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South Texas Water Resource Mental Models: A Systems Thinking, Multi-stakeholder Case Study

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Abstract: The Coastal Bend (CB), Lower Rio Grande Valley (LRGV), and Wintergarden (WG) subregions of south Texas co-exist in similar socio-economic contexts but rely on markedly different water sources (CB: precipitation; LRGV: surface water; WG: groundwater). This has led to unique agricultural practices and municipal policies and reinforced mental models adapted specifically to each subregion, both of which are critical to understanding structural causes behind current water use and future water sustainability. To better stakeholder mental models in each subregion, semi-structured interviews were conducted with individuals with a significant stake in water resource use and management. Results indicated near unanimous consensus among farmers and other stakeholders that water supply is limited and will be increasingly stressed under continued urban population growth. Farmers expressed concern that it will become more difficult to continue farming if additional water resources are not available, while each subregion expressed their own unique concerns: growing bureaucratic oversight and growing population problems (CB), lack of inflows, poor water quality, and international disputes with Mexico (LRGV), and political subdivision, declining groundwater levels, and information technology costs (WG). Mental models were synthesized based on dominant themes expressed by respondents; we synthesized these into two systems thinking archetypes: Tragedy of the Commons and Success to the Successful. Though it is unreasonable to create blanket region-wide policies, the adoption of under-utilized conservation practices coupled to stakeholder outreach remains unexplored leverage points, given most stakeholders are unaware of the feedback processes continuing to threaten south Texas water resources.

Keywords: *water management, mental models, systems thinking, stakeholder analysis, Texas*

South Texas is a major agricultural region reliant upon three distinct water sources: precipitation in dryland cropping systems in the Nueces River watershed and surrounding Coastal Bend (CB) plains; surface water flows for ditch irrigation that are generally low quality in the Lower Rio Grande Valley (LRGV) (Vargas 2019); and groundwater sources for pivot sprinkler irrigation in the Wintergarden (WG) area (Figure 1). Each subregion is stressed by water availability and quality fluxes that are often exacerbated by management of cropping and irrigation system decisions as well as drought conditions which limit crop productivity, streamflow, and groundwater recharge (Figure 2). Additionally, each subregion faces unique water quality challenges, such as nutrient loading and urban stormwater runoff problems, leading to excessive aquatic plant growth and potential disease transmission pathways in the LRGV, or perennial salinity issues due to poor soil quality and declining groundwater tables (CB and WG). Each subregion is additionally stressed by population growth and economic development (which compete with agriculture for both land and water), including water sharing agreements with Mexico (CSIS 2003; Fischhendler et al. 2004; Carter et al. 2017) and escalating effects of climate change (Seager et al. 2007). Cumulatively, these threats put the sustainability of south Texas water resources at risk, escalating pressure on agricultural

Research Implications

- Stakeholder mental models expressed more concern than optimism and contained unrecognized vicious feedbacks connecting to other stakeholders.
- These mental models and feedbacks must be recognized if adaptive water management is to succeed.
- Collaboration and better communication are high-leverage strategies needing investment for improved water resource management.

stakeholders to minimize water losses, which often requires investments or tradeoffs too costly for many irrigation districts or producers to consider (e.g., relining ditches or replacing failing pipe systems in the irrigated areas, or investing in alternative nutrient management or cropping systems in the dryland areas). Research from similar contexts around the world has shown that attempting to solve any one of these issues in isolation has led to far-reaching, unintended ecologic, hydrologic, or economic consequences (e.g., reduced ecosystem services as result of effort to minimize conveyance loses; greater per capita water use in the face of water rationing policy; increasing investment in agricultural land and therefore irrigation demand as a result of investment in maximizing irrigation efficiency) (Gohari et al. 2013; Breyer et al. 2018; Di Baldassarre et al. 2018; Grafton et al. 2018).

Such complex, dynamic trade-offs have increasingly led investigators to adopt a systems approach to problem-solving (reviewed in Turner et al. 2016a, with exemplary case-study examples in Stave 2003 and Gunda et al. 2018). For all these reasons, holistic water management research is becoming increasingly important in this semi-arid region facing increasingly frequent and severe droughts. Unfortunately, decision-making models integrating hydrologic, ecological, agronomic, and socio-economic structures (similar to Turner et al. 2016b and Gunda et al. 2018) specific to south Texas, needed to compare tradeoffs from various coping strategies or their impact to other ecosystem goods and services requiring conservation and enhancement, are not available.

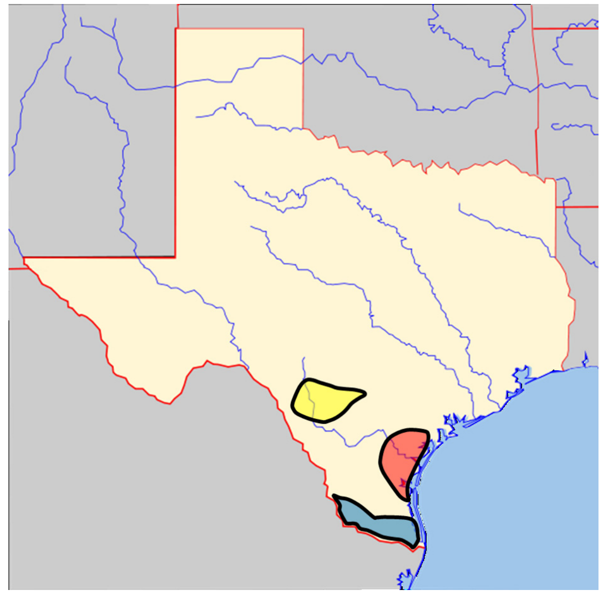

Figure 1. Map of south Texas illustrating the three project study areas: Wintergarden (yellow shaded), Coastal Bend (red shaded), and Rio Grande Valley (blue shaded). Modified "Blank map of Texas" by "Angr" is licensed under CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0/deed.en).

Although identifying farm- and catchment-scale drivers may reveal dynamic linkages between uplands with irrigated landscapes previously not emphasized, a better understanding of water resource stakeholders' decision-making goals, constraints, and mental models (by which decision-makers process information) is vital to improve model realism, quality, and adoption and use by stakeholders.

