature focuses on transaction costs which builds on classic transaction cost theories where optimal organization structure minimizes costs of exchange [32]. ICA, along with other governance system theories, incorporate collaboration and cooperation as mechanisms to reduce transaction costs [33,34]. Similarly, there are costs to centralization including uncertainties about the balance of authority among actors, disruption of ongoing governance activities, and the potential transformation of an interorganizational dilemma into an intraorganizational ICA dilemma [17,35,36]. Understanding these costs is necessary, but increasingly difficult, as the complexity of the ICA dilemmas involved increases, as in the nexus case.

As described in the ICA literature (A full list of ICA scholarship is available at https://localgov.fsu.edu/research-programs/institutional-collective-action-ica-framework), there are a variety of collaborative mechanisms available to local actors [17,21,22]. These mechanisms rely (to varying degrees) on political authority, legal or contractual arrangements, or social embeddedness as well as the complexity of the issues and sets of actors. Among the described mechanisms for integrating ICA problems, nexus governance exemplifies the "multiplex self-organizing systems" category, where these systems "rely on embeddedness for policy coordination across various policies and functional areas. Agreements that are difficult to negotiate individually may be more feasible when embedded in a set of relationships for a related policy ... cross-policy reciprocal relationships can provide both parties greater assurance for much more stable exchange than if the relationships are one directional" [17] (p. 403). Within the ICA framework, multiplex self-organizing systems, such as the WEF nexus, use network embeddedness as a mechanism for encouraging collaboration. Specifically, network interactions that connect one functional area to those in other policy areas can help build social relationships, identify partners who are less likely to defect, and may reduce transaction costs [17].

Social connections and overall network connectivity are at the heart of nexus governance. Two specific sets of conditions that are related to connections between policy and management sectors

have referred to these as "intersectionality" and "interactionability" [37]. These concepts capture the extent to which the connections among actors in each of the water, energy, and food sectors are understood, and the extent to which these three sectors interact with each other. In a recent study of nexus issues in the Mekong River Basin, Smajgl et al. [25] introduce the concept of the "dynamic nexus approach" that concentrates on continuous interactions among the three sectors (water, energy, food) as well as the interaction of each sector and the "nexus core". The nexus core is made up of critical drivers for water, food, and energy sector dynamics and cross-sector feedbacks. In the Mekong, for example, population growth and climate change are identified as nexus core properties. The nested conceptualization of multi-sector interactions is helpful in developing a broach framework that encompasses the interactions of the various sectors as well as how each sector may interact with core properties that have either direct or indirect externalities. This cross-sector perspective can guide development investment by identifying tradeoffs that may offset or complement economic or social benefits from one sector to the next. The overarching goal is to develop policy interventions that account for cross-sectoral dependencies rather than focusing on policies that historically have been sector specific and independent.

In considering the WEF nexus as an ICA dilemma and applying the ICA governance framework to understand how collaborative partnerships develop and evolve within regional policy networks, there are obvious similarities to the dynamic nexus approach as described in Smajgl et al. [25]. Both approaches emphasize the role of actors, institutions, and networks in navigating complex policy environments with interdependent processes. The value of applying ICA to nexus governance research is that it provides a more formalized process by which actors participate in policy venues and how the product of those interactions would be expected to produce operating rules. While there are many theoretical linkages to explore in the dynamic nexus approach, we focus on the first stage—the participation of various actors.

It should also be noted that within the larger water governance space, there is little question that the focus has been on understanding the polycentric, multi-stakeholder, and multi-level character of policy and management decisions [38,39]. The conceptual foundations of much of this research has shown that there are many parties and interests involved in making decisions about the use of natural resources [40]. The efficient use of water resources, for example, likely requires some type and level of joint decision-making, yielding results that represent complex optimal (even sustainable) outcomes [41–43]. However, institutional and organizational factors that drive effective and equitable service outcomes may differ across sectors and be context specific [44]. Regardless of policy areana, joint decision-making is grounded in the idea that there needs to be a high level of communication, collaboration, coordination, and cooperation among the parties involved in making policy decisions.

The general conditions under which this joint decision-making occurs, specifically the conditions under which different parties do (or do not) communicate, collaborate, coordinate, or cooperate with each other in making decisions, are key to solving these complex collective action problems [17]. Public policy and management domains that would benefit from, even require, joint decision-making face exceptionally high barriers and impediments. Stated another way, while increased joint policy and management promises to produce better (more optimal) outcomes, these outcomes come with significant trade-offs [17]. As discussed below, some of these trade-offs are thought to be so significant as to make joint policy and management extremely unlikely or impossible to achieve.

In the sections that follow, we take the case of the San Antonio, Texas region to explore the connections and level of communication across a wide variety of WEF nexus actors to determine the level of "siloing" that occurs across the three sectors and identify potential cross-sector policy institutions that may be used to guide mutually beneficial development investment. The crux of this paper is that nearly all of the conceptual underpinnings to consideration of nexus governance issues seem to agree that inter-connections, communications, and interactions represent the keys to achieving greater resource efficiencies. The analysis below outlines and examines the presence of the nexus

communication network in an attempt to identify the extent to which that network exists at different communication time points and identifies important regional actors in the communication network.

## 3. WEF Nexus Governance: The Case of the San Antonio Region

The South Texas region centered in San Antonio, Texas presents a particularly salient location to examine nexus governance issues. We use the term "region" here to convey the idea that the geographic area of relevance is larger than the city or its county. Pragmatically, the region consists of the geographic areas where the natural resources are, including the surface water (river ways), groundwater (aquifers), watersheds, natural gas and petroleum deposits, and farmlands. The San Antonio region used here roughly corresponds to the Texas Water Development Board's "Region L" planning district but includes part of "Region K" as well. San Antonio is considered a "nexus hotspot" because this region presents an extensive array of water, energy, and food/agriculture challenges [45]. The primary source of water—the Edwards Aquifer—corresponds geographically with a large and growing city, a significant source of energy (natural gas and petroleum) resources in the form of fracking in the Eagle Ford Shale, electricity generation, and the location of significant agriculture, farming, and food processing industries. The city also faces challenging water shortages, and projections into the future suggest that these shortages will likely only get worse. Whether due to population growth, periodic and prolonged drought, increased demands from energy producers and electricity generators and the agricultural and food processing communities, or judicial mandates that the Edwards Aquifer not be depleted, the water challenges are clear.

In the San Antonio region, there are numerous governance organizations, some operating at local levels, and others having regional or statewide authorities and jurisdictions. In the water sector alone, there are at least 58 organizations with decision-making authority at multiple levels of government. These include the two primary state agencies, the Texas Commission on Environmental Quality and the Texas Water Development Board. In energy, there are at least five governmental organizations, not including a number of the river authorities that have responsibility for generating and selling hydro-electricity. In the food/agriculture sector, there are at least six such governmental organizations including the primary food and agriculture agency, the Texas Department of Agriculture. Regional levels of governance include a number of river authorities, regional planning offices of the Texas Water Development Board, and others. Local level governance includes a number of municipal water and energy utilities, including the San Antonio Water System (SAWS) and CPS Energy, the San Antonio Office of Sustainability, and seventeen largely county-based, state legislature-authorized, Groundwater Conservation Districts. These districts have legal authority for permitting water wells and water extraction within their geographic areas, including wells that might provide cooling for electricity generation.

Each of the water sector institutions play a role in water management and policymaking, ranging from long-term planning, to monitoring and regulating groundwater, to managing water resources and municipal wastewater, overseeing the major rivers, and implementing programs and policies to achieve greater water efficiencies. With a more detailed outline of the responsibilities of each organization, it becomes clear that the responsibility for nexus management and decision-making is complex and potentially fragmented.

From a governance perspective, the San Antonio region possesses institutional characteristics that make it a highly complex and fragmented area for water, energy, and food management and policy. Although space does not permit a full recitation of the legal authorities and responsibilities of all the water, energy, and food/agriculture agencies, it is clear that each type of organization has specific authorities. Perhaps more important, there is no agency that has explicit authority for managing nexus issues per se, although all organizations may potentially produce impacts beyond their own respective sectors. Of course, there are many state laws—statutory, case, and constitutional—that both authorize and constrain water, energy, and food decisions in the San Antonio region.

The ICA approach applied to nexus governance would suggest that fragmentation among institutions will pose challenges in effectively managing the environment [46,47] and that more successful management of natural resources occurs when organizations communicate and collaborate [21]. Given the multiplex self-organizing system problem with no externally imposed authority or mandate for cooperation, if there are few social connections or low levels of interconnectivity, we would expect sub-optimal natural resource management. In the absence of a mandate, any cooperation or coordination among the nexus governance agencies would be the result of voluntary, self-organizing arrangements. Such voluntary arrangements would have to address the myriad impediments, including high transaction costs, perceived risks associated with potential loss of various benefits, free-ridership, and many other externalities [48]. As explained below, this analysis focuses on a central prerequisite of cooperation and coordination, inter-agency communication.

## 4. Data Description and Social Network Analysis

As an initial step in the process of delving into the nature of public decision-making related to the nexus, a preliminary study was designed to elicit information from the people and agencies with legal water authorities, as outlined in Portney et al. [49]. A questionnaire was designed to ask water managers and decision makers in the San Antonio region many questions about their roles, responsibilities, decisions, and interactions with other decisionmakers. A list of 289 water managers and decision makers was compiled in September 2017. Of those, 58 people were subsequently determined to be unavailable or inappropriate for the purposes of this study. The following analysis is based on 101 responses from that survey. The response rate is estimated to be 43.5%.