Objectives

The primary focusing question of our case study was the following: why do south Texas stakeholders struggle to balance the current water needs of diverse users with conservation efforts for everyone's long-term benefit? The goal or objective was to uncover the predominant mental models of individuals who maintain a high stake in water resource management in the CB, LRGV, and WG areas of south Texas. By doing so, this work aims to more usefully inform regional scientists currently developing improved quantitative management models for decision-support purposes; without capturing valuable mental model information,

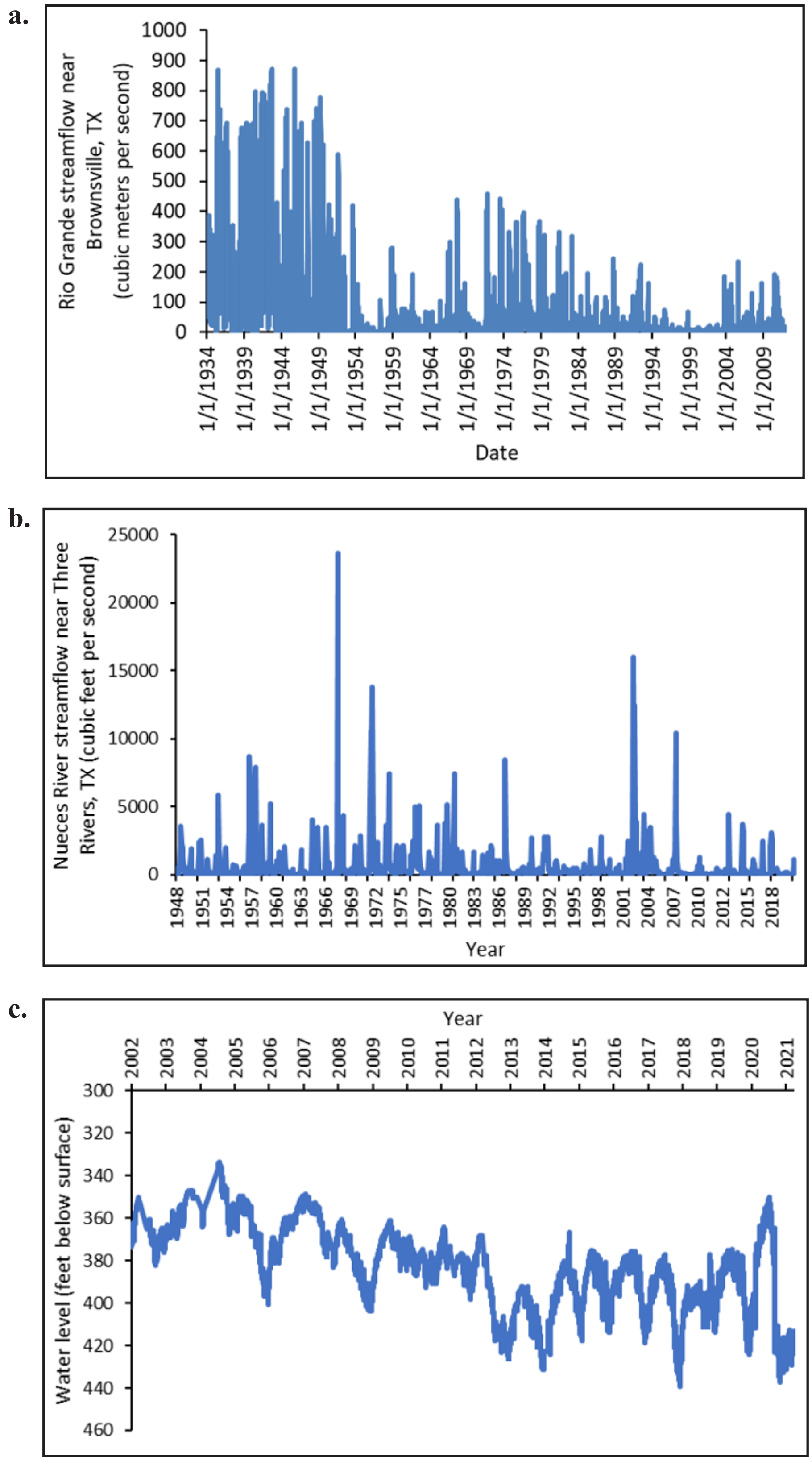

Figure 2. Illustration of stressed water supply sources in south Texas. (a) Rio Grande streamflow near Brownsville, TX, 1934-2021 (IBWC n.d.). (b) Nueces River streamflow near Three Rivers, TX, 1948-2021 (USGS 2022). (c) Carrizo-Wilcox groundwater levels near La Pryor, TX, 2002-2021 (Texas Water Development Board 2022).

important conceptual considerations, objective function assumptions, and/or modeled feedback processes may not be representative of decision-maker considerations in practice, therefore running the risk of disseminating decision-support tools of limited utility. Mental models tend to be accessible and enduring, albeit limited, conceptual representations about the world around us and how it works (Senge 1990; Doyle and Ford 1998).

To begin, we outline the general background policy context of Texas and the characteristic water sources used in each subregion: CB, LRGV, and WG, respectively. We then describe a qualitative data collection process using semi-structured interviews to elicit mental models of water resource stakeholders in each subregion. Analysis of interview responses is then presented. Finally, using concepts from the systems thinking methodology (Senge 1990; Sterman 2000), we generate integrated mental model descriptions of each stakeholder group and synthesize their high-level observations and concerns into causal loop diagrams (CLD), which illustrate the pressing water resource challenges using structural feedback mechanisms. The case study concludes with management and policy implications and questions for future investigations needed to find tangible solutions that are both socially acceptable and economically feasible.

Background Case Study Information

Policy Context

Water rights and resource use in Texas have historically been driven predominantly by economic forces, grounded in private property or "right of capture" legislation (Texas State Library and Archives Commission 2016). Given the variability of water fluxes (described below) and the multitude of stakeholders involved, this approach has made water sharing difficult, which is exacerbated during droughts (Sturdivant et al. 2007).

Legislation has evolved to reserve portions of current water storage or reduce pumping volumes for times of water scarcity (where municipalities and irrigation and groundwater districts have instituted such measures), although in many cases surface rights holders maintain their "right of capture." Texas began issuing water rights for surface water stakeholders in the 1890's (Texas State Library and Archives Commission 2016), but did not recognize the importance of protecting water for the conservation of aquatic ecosystems until 1985 (Sansom 2008).

Texas groundwater regulation is severely lacking relative to its surface water counterpart. Groundwater ownership is predominantly still regulated by the right of capture. The creation of groundwater districts is the exception to the rule of the right of capture. In applicable areas, groundwater districts develop and manage groundwater resource plans, address conservation, and adopt rules of procedure for their respective districts (Texas A&M University 2014).

Bordering both Mexico and the USA, the Rio Grande River has its own unique set of policy characteristics. Because it is both a water source and international border, distribution of water rights is determined by international treaty, the most recent of which was agreed to in 1944. Besides specifying water rights and delivery obligations, the treaty also dictated that both countries construct and operate dams along the main channel of the Rio Grande (IBWC 2021). Populations in south Texas and northern Mexico have grown and precipitation has decreased due to more frequent droughts, resulting in failures to meet 1944 treaty agreements and rising tensions between the two countries.

Sources of Water Supply and Its Variability

The CB, WG, and LRGV subregions rely on different water sources for agricultural, industrial, and municipal use, despite their close proximity.