The questionnaire asked each water sector respondent to identify frequency of contact with other water sector agencies, with energy sector organizations, and with food and agriculture groups "over the last year". The survey instrument is available online at https://u.tamu.edu/water.Specifically, the question asked relating to contacting water organizations was:

"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?"

We also asked each water decision makers to identify the frequency with which they have contact with people in energy agencies and organizations, and with food and agriculture agencies. The question asked relating to contacting energy and food/agriculture organizations was:

"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?"

The survey used a multi-modal approach, as prescribed by Dillman et al. [50]. First, a mailing was prepared with a cover letter addressed by name to each potential respondent. This mailing included a paper questionnaire, a post-paid return envelope, and a post-paid postcard used to separately track those who responded. The letter offered an option to complete the survey online using Qualtrics. Among the respondents, 41 completed the questionnaire online, and 60 returned the paper questionnaire.

Social network analysis has long been used as a method of examining relational data and has recently emerged as an important tool in policy and governance sciences [38,51–53]. An underlying theme of WEF nexus research is the idea that connections and trade-offs must be better understood, and that decisions that affect the uses of one resource must take into consideration the impacts on the others [15,54]. Indeed, the implicit goal of WEF nexus research is coordination of these decisions such that the connections or trade-offs are optimized. We therefore suggest that effective governance of the WEF nexus requires a high level of cooperation and coordination among decision makers, stakeholders, and managers [41,54]. Conversely, decisions made in one sector with no regard for impacts in the others inevitably yield suboptimal results. Understanding the structural connections as stated in Smajgl et al. [25] is the entry point at understanding other aspects of coordination and effective governance.

Social network analysis provides a useful set of strategies and metrics in depicting the structural connection in the nexus communication network. Social networks are comprised of "nodes" and "ties", where the nodes are individuals or other social actors and the tie represents some defined relationship. These nodes and ties are often depicted graphically in a network "map". There are many metrics available to examine the nature of a given social network, such as structural analysis, which can examine the extent to which an overall network is densely or weakly connected. It can also identify the most centrally connected nodes, or the nodes that are connected to these central nodes, among other things. In the description below, we refer to some of the metrics that we would expect to accompany different possible hypothetical maps in WEF nexus governance networks.

While social network analysis initially omits all qualitative or descriptive information, recent developments allow network analysts to incorporate actor characteristics into the analysis [55]. For example, a network comprised of individuals would benefit from integrating gender, age, and marital status. Within the WEF nexus framework, it may be useful to examine organizational size, age, geographic location, public/private ownership, natural resource sector, etc. It becomes important to accurately identify the patterns of relationships, e.g., weakly/sparsely connected or densely connected, within the policy making or agenda setting arena. In Figures 1 and 2 below, we demonstrate this visually by identifying the organizations that belong to the water, energy, or food sectors.

An important aspect of network analysis in natural resource governance is outlining or capturing potential flows of resources and information [56]. For instance, organizational network studies demonstrate how gatekeepers often use their strategic location as a network broker to attain power or exert control over some resource [57]. This gatekeeping behavior potentially thwarts efforts to create efficient and sustainable communities and instead may provide opportunities for managers to engage in opportunistic behaviors and control or distort flows of information [58,59]. When present, network analysis can effectively identify holes or disconnections in the overall structure, as well as identify the key gatekeepers or key players in the overall network. The most clearly identifiable disconnections are the number of components or otherwise disconnected "cliques" in the overall network. When "siloing" is present, we expect to see several subgraphs or cliques that are completely disconnected, or only tangentially connected.

In addition to the individual connectivity characteristics, network analysis also measures aspects of the global, or overall, network. Measures of connectivity at the global level allow us to determine if the specific geographic area has a high or low level of connectivity which will influence strategic cooperation and collaboration on projects dealing with policy implications on natural resources. Thus, network analysis allows for examination of relationships at the node level as well as the network level. Average degree centrality and whole-network density are two commonly utilized and appropriate measures of overall connectivity. Degree centrality is simply the number of connections each actor is connected to, and average degree is the average of all actors' degree centrality scores present in the respective network. Whole network density is measured as a ratio of the number of ties present to the number of possible ties. It can be expressed as a percent and easily interpreted as the percent of ties observed in the total network.