Coastal Bend. In the CB, precipitation is the primary water source for agriculture, groundwater being too saline, while municipalities rely on surface water storage on the Nueces River. Due to the scale of row-crop agriculture (primarily cotton and sorghum) in the CB plains, limited surface water flow and storage potential on the Nueces River, and demand for water in Corpus Christi and surrounding municipalities, the majority of CB surface and groundwater supplies are owned by the City of Corpus Christi and the Nueces River Authority and reserved for municipal and industrial use (Coastal Bend Regional Water Planning Group 2015). Historical rainfall varies in range from 13.6

to 35.7 cm per year and predicting precipitation is not reliable (Murdock and Bremer 2016). Therefore, agricultural stakeholders must manage water resources during droughts differently compared to WG and LRGV areas (primarily through crop insurance rather than water sharing agreements).

Wintergarden. The WG area produces fruit and vegetable crops and relies predominantly on groundwater for both agricultural and municipal use. Major aquifers include the Edwards, Trinity, Edwards-Trinity, and Carrizo-Wilcox. The mean water depth for the area from 1940 to 2021 was 37.58 feet below land surface with a standard deviation of 15.14 feet (Texas Water Development Board 2021a). The Uvalde County Groundwater District predicts that future demands are going to continue to outpace inflows of supplies for the area, with the City of Uvalde taking the largest net deficit (UCUWCD 2015).

Lower Rio Grande Valley. The LRGV is well-known for diverse fruit, vegetable, and row-crop production and relies on surface water for irrigation. Rio Grande flows are stored at Falcon Reservoir, located southeast of Laredo, Texas. Irrigation districts order water from the reservoir and then divert via pumping from the river to canals that deliver to both farms and municipal providers. The Falcon reservoir has a 2,646,813 acre-feet conservation storage potential, of which 59% is allocated to Texas (lifetime mean actual storage = 1,550,632 acre-feet, standard deviation = 821,892 acre-feet; Texas Water Development Board 2021b). The average Rio Grande flow below the Falcon reservoir from 1958-2011 was ≈88 cubic meters per second with a standard deviation of about 118 meters per second. The Rio Grande flow near Brownsville/Matamoras from 1934-2011 was ≈44 cubic meters per second with a standard deviation of about 95 meters per second (IBWC n.d.).

Materials and Methods

Stakeholder Analysis

Stakeholder analysis is a method for understanding stakeholders' reasons, purpose, regard, and behavior and how the relationships between those factors would influence their resource use and decision-making (Brugha and Varvasovszky 2000). Stakeholder analysis is a useful approach to identify convergent (reinforcing) or divergent (destabilizing) economic, social, and ecological problems confronting stakeholders (Moodley et al. 2008). Whereas stakeholder analysis has a longer history in social or corporate management situations (Preston 1975; Carroll 1991), its use in agriculture and natural resources areas is growing, including in natural resources management (e.g., Mayagoitia et al. 2012; Turner et al. 2014). In this study, formal interviews were conducted with various stakeholders involved in south Texas water use. For analysis purposes we grouped participants into two categories: those directly involved in management of production agriculture (e.g., farmers and ranchers; denoted as x_f), and those involved in the management or use of water resources but not directly production agriculture (e.g., irrigation district managers, extension agents, urban managers; denoted as x_s).

Interview Methods

Data were collected using semi-structured interviewing methods, where the researcher starts the interviews with a fixed set of questions for the interviewee to answer but permits the discussion to diverge depending on the discussion (Hancock et al. 2007). An advantage of utilizing semi-structured interviews is that it gives the researcher the ability to identify in-depth insights into stakeholder ideals and relationships, as well as the ability to link sources together (Reed et al. 2009). Due to health concerns stemming from the COVID-19 pandemic, no face-to-face interviews were done. Interviews took place either over-the-phone or through a video conference medium (e.g., Zoom) at the individual participant's discretion.

The interview guide consisted of a total of 15 open-ended questions per stakeholder (summarized in Table 1). However, questions were broken up and were varied between different stakeholders in different fields (i.e., dryland vs. irrigation reliant farmers, producers vs. industry stakeholders). The audio from the interviews were recorded and transcribed for further analysis.

Coding Procedures

Open coding was used to define stakeholders' problems and their boundaries, and to distinguish

Table 1. Interview sections with example questions.

Interview Sections	**Sample Question(s)**
Enterprise and water resource description	• How would you describe the nature and scope of your operation? • In terms of water sources, are you most dependent on surface water, groundwater, or precipitation? • In your area, what do you consider the most pressing issues or problems regarding water resources and their use?
Current tradeoffs and long-term insight	• In your area, is there a particular irrigation system (furrow/flood, sprinkler, drip) that you rely on for water delivery? If so, what are the advantages and disadvantages of that particular irrigation system? • Do you foresee any long-term economic or environmental consequences of current irrigation practices in your area (e.g., water quality degradation)?
Public policy and resource conservation	• In your area, how is water shared amongst user groups? Have there been any conflict or frustration among users due to these agreements or lack thereof? • In your area, how influential is local or state water policy in your water use or water management decisions? • In terms of water resource sustainability, what steps, if any, have been made in water conservation efforts to sustainably manage water in your area?
Personal perspective and emerging technology	• From your perspective, what emerging technologies and/or management practices hold the best promise for improving water resource sustainability conservation in your area? • From a personal perspective, how would you describe your own personal values that guide your management of and advocacy for improved water resource management?

apparent variables and mental models as they relate to other factors relevant to south Texas. Each transcribed interview was read and color-coded based on sustainable water-use related factors. For example, water inflows and outflows were colored blue. Environmental externalities were colored green. Urban water factors were colored grey. International issues were colored red. Agriculture management, technology, and traditions were colored purple. Lastly, any other miscellaneous factors were colored yellow.

Axial coding is the process where disparate data from various respondents are aggregated by common trends and patterns among the different categories of code, as described above. This process is similar to knowledge mapping, which also utilizes semi-structured interviews to help recognize different variables from stakeholder interviews (Reed et al. 2009). Memoing was used widely throughout axial coding to describe implicit structure, sub-factors within a given color code (e.g., commodity prices or input costs within the open coded "economics" theme), general observations, and sometimes questions to be reflected upon later.

After the coding procedures were complete and interview data were processed, a systems thinking perspective was applied to synthesize the stakeholder responses into a conceptual model (Sweeney and Sterman 2000; Kim and Anderson 2012), in this case an archetype-based CLD, that best reflected the problematic water resource dynamics of concern in south Texas. By doing so, we made explicit causal connections of the feedback processes at work that stakeholders are subject to, and that they identified during the interview process. This approach has been used in other domains where interview data were directly converted in a CLD (Kim and Andersen 2012), including agricultural and natural resources (Turner et al. 2014). In this case, due to the responding categories from open coding, we examined the responses as a whole to identify commonly occurring descriptions of feedback, and then illustrated those in the form of systems thinking archetypes (Senge 1990).

Stakeholder Factor Analysis

A structured approach, identifying sub-factors within each theme from open coding, was used to characterize the level of stakeholder interest across responses. A stakeholder-factor matrix, following Moodley et al. (2008), was constructed to quantify priorities of each response group and understand any interactions or divergences among regions or major themes. The matrix was created by counting the number of instances certain responses or arguments were raised from each respondent group within the aggregated (axial) coding. The matrix allowed for relatively rapid identification of the most important sub-factors for each response group.