We use social network analysis (SNA) to determine the structural characteristics and locations of organizations involved in the nexus governance network in San Antonio. As stated above, SNA is a method used to gather information about social relationships and examine them within a larger relationship structure. In each SNA study, the node and tie are defined; here, the node is a WEF institution and the tie is the frequency of communication between nodes. These ties are examined as a larger social network structure, see figures below, and graph theoretic methods are used to determine which institutions occupy specific locations and levels of connectivity within the larger social structure. These methods are applicable to WEF systems in any geographic region. It is possible that there are three separate individual networks representing the three sectors of food, energy and water, and that these networks are largely disconnected from each other. This, of course, would depend on which frequency of communication is being highlighted.

Figure 1 captures the image of the communication network in the San Antonio region for water organizations. This figure shows the connections between organizations involved specifically in water policy and management without the energy or food connections. The tie represents communication that occurs at least once a month. Light grey nodes represent water management organizations and the nodes are sized by degree of centrality, or the total number of ties for the individual node. What this figure visually reveals is several levels of connectivity among water organizations. A few represent high levels of connectivity with other organizations, but there are many organizations that are tangential or connected only to a small number of organizations. For example, some state and larger regional agencies—the Texas Commission on Environmental Quality (TCEQ), the Texas Water Development Board, and the Guadalupe–Blanco River Authority—are represented as larger, more connected organizations in the network. Other larger and more connected organizations represent important actors in the city of San Antonio and regional authorities headquartered in San Antonio, such as the San Antonio Water System (SAWS), professional hydrologists and the Edwards Aquifer Authority. This information is important for local governments and governing bodies because it provides information on potential avenues for information dissemination, identifies the predominant actors in the water governance network, and also identifies those which are not well-connected. It is also important to note that there are numerous organizations connected to the network by only one tie. This problematic network structure is elaborated more below.

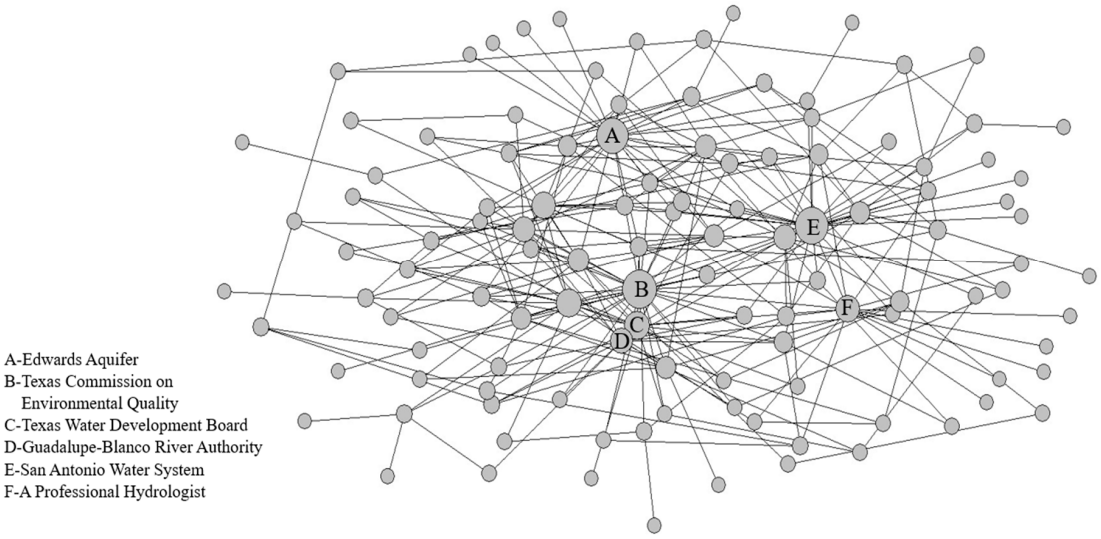


**Figure 1.** Water Governance Network in the San Antonio Region. Note: Monthly communication network graph. The nodes in each graph are sized by degree of centrality.

Figure 2 shows the water governance network connections depicted in Figure 1, but adds to it connections with energy organizations, represented as dark grey nodes, and food/agriculture represented as white nodes with dark rims. There are five energy organizations and five food organizations that seem to be in regular communication with at least one water organization in the region. One of these is CPS Energy, which is the city-owned electricity and natural gas utility company for San Antonio. Two of the energy organizations are state agencies—the Texas Public Utility Commission and the Texas Railroad Commission—both of which have statewide authority for some aspects of energy regulation. The fourth organization is EOG Resources, a large private sector oil and gas extraction (including hydraulic fracturing) company that operates in the Eagle Ford Shale just south and west of San Antonio. The fifth is a nonprofit organization called San Antonio Green Space Alliance, that works with municipal and county agencies to promote energy conservation and environmental protection. Two of these five agencies are network pendants, meaning they are only connected to the network by one tie. These organizations, Texas Railroad Commission and EOG Resources, would be completely disconnected

from the network if that relationship was severed. As such, they occupy a very tenuous connection to the larger network and, arguably, are not likely in collaboration with other WEF organizations.