Author Involvement and Sampling of Interviews

The amount of time the author spent with each participant varied between stakeholders. Most interviews were kept within an hours' time; however, the amount of time spent with each participant differed due to individual schedules and logistics. Students enrolled in an undergraduate agribusiness class, Decision Support Tools in Agriculture, were employed to collect some but not all of the interview data for this project, with the first author completing the remainder. All interviewers completed Collaborative Institutional Training Initiative (CITI) training for human subjects research. All of the interviews conducted by the first author and student assistants occurred either through a video streaming medium (e.g., Zoom) or through a recorded phone call. Although the physical appearance, attitude, and domain experience of the interviewer is known to influence interviewee responses (see discussion in Turner et al. 2014 for example), it was assumed that these were marginal given the method of interaction. Other contextual factors, such as when and where the respondent chose to answer questions, likely outweighed any potential bias introduced from the interviewer. However, the lack of physical presence may have had other consequences on responses, such as how respondents perceived the importance of their responses, given the lack of personal interaction and non-verbal ques with interviews. This was evidenced by a shorter than expected average interview time (around 30 minutes). In total, 30 participants were interviewed (4 WB, 7 CB, and 19 LRGV; Figure 1).

Results and Discussion

Open Coding

As expected, the recorded perspectives about water resource management and allocation evaluated in the CB, WG, and LRGV subregions were distinct from another. While some common themes did emerge from reviewing the transcripts, including water quality concerns and the role of government programs (Table 2), there was not enough evidence to suggest that a wide range of high-level water resource management issues were shared between the regions.

Water Supply and Quality. Stakeholders referred to the Texas State Soil and Water Conservation Board (TSSWCB), the United States Department of Agriculture (USDA), and the Texas Commission of Environmental Quality (TCEQ) when regarding the minimum quality standards that must be met for public drinking water. On the other hand, water that is intended for agriculture use utilizes different standards. Key stakeholders delineated the difference between raw and treated water uses in that raw water is extracted from its source, not put through any filtering process, and is the primary source for agriculture use. Responses about the quality of raw water varied greatly from region to region (e.g., raw water could potentially have high levels of salts and other chemicals). Being that irrigated agriculture enterprises predominantly utilize raw water, issues regarding raw water effects on soil health and eventual crop productivity were of interest to respondents.

The CB, WG, and LRGV subregions each have their own bureaucracies in place to manage their water resources. While there are primarily dryland farmers and ranchers in the CB subregion, there are small groups of producers who rely on groundwater

Table 2. Open coding resulted in two themes: water quantity and water quality. Additional concerns are labeled region-specific. Responses are noted (S) for stakeholders, (F) for farmers, or (S and F) for congruent responses, although only one quotation is used.

Open coding theme	Coastal Bend (n = 7)	Wintergarden (n = 4)	Rio Grande Valley (n = 19)
Water quantity and quality	"Water would probably be the number one limiting resource." (F)	"Counties that haven't managed their supplies very well and they're going to get to a point where they're going to be out of water and it's going to be a nightmare for those areas." (S)	"When you don't have the ability to create rain whenever you want, it's definitely the most limiting factor." (F)
	"I think it's going to get much more expensive, I mean, I think its supply and demand." (S)	"Water gets in big demand. You know we live in a fragile environment in south Texas, and we've all got to do what we've got to do to conserve water." (S)	"There's no concrete, nothing, no liner or anything to be able to keep the water from evaporating or seeping and losing the water so the constant pressure that we need to provide to a canal system." (S)
	"Reliable or drought resistant types of water resources; we're getting to a population size and as a region…we need to think of having multiple water sources and not being afraid to see that investment put in not just for the day but for tomorrow." (S)	"You're talking about ground water through irrigation under the Edwards Aquifer Authority." (S)	"The other pressing issues is maybe water quality or like water treatment for treating the water once you get it to the surface." (S and F)
	"Seawater desalination project that the city of Corpus Christi is actively pursuing. We're looking at constructing a 20 mgd expandable 30 mgd seawater desalination plant that could provide a resistant water situation to our growing needs for the future." (S)	"People don't necessarily understand why we develop the way we do. You know, you can't just build a water supply project for five thousand acre-feet of water because that's all you need, but ten years later you need twenty acre-feet." (S)	"I guess it's probably more the river being overutilized further upstream." (S)
	"Utilizing our wastewater as a potential source of water." (S)	"We have environmental issues as far as drought that'll take our alluvial water away and take those shallow wells away." (S)	"Water is just not available when farmers are ready to irrigate. You know, the water is just not available or they may be restricted on the number of waters that they can do within a given season." (S and F)

Table 2 (continued).

Open coding theme	Coastal Bend (n = 7)	Wintergarden (n = 4)	Rio Grande Valley (n = 19)
Region-specific	"I get a little worried when groundwater conservation districts start to dictate what a landowner can and cannot do with their water." (F)	"The state has developed these groundwater districts, they are not necessarily designed for the aquifers benefit, they're designed for the political subdivision." (S)	"Make it accessible to have these technologies communicate at an affordable price…that even goes for row crop farming or farming where you could have these sensors that communicate over rural internet access." (S)
	"Other challenges for the strip-till and no-till kind of perspective, as opposed to other parts of the country, we don't freeze, or when we do freeze it's kind of a rare event. We have to control weeds chemically all year long." (F)	"The amount of exotic species, they're not as efficient at putting water in the ground as are rangeland plants are." (S)	"If we're in a severe drought and water is allocated, agriculture is going to get cut off first. No trade-off, it's just a reality." (S)
	"It's kind of hard to teach an old dog new trick, and so it's kind of like well we've always done things like this. I think the key is getting new blood in…getting individuals that are educated." (F)	"Industry and environmental flows all take precedence over the farmers and the ranchers which has resulted in extreme dissatisfaction during periods of extreme drought." (S)	"Of course, we have a treaty between Mexico and the United States, Mexico tends to fall back on their commitment or the responsibilities that the 1944 treaty calls for." (S)
	"Water resources and how things grow in this area, it goes hand in hand. As population and industry grows, population growth rate accelerates even more." (S)	"Biggest problem would be the municipalities trying to set the rules…to how reallocate water and how it is used." (S)	"If we could get what's supposed to be delivered to us by the treaty, most likely we wouldn't have our issues, but we don't control the source of the water another country does." (S and F)
	"Economic protection comes in the form of crop insurance and of course crop insurance is both purchased at the private level and you're paying your share of it, but it's also subsidized by the government…we can't operate the way we operate without having crop insurance." (S and F)	"[Municipalities] making the rules where it's more difficult to farm, the farmers will be pushed." (S)	"I know that locally, they're not really enforcing very much as the moment… not much is being done to conserve water." (S and F)

for their production. This minority of groundwater-dependent CB area mangers expressed fear that groundwater districts will strip them of their "right of capture" on their properties, and thus, their means of production. Stakeholders in the WG area feared that the groundwater districts were not designed to benefit their respective aquifers, given that multiple groundwater districts have access to the same aquifer, yet have different mandates based on the political subdivisions of the region rather than needs of the underlying groundwater source. Along the LRGV, multiple municipalities, farmers, and ranchers rely on Rio Grande surface water for their residents and agricultural production. Stakeholders in the LRGV were worried about water quality/salinity issues and international disputes about Mexico's water supply obligation to the United States. Therefore, in the eyes of the LRGV stakeholders who heavily rely on consistent surface water availability, negotiations between representatives of the United States and Mexico are increasingly necessary.