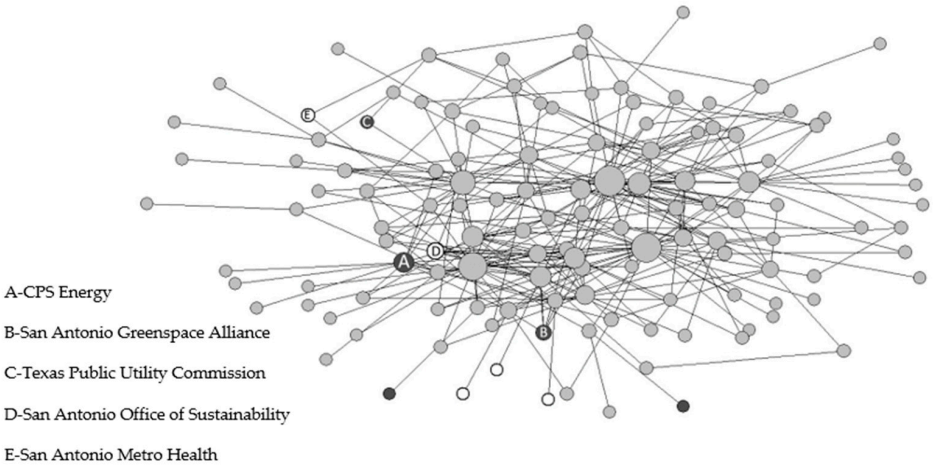


**Figure 2.** Water–energy–food/Agriculture/Nutrition Nexus Governance Network in the San Antonio Region. Note: Monthly communication network graph. Light grey = water, dark grey = energy, white with dark rim = food/agriculture.

Of the five food and agriculture organizations, four are local level, including the San Antonio Food Bank, the San Antonio Food Policy Council, the San Antonio Metro Health District, and the San Antonio Office of Sustainability. The fifth agriculture organization, the Texas Farm Bureau, is a statewide nonprofit trade association. Although these organizations have some connections, particularly to the water organizations, only two organizations have more than one tie and are not connected to the core water agencies. The Texas Farm Bureau, San Antonio Food Bank, and the San Antonio Food Policy Council are pendants. Like the energy organization listed above, if that one tie is severed, they are no longer connected to the network. While the connection is present, it is weak and susceptible to defection or fragmentation. Finally, there are several energy and food organzanizations that were completely disconnected from any aspect of the larger network.

There are several energy and food organizations that were completely disconnected from any aspect of the larger network. Generally, there is little evidence that WEF nexus governance is taking place, under the assumption that communication across the three natural resource and policy areas is a precursor to collaborative governance. Although there are two state agencies with some connection to water policy and management organizations, the connections are weak. If it does exist, it would have to operate through mutual connections with specific agencies, especially the Texas Water Development Board and SAWS.

Based on the information from the visual representation in the network analysis, it appears to be clear that there is little cross-section communication among the surveyed actors. Specifically, there is little evidence that across policy areas of water, energy, and food organizations that there is much communication or collaboration. However, it should be noted that in each figure there is only one network component. This suggests that while connectivity may be very weak and infrequent, the ties present create one overall network. The contrary would be several disconnected and smaller networks which would imply siloing or identifiable fragmentation. There is some evidence that what communication that is taking place is occurring through state and local agencies. Yet even here, the connections are relatively weak, as these ties represent the presence of communication at least once in a month.

The network graph highlighting weekly communication is even less connected, explained more below (Network D, Figure 3). The resulting network for weekly communication includes no food organizations and only one energy organization. Many connections between water

organizations also disappear and the overall network breaks apart into seven smaller components or cliques. This phenomenon occurs when looking at weekly communication in the water–energy, and water–energy–food networks, specifically, with very few ties among disconnected subgroupings. While there may be opportunities for analogous connections in the energy and food sectors, the role of state agencies seems weaker than within the water sector.

## 5. Frequency of Communication

As a robustness check on whether our findings are an artifact of the frequency of communication, we examine several network metrics across different time points to highlight trends and features of the nexus communication network. The graphical depiction of the Nexus Communication network across four different time periods is available in Figure 3. In each network graph, the water organizations are represented by light grey circles, agriculture by the dark grey circles and food/agriculture by the white circles with darker rims. It is clear that the network size and connections decrease as the progression from annual to weekly communication occurs, though as stated above, this is expected. There are some other notable interpretations to be taken from this figure. First, while it is commendable that several energy and food/agriculture organizations are visible in the network, they are nearly all located in the periphery or toward the bottom of the larger network. Second, several of these same organizations are pendants, meaning they are connected to the network by only one tie (see bottom-left quadrant of A. Annual communication). This remains the case in the quarterly and monthly communication, unless the organizations drop out of the network. Finally, the potential fragmentation in the weekly communication network creates high risk for the cohesion of the overall network. Specifically, there are numerous areas where, in the case that one actor defects from the network, the overall network will fragment or separate into smaller network components. Overall, this is due to the sparse connections throughout that specific network.