Almost every stakeholder and farmer from each region agreed that sustaining a steady supply of clean water is necessary for the continued growth and vitality of their respective subregions. Nevertheless, water resource issues between the three subregions varied widely (Table 2). Attempting to adopt a single solution on a state level would not give each subregions' water resource issues the respect and attention they deserve. Many stakeholders and farmers expressed concerns over urbanization. Farmers indicated increased agricultural land sales in their area due to the lack of profitability in agriculture caused by unpredictable water resources availability. The fragmentation and urbanization of agricultural land could become even worse in these conditions if farm subsidies and insurance were not available.

Coastal Bend-centric Issues. Farmers and ranchers in the CB area indicated continued reliance on precipitation both now and into the future, given no current organization for irrigation districts and relatively low groundwater district interventions. Regarding conservation agriculture, some respondents mentioned the use of reduced tillage practices, but most respondents had a negative disposition toward the use of conservation practices (e.g., no-tillage, efficient irrigation methods, and high intensity/low frequency grazing), often citing that conservation agriculture methods are costly, labor intensive, and do not provide enough short-term benefits to their production. Farmers also noted that, due to the extreme precipitation variability in the area, they heavily rely on subsidized crop insurance to stay in business.

Fears over a growing population were also prevalent. Key stakeholders in the area did not believe that current politicians and water resource managers were doing enough to ensure a steady supply of quality water for future generations. However, despite public backlash, the Corpus Christi city council recently budgeted a desalination plant proposal (Kovar 2021). While there was no standalone question regarding desalination in the predesigned survey instrument, several of the stakeholders and farmers mentioned desalination with a positive connotation and none expressed any backlash or concerns to the idea of desalination investment to support future water supply sustainability.

Wintergarden-centric Issues. As opposed to the CB subregion, the residents in the WG area were acclimated to having a groundwater district and the division of their water rights. Consistent with other areas, WG respondents indicated that managers allocate more water toward industry and municipalities during times of drought. Farmers and ranchers in this subregion feared that shifting local politics and urbanization will make operations more difficult (and therefore less profitable), which may force some farmers to leave the area or go out of business.

Stakeholders for the WG subregion expressed desire to have more money invested toward information technology (e.g., groundwater monitoring sensors, infrared drone technology, soil moisture sensors). They believed readily available information will help the groundwater districts be more prepared for drought conditions. Stakeholders also stressed the need for more public outreach about issues regarding water sustainability, water supply, and water conservation strategies (e.g., relying on native species who are already adapted for the climate and soil conditions). The biggest fear that stakeholders in the WG area maintained was the poor design of the groundwater districts, given that multiple groundwater districts could share an aquifer, yet apply different policies to the same aquifer (a form of a transboundary water problem exhibited in many geographic contexts where stakeholders in diverse socio-economic systems and policy contexts are reliant on a single groundwater source; Uitto and Duda 2002; Earle 2013) . However, other entities, such as the Edwards Aquifer Authority, could alleviate some of these stresses.

Lower Rio Grande Valley-centric Issues: Akin to the WG subregion, LRGV farmers and ranchers desired greater investment in information technology, including at the farm-scale, to improve water management for the sake of improved operations. They also expressed concerns over agriculture businesses not receiving water allocations during droughts or inadequate water supply. Farmers described missing irrigation windows dependent on the status of the river and irrigation district. Water quality issues (e.g., salinity, salination, miscellaneous minerals) caused by upstream water over-utilization were also a concern. Concerns over water availability, supply, and quality were further amplified by statements pertaining to the fact that Mexico has historically not fully met its annual water supply obligations to the United States on a regular basis, as per the 1944 treaty. All stakeholders (farmers, ranchers, and others) believed that all their current resource supply issues would be relieved if Mexico met their obligations as intended.

On a local level, respondents believed that there is not enough water scarcity pressure endured by everyday residents in the LRGV to incentivize local politicians and stakeholders to create or enforce more water conservation efforts. It was suggested by respondents that very little is being done to conserve water in the LRGV area. However, concerns over inadequate water flows into the Gulf of Mexico were raised, indicating environmental concern from stakeholders. They expressed concern that aquatic life in the bays and estuaries and the vegetation along the Rio Grande are not getting the supply they need to survive and thrive in their environments; these concerns were juxtaposed against comments pertaining to the volume of water being utilized by irrigation districts and municipalities before it can reach the Gulf of Mexico.

Axial Coding

A total of five subthemes and factors were identified and analyzed (i.e., Water Supply, Bureaucracy, Water Conservation, Water Quality, and Environmental). The subthemes and factors synthesized from the open codes were then split up into "concerns" and "optimisms" (Table 3). The transcripts were reviewed for content within the five categories and were counted and sorted to be a "concern" or an "optimism." The threshold on whether water supply was a "concern" or "optimism" was dependent on the respondents' regard to current water demands being met. Bureaucracy was evaluated on the governmental agencies perceived roles, functions, and necessity in the opinions of the respondent. Water conservation "optimisms" were counted based on applied agriculture or water conservation strategies and their "concerns" were counted based on the externalities of, or the perceived costs, of implementing conservation strategies. Water quality was measured based on the references to the drinkability of water or if there were any concerns utilizing it as irrigation water. Environmental "concerns" were measured based on answers regarding current practices that lead to any negative environmental externality of the lack of water availability and quality, while environmental "optimism" referred to current practices that lead to positive environmental externalities.

Overall, interviewed farmers and stakeholders expressed many more water conservation concerns rather than optimisms (Table 3). While the overall differences for average concerns and optimisms between the farmers and stakeholders were marginal, farmers expressed more optimisms and stakeholders expressed more concerns per interview. On a per-interview basis, stakeholders mentioned water supply concerns more than farmers ($\bar{x}_s$ = 4.94 mentions/interview compared to $\bar{x}_f$ = 3.46), but overall, stakeholders and farmers expressed over three times the number of concerns than they did optimisms (139 observed water supply concerns compared to 39; Table 3). Farmers seem to also have more bureaucratic concerns and hold much less optimism ($\bar{x}_f$ = 1.31 mentions/interview vs. 0.38, respectively), than stakeholders ($\bar{x}_s$ = 1.06 mentions/interview vs. 1.35, respectively). In terms of water conservation strategies and concerns, farmers and stakeholders seem to be

Table 3. Results from axial coding highlighting similarities or differences in response rates between farmers and stakeholders. Total responses per stakeholder group are shown with mean number of responses per respondent in parentheses.

Subtheme Factors	Farmers n=13	Stakeholders n=17
Concerned/Problematic		
Water Supply: "Water, if it isn't already, is going to be our next gold."	45 ($\bar{x}_f = 3.46$)	84 ($\bar{x}_s = 4.94$)
Bureaucracy: "We have this underground water district now, we don't know where that's going …"	17 (1.31)	18 (1.06)
Water Conservation: "I think we have to try to conserve; we're using more and more water and we don't have a whole lot of it."	38 (2.92)	39 (2.29)
Water Quality: "The most pressing issues I would say is water quality. The water we get from the canals are high in salts at certain times of the year."	11 (0.85)	26 (1.53)
Environmental: "The river does not have any allocation for the environment. So if the river goes dry, the environment's going to suffer…"	32 (2.46)	27 (1.59)
Total	**143 (11)**	**194 (11.41)**
Optimistic		
Water Supply: "Business and politicians are aligned to a certain extent. They want to make sure that there is a stable supply of water."	14 (1.08)	25 (1.47)
Bureaucracy: "I think one year, we did have a drought but because we belong to a water district that had plenty of water allocated to them we never suffered from not having enough water."	5 (0.38)	23 (1.35)
Water Conservation: "We have a water conservation plan we are continuously reviewing and updating; it's not a static document."	68 (5.23)	55 (3.24)
Water Quality: "I think these irrigation districts test them (canals) weekly and they would know where the salt levels are."	0 (0.00)	5 (0.29)
Environmental: "[We do] everything from brush management, if you're reclaiming areas to range planting utilizing native species for maximum effect."	8 (0.62)	9 (0.53)
Total	**95 (7.31)**	**117 (6.88)**
Concerned Responses (% of Total)	60.1%	62.4%

confident in the fact that the ability and techniques used to conserve water are available, but still maintain some degree of reservation regarding current water conservation practices and economic limitations (38 and 39 concerned responses compared to 68 and 55 optimistic responses; Table 3). However, water quality concerns are primarily specific to the LRGV subregion. Overall, very few concerns or optimisms were expressed for water quality (37 observed water quality concerns compared to 5; Table 3). There seem to be many more environmental concerns than optimisms from both stakeholders and farmers (59 observed environmental concerns compared to 17; Table 3), in response to the environmental externalities of current water management practices, or lack thereof (Table 3).

Mental Model Descriptions

Peoples' management responses (or heuristics) for routine decisions are often a function of their underlying mental models (broad mental pictures or world views developed through experience and tradition); in many cases such heuristics lead to desirable outcomes. However, people often apply heuristics in response to complex problems or issues that may lead to undesirable outcomes (Kahneman 2011) contrary to what their underlying mental model inferred about the situation. Unfortunately, heuristic use in complex, feedback-driven problems can have devastating long-term consequences, potentially making the initial issue more destructive (Turner et al. 2016a; 2020a). Given the complexity of water resource systems and their overlapping connectivity to agricultural, industrial, and municipal systems, it is critical to understand heuristic responses and the mental models of stakeholders they are embedded in, prior to generating up-to-date decision-support tools.

The farmers and stakeholders interviewed maintained a variety of mental models regarding complicated issues and the proper management of water resources. To better communicate mental model insights and crystallize their potential role in developing decision-support tools, we synthesized the results of open and axial coding into the following brief descriptive quotes representing each respondent group:

Coastal Bend

- Farmers: "We are hoping for a timely rain for our production. We are worried about groundwater conservation districts interfering with our ability to stay profitable."
- Stakeholders: "Water resources are going to continue to get more expensive. We must find new sources of water and conserve what we have for future generations."

Wintergarden

- Farmers: "Farming is becoming more difficult because of urbanization and the lack of water rights for farmland."[1]
- Stakeholders: "Utilizing soil-health principles and techniques in agriculture are necessary for the long-term sustainability of our natural resources."

Rio Grande Valley

- Farmers: "Working with irrigation districts can be difficult and irrigation timing has to change depending on water availability."
- Stakeholders: "Mexico owes the United States the water resources they promised in the 1944 treaty. All of our water resource issues would be resolved if Mexico met their obligations."

Discussion and Implications

Given Texas' size and complex land and water resource features, it would be impossible to assign widespread blanket policies to problems at any scale. On the other hand, supporting and maintaining water conservation policies and plans that are well-adapted to specific regions seems more appropriate. Questions concerning whether policies should be based upon political, economic, cultural, or geological boundaries should be asked. Either way, the role of government (both local and state) will be vital for information generation and public outreach and education regarding current water supply levels and water conservation efforts.

[1] No farmers were interviewed. Mental model was synthesized from stakeholder responses regarding farmers during interviews.

The Role of Mental Models in Agricultural Systems

Mental models are defined as cognitive representations of how individuals view the world (Levy et al. 2018). Mental models tend to be very accessible and lasting; however, they are limited in scope in abstract and complex systems (Doyle and Ford 1998). Mental models are prevalent in every aspect of society, but, managing dynamic and complex variables in the environment makes it difficult for agriculturalists who are balancing several and often conflicting responsibilities (e.g., increase production, minimize inputs and runoff, etc.; Wilmer et al. 2020). Being part of extremely dynamic systems, agriculturalists can find themselves anywhere between considering themselves either the "controller" of nature or simply a "member of it" (Wilmer and Sturrock 2020). Although subjective, the general implications of environmental ethics assume that individuals in agriculture will adopt less environmentally damaging behaviors based on intrinsic values, care ethics, and land ethics (Turner et al. 2014; Batavia et al. 2020). Previous research suggests that many agriculturalists make "middle-ground" decisions to hedge themselves for ecological or economical risk (Wilmer et al. 2020). However, the definitions of sustainability should be grounded in practitioners' viewpoints, particularly farmer goals and concrete strategies for achieving those goals, for improved relevance for academics and policy makers pursuing sociological, economical, and ecological aspects of sustainability (Hoffman et al. 2014). Rural communities are key to understanding the relationships between land-based resources and the society that manages them (Mayagoitia et al. 2012). Water resources in agriculture are important for healthy soil and plant relationships. However, decades of relatively accessible water resources in agriculture have led to irrigation methods that maintain low standards of irrigation efficiency.

By articulating stakeholder mental models surrounding water use we gained greater appreciation for the complex dynamics driving current and emergent challenges in the region (e.g., urbanization and population growth, segmented groundwater conservation efforts, international boundary and water quality issues, among others). In order to inform future efforts to craft sustainable and actionable solutions, emerging hydrologic and socio-economic models must incorporate stakeholders' perspectives, goals, and values. Without doing so, emergent models run the risk of missing critical feedback linkages that, when unaccounted for, can lead to unintended consequences (Sterman 2000; Turner 2020b).