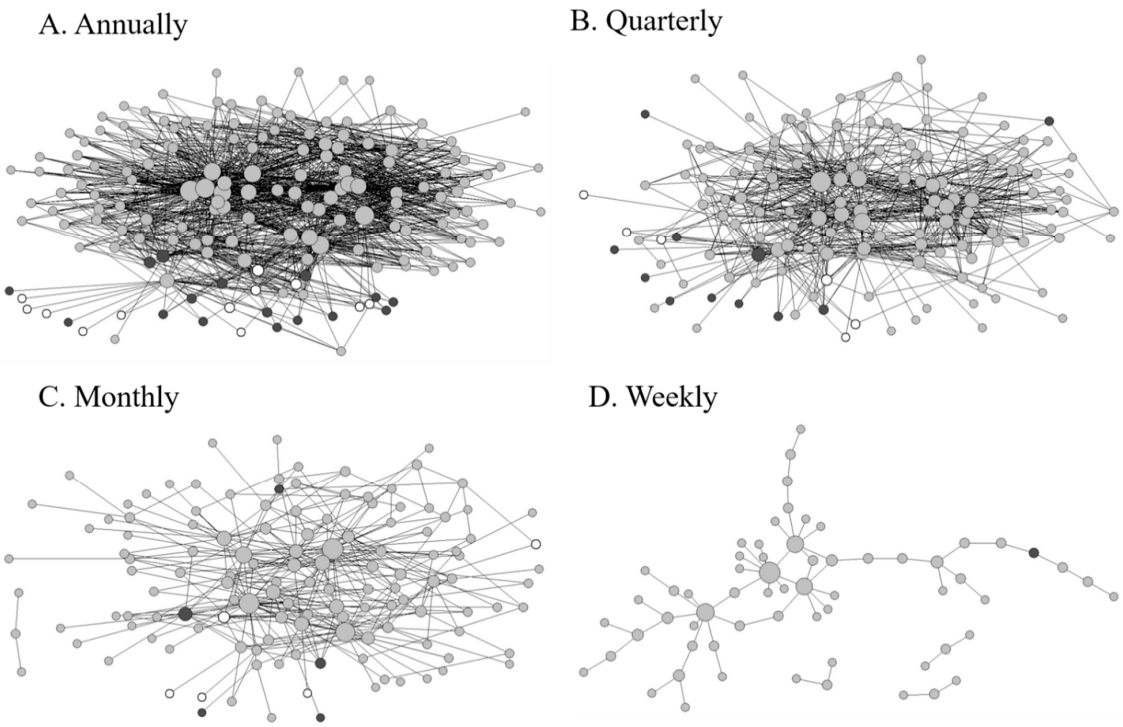


**Figure 3.** Nexus Communication Network at Four Periods of Time. Note: light grey = water, dark grey=energy, white with dark rim = food/agriculture.

Table 1 provides communication network metrics at different time intervals. It starts with the total number of nodes, or organizations, that are communicating with other actors in the corresponding time

frame (column 1). The second column highlights the total number of ties. It is important to note, that each of these measures decreases significantly as communication moves from annually to weekly. This decrease, however, is expected and likely appropriate for nexus governance. It can easily be argued that not all organizations and managers need to be involved in each aspect of network governance. It is, therefore, expected that these two metrics would decrease as communication becomes more frequent.

**Table 1.** Communication Network Metrics at Different Time Scales.

| Communication Frequency | Total Number of Nodes | Total Number of Ties | Average Degree | Whole Network Density |
|---|---|---|---|---|
| Annually | 169 | 2470 | 14.6 | 0.087 |
| Quarterly | 151 | 1382 | 9.2 | 0.061 |
| Monthly | 132 | 618 | 4.7 | 0.036 |
| Weekly | 63 | 124 | 2.0 | 0.032 |

The other two metrics in Table 1 address less of the presence of actors in the network and instead reflect aspects of individual and overall connectivity for each level of communication. Average degree centrality is the average of all individual degree centrality measures. As stated above, degree centrality is the sum of the individual network actor's ties. The larger the value, the more connections the node has. As seen in Table 1, organizations in the nexus communication network communicate with an average of over 14 other organizations annually, and only 2 organizations weekly on average. Overall, the impact of the decreasing degree centrality scores suggests that as frequency of communication increases, institutions are communicating with fewer other institutions. While it is unknown what the optimal level of communication is and communication may vary depending on specific environmental and governance characteristics, the empirical implications of the decreasing degree centrality score highlights the weakening of the communication network by frequency of communication.