Our mental model syntheses highlighted several key feedback interrelationships existing below the surface of awareness that will influence emerging water management challenges. For example, in the CB subregion, stakeholders concerned with the rising cost of water expressed explicit interest in utilizing new water sources, such as groundwater. This may be viewed as a threat to agricultural producers relying on precipitation, since groundwater recharge is partly a function of effective rainfall (i.e., rainfall minus runoff). If land use and management were shown to reduce recharge potential, then creation of groundwater management areas may lead to unintended frustration among stakeholder groups. Or consider the LRGV, where farmers are some of the first stakeholders that must adapt during times of water scarcity. Frictions may arise between irrigation district members and managers, since irrigation districts also provide water to municipalities. Relationships must be managed to minimize erosion of trust over time and ensure adequate resources are allocated to much needed investment in irrigation upgrades, which may seem undesirable if farmers do not perceive a positive return on investment. On the other hand, non-agricultural stakeholders, who identify water scarcity as a political issue as well as an environmental one, are incentivized to keep demand growing in order to mount evidence for international responses. Pressure on growth fuels water demand in both sectors, which reinforces scarcity-induced frustration amongst users, and makes coordinated international effort more fragmented.

Integration through Systems Thinking

Systems thinking archetypes are visualizations of complex issues, made up of balancing and reinforcing feedback loops, that illustrate structural relationships underlying significant events and behaviors over time (Senge 1990; Kim 1992; 1994; 2000). Balancing loops move toward an equilibrium condition or goal whereas reinforcing loops lead to an exponential increase (i.e., virtuous) or decline (i.e., vicious). Unique combinations of balancing and reinforcing loops, along with commonly occurring problem descriptions or stores, constitute individual systems archetypes (Senge 1990).

One systems archetype identified in our responses was "Tragedy of the Commons" (TOC). The story of TOC revolves around constrained growth due to resource limitations shared by multiple stakeholders, who through competition to acquire and utilize the resource accelerate its depletion or degradation (Senge 1990; Kim 1994). In our case, the common resource shared by stakeholders is water, that, regardless of source (precipitation, surface water, or groundwater), is supply-constrained. Given fluctuating weather patterns that make water inflows or recharge rates extremely variable, as well as domestic (e.g., water rights structures) and international issues (e.g., water quality degradation), stakeholders face mounting pressure to secure and use available water for their respective operations. For example, Figure 3 highlights the stake that both farmers and municipalities have for water resources in the LRGV. Municipalities rely on water for continued growth and development, while farmers need water for their enterprise to be profitable. Frustration around water resource limitations was highlighted by one of the interviewees, who stated "When you don't have the ability to create rain whenever you want, it's definitely the most limiting factor," (Table 2). Both parties extracting from the same source,

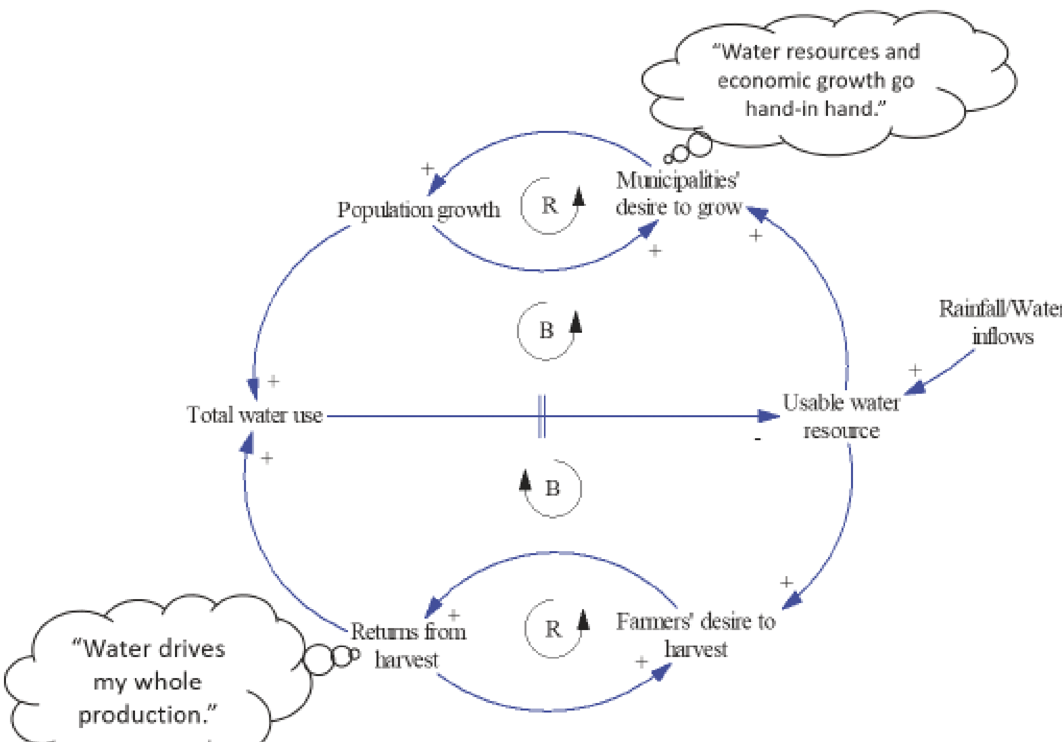

Figure 3. Tragedy of the Commons archetype. Positive "+" links indicate the effect variables at the arrow head move in the same direction as the cause variables at the arrow tail, negative "–" links indicate effect variables move the opposite direction as the cause variables, "R" indicates a reinforcing process, "B" indicates a balancing process, and double-hash marks across causal links represent time-delays. Given that rainfall and water inflows are limited, the total amount of usable water for agriculture and cities are also limited. Both cities and agriculture have their own intended goals and reasons for utilizing water. Agriculture wants to make a return on their investments, while cities desire more growth and output. However, both utilizing the resource without regard for the other will lead to the totality of the resource declining. Their actions unchecked can lead to a decline of water supply and quality. Text in the thought bubbles provide mental model descriptions of stakeholders based on survey responses.

without any regard for negative externalities or other stakeholders, will lead to eventual water supply and quality issues as supplies become increasingly stressed in the long-term.

The second identified archetype was "Success to the Successful" (S2S), which is the story of self-fulfilling prophecies. Success to the Successful begins when, in the face of competition between users of a given resource, one party is given an unfair or disproportionate competitive advantage over another, who then becomes more competitively disadvantaged over time as the initial "winner" garners more and more success (Senge 1990; Kim 1994). For example, Figure 4 highlights the stories heard regarding the fight for water rights between municipalities and farmers. Municipalities, who are given priority for water resources during times of stress, utilize those resources to maintain growth and development, with farmers receiving what remaining water allocation is available (if any remains). As one respondence said, "[Municipalities] make the rules where it's more difficult to farm, the farmers will be pushed [out]," (Table 2). Farmers argue that cities are harming the agriculture industry by means of urbanization and by buying more water rights, making it extremely difficult if not impossible to justify expansion of farm sizes or the number of farm operations as water supplies for agriculture get tighter and tighter.