Whole network density, again, is a measure of overall connectedness in the overall network. The overall network density measure is quite low, with between 3 and 8 percent of possible ties observed. With density, we see a similar trend, namely that connectivity is decreasing overall, albeit only slightly, from monthly to weekly. Essentially, this decreasing value suggests that as communication becomes more frequent, there is less of a densely connected network and instead a more sparsely connected network. The sparseness is visually evident in network D of Figure 3. While it is expected that the size of the network will decrease, ideally the connectivity would not. The impact of the decreasing connectivity may result in an increased risk of fragmentation, with the communication network being arguably less effective than it could be otherwise. The potential inefficiency exists because the sparseness in the network may impede the transmission of information among actors and allow certain actors to control or distort the information transmitted. There may also be a general unawareness of what policies, strategies, and practices other clusters of actors are engaging in when organizations are mostly disconnected.

These measures serve as a robustness check on our previous results. We find additional support that when it comes to regular intervals of communication, there are relatively low levels at the weekly or monthly level. For specific organizations, such as a local government, this indicates relatively low WEF communication in day-to-day decision-making regarding resource management. As stated, this type of communication mapping is a necessary first step to understanding how resource trade-offs decisions are made for WEF governance.

## 6. Discussion: Beyond Network Descriptions

The institutional collective action approach emphasizes institutional structures and the participation of actors in regional policy networks. As described in the theoretical framework, the first step in developing effective nexus governance is to understand the interactions among stakeholders. Once the connections are identified and understood, we can then begin identifying

potential trade-offs and synergies to design effective governance policies. As shown in Figure 1, Figure 2, and Figure 3, there is little direct communication across the policy areas in San Antonio, which suggests that resource management decisions across the policies areas are siloed. This raises questions about how effective nexus governance can be developed in such a region. However, there are several findings, combined with generalizations from the ICA framework, that we might use to build a path forward towards improved governance. For example, within the water sector communication exists between local and state agencies, suggesting that there is some degree of multilevel governance. Drawing on the ICA literature, we propose three potential paths forward: 1) build on the existing "vertical" connections by focusing on regional state actors; 2) recognize the role of high capacity actors such as large municipal providers; 3) develop network-based measures of potential trade-offs and synergies.

In the ICA literature, actors participate in policy venues to produce operational rules that govern common pool resource dilemmas. As demonstrated by the water sector graph (Figure 1), several of the central actors are state level institutions such as the Texas Water Development Board (TWDB) and the Texas Commission on Environmental Quality (TCEQ). This result suggests that rather than interacting directly to already established rules, water actors may interact with state agencies to develop policies and set those governance rules. In ICA theory, state and regional agents can serve as the policy venues to be used to bring together stakeholders. The water–energy–food network graph (Figure 2) offers moderate support to this possibility, with most state agencies having the majority of their contact within their policy area. However, there are a few exceptions. The Texas Public Utility Commission and Texas Railroad Commission are connected to water actors but are not central to the network. Instead, a regional nonprofit, the Green Spaces Alliance of South Texas, seems to play a bigger cross-sector role. The most central cross-sector actor is CPS, the municipal energy utility, which supports the second path forward—high capacity actors.

There are several avenues to extend this research. While the central goal of this paper is to outline levels of communication across the WEF nexus, the obvious subsequent question is why are some organizations communicating more than others? Certainly, organizational capacity will impact what actions organizations are able to take on. However, there may be other reasons why some organizations do not communicate frequently. Understanding this reasoning provides a useful source of additional information. As also stated above, it is unclear how much communication is necessary for effective nexus governance. This project may outline and elaborate on challenges faced by the nexus, or each resource individually, and try to determine how much communication is requisite to solve specific issues, vs. how much is too much, which will add further transaction costs to an efficient nexus governance network.

Another path forward, rooted in the work of Kurian [60], suggests that the extent to which a given nexus governance network produces effective trade-off decisions can be systematically measured. For example, Kurian develops an example of a "wastewater reuse effectiveness index" (WREI) that measures, for a given jurisdiction (in his case, a nation), an important policy outcome or result. What SNA promises to add to this analysis is the inclusion of a key explanation for why some jurisdictions seem better able to produce high effectiveness while others produce lesser effectiveness. The underlying assumption about inter-sectoral connections is that connections increase the levels of resource efficiency or efficient governance of the resource at hand. Following this argument, creating and fostering connections among organizations may be an effective way to increase natural resource governance and equitable distribution of natural resources. Our expectation is that better connected networks will produce higher levels of WEF efficiency and effectiveness. However, as seen in the figures above, there does not appear to be much communication across the different sectors of the WEF system. Ideally, efforts moving forward must first increase inter-sectoral communication and collaboration before more of a complete understanding of trade-offs and synergistic activities within the WEF system can be examined.

## 7. Conclusions and Implications

This paper relies on the Institutional Collective Action theory as a foundation to highlight the importance of communication among different resource sectors of the water–energy–food nexus. The paper also relies on role of communication in collaborative governance to highlight the different sectoral connections in the WEF nexus, as proposed by Smajgl et al. [25]. The results presented here highlight important initial steps in identifying coordination and collaboration among water, energy, and food/agriculture agencies. If coordination and collaboration among organizations represents a necessary condition for achieving nexus efficiencies, then there is much room for improvement in the San Antonio region. There is very little evidence of joint governance of water, energy, and food and resource management decision-making appears to be siloed.

The characterization of communication, however, represents only a step in creating a more thorough understanding of potential cooperation and collaboration among WEF actors. The nature of the network analysis does offer some insights into pathways to cooperation and a communication network structure. Based on observable behavior, it is clear that some larger regional organizations along with the state water agencies are more centrally positioned than others and are more involved in communicating with other actors about water management. In the search for ways to further develop understanding of policy preferences and concerns about nexus between water, energy, and food, targeting central organizations that already have significant contacts and connections with other agencies may provide important and influential information.

If one were to prescribe where, in the San Antonio region, efforts to improve awareness of WEF nexus, the core water agencies would seem like the logical place to start. These agencies include the Texas Commission on Environmental Quality and the Texas Water Development Board, along with more localized and regional agencies including the San Antonio Water System, the Edwards Aquifer Authority, and the several river authorities. To improve WEF governance in the San Antonio region, we find that cross-policy area communication is a necessary place to start. More specifically, communication networks both within a single policy area and between multiple policy areas are relatively sparsely connected. We do not have a prescribed optimal level of communication, but we find that such low levels of communication exist that the theoretical optimum is almost certainly at a level that is higher than what we currently observe. To improve these communication networks, we find that the regional water authorities may prove to be valuable central nodes.

An important point to note for this study is that none of the water governance organizations in this region have explicit legal authority or responsibility for engaging in cooperative or collaborative actions with energy or food agencies. Anecdotally, some organizations have suggested that they cannot engage in such actions under their current authorities and missions. In addition, none of the agencies have a specific identifiable incentive for engaging in collaborative behaviors. The starting point for serious reform efforts is to, where possible, alter the legal authorities and responsibilities for water agencies to engage with their energy and food counterparts. Even simple mandates to periodically engage with other agencies could make a significant difference in raising awareness of nexus trade-offs. Suffice it is to say that, in the absence of such mandates, coordinating and communication mechanisms do not seem to develop on their own. ICA points to the myriad reasons why such coordination is unlikely such as high costs of communications and coordination, perceived risks associated with potential loss of various benefits, free ridership, among other things.

There are several limitations in this paper that need to be noted. First, like all survey research, this paper may be subject to potential survey bias. We do not believe this potential bias is fatal in this type of survey as questions are being directed toward organizational behavior and not the individual themselves. However, there is yet potential for survey bias. Another shortcoming of this paper is that we survey only water managers, or those with legal authority to make decisions regarding water. We make the assumption that communication is reciprocated, meaning that when the water organization states they have communicated with another organization, we assume that the communication goes both ways. However, since we did not ask about communication from the energy

and food sectors, we cannot be completely certain that the communication is indeed reciprocated. This limitation opens a potential avenue to further explore this line of questioning from all organizations. This dilemma, however, was beyond the scope of this initial paper.

The other aspect which needs further discussion beyond this paper is how much conversation and communication "should" be happening among stakeholders and managers in these sectors. While it can be argued that more communication may result in a better and stronger relationship between the organizations, it could also easily be argued that frequent communication may be required to resolve conflicting issues among organizations with vested interest in the natural resource. Ultimately, we are not suggesting or providing a framework about how much communication is required, or minimum levels of communication for an effective and efficient relationship. However, while we do not provide minimum levels of communication, we do suggest that no communication is not optimal for effective WEF governance. Establishing a framework or typology of efficient WEF communication is a fruitful avenue for future research.

This research is a preliminary step in a larger effort to understand network and polycentric governance of natural resources. Initial additional steps include distributing the survey to energy and food/agriculture managers. Further analysis will also be helpful in empirically examining the full foundational framework presented by Smajgl et al. [25]. For example, once the communication network is documented we may then proceed to identifying trade-offs and synergies in the policy making process as well as distribution of resources to certain populations. Once the network structures and processes are outlined and understood, then effective measures can be prescribed to help mitigate and reconcile natural resource issues in an ongoing effort to promote sustainability.

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