Implications for Tragedy of the Commons. Given that water is a shared resource needed by all, its allocation and extraction is highly valued. While water resources are considered renewable, they are limited by their natural inflows and recharge rates. Water resources may not seem limiting immediately, yet south Texas farmers and water resource stakeholders have felt the pressure of living with limited water during drought and anticipate future shortages. Some common high leverage interventions for TOC include: finding a central point for resource management, developing a shared vision to guide individual and collaborative actions, developing a central information database that tracks resources over time, or employing a final mediator who allocates the resource dependent on the needs of the whole system (Ostrom 1990; Ostrom et al. 1994; Dietz et al. 2003).

Implications for Success to the Successful. Local government can play several important roles in a community, for example providing protection (law enforcement), supporting and maintaining public infrastructure and utilities, and incentivizing business development to improve standards of living, among other roles. Being that water is a limiting resource for the further development of municipalities, major city stakeholders have reason to allocate water inflows to current and future development projects intended to increase the cities growth and prosperity. However, rural

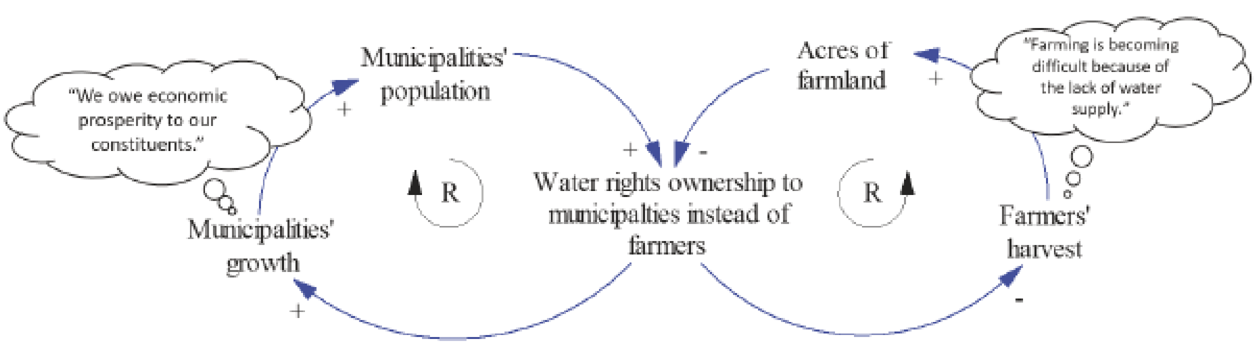

Figure 4. Success to the Successful archetype. Positive "+" links indicate the effect variables at the arrow head move in the same direction as the cause variables at the arrow tail, negative "–" links indicate effect variables move the opposite direction as the cause variables, "R" indicates a reinforcing process, "B" indicates a balancing process. Farmers have a fear that municipalities will continue to encroach on agriculture production. As municipalities have the desire to grow, they will continue to buy more water resource rights to help their internal development. Given that cities and residents are given priority to water resources and that water is considered a finite resource at any given point in time, farmers fear that the further urbanization of rural land will leave them with less water resources for their production, and eventually make their enterprise unprofitable. Text in the thought bubbles provide mental model descriptions of stakeholders based on survey responses.

communities who traditionally relied on agriculture will begin to suffer as local cities rapidly develop, fragmenting agricultural land, and increasing urbanization. As water resource allocations pivot toward municipalities, farmers' total harvests will decrease, and may eventually lead to less acres allocated for agriculture production. Some potential high leverage intervention points, originating from the generic points in Senge (1990), include: looking for overarching goals for all parties involved (e.g., municipal-supported investment in on-farm water storage to facilitate precision irrigation, reduce total agricultural water use, and free up supplies for municipal use); locating supplementary resources if all activities warrant investment (e.g., water reuse infrastructure); reducing or eliminating competition (e.g., water-use efficiency or water reuse); and allocating resources based on the total potential benefits of each activity, not just economic utility (e.g., valuing non-provisional ecosystem goods and services from agricultural water use, such as habitat support and recreation fishing from surface water systems).

Risks of Limited Water Resources to other Regional Challenges

Outside of consistent water supply, the CB, WG, and LRGV areas each have their own unique water-resource problems. Systems archetypes can help key stakeholders and academics identify relationships in highly dynamic and complex systems. However, concerns about or limitations of the aforementioned leverage points could include competency of management and lack of incentives to change and innovate, the role of government that guides adaptive management, and the time and effort needed to update current underlying mental models to incorporate a wider array of potential management pathways. In any case, the inherent risks of not conserving existing water resources or finding new sources will yield accelerated loss of agriculture production, environmental externalities to water quality, and increased stress as water supply shortages become more widely felt among all community members.

Conclusions

The goal of this research was to uncover and articulate mental models surrounding sustainable water use in south Texas. We found that, in general, stakeholders were more concerned than optimistic about the current state of water resource issues in the region with the largest concerns being water supply availability (for all uses) and environmental quality loss. The most optimistic or favorable area for stakeholders was conservation given existing surface- and ground-water organizations leading adaptive conservation efforts. Mental models, useful for identifying and interpreting possible decision-making rules, were synthesized from coded transcript data, that, combined with axial coded factors, yield several systems thinking archetypes, including TOC and S2S. Understanding the regional structures and forces that shape these archetypical behaviors, stakeholder mental models, and decision-making rules is vital to understanding and identifying high points of leverage in south Texas water conservation and sustainable management efforts, which themselves will largely depend on how farmers and other stakeholders (industrial and municipal) *interact* collaboratively (rather than combatively) in creative ways conducive to finding and sustaining novel practices and relationships that to-date have gone unexplored. Improved collaboration and communication ensure everyone is aware about the current state of their water and the economic and social impact that a lack of water resources (of extreme fluxes) will have on local communities. Given the tightly-coupled nature of soil processes and water conservation, emerging evidence in soil health management at field and farm scales presents novel opportunities to connect immediate productivity goals in agriculture to broader societal interests beyond food production. Technologically, on-farm information systems (e.g., real-time moisture and climate monitoring) will shorten the delay between water stress and management response. Each subregion in our case was unique; water management decisions should therefore be made on a local-level through collaboration of policy makers, stakeholders, and farmers, using the best information available for their area in attempts to avoid the cascading feedback impacts that will contaminate sustainable management efforts over time.

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References

Batavia, C., J.T. Bruskotter, and M. Nelson. 2020. Pathways from environmental ethics to pro-environmental behaviors? Insights from psychology. *Environmental Values* 29(3): 317-337.

Breyer, B., S.C. Zipper, and J. Oiu. 2018. Sociohydrological impacts of water conservation under anthropogenic drought in Austin, TX (USA). *Water Resources Research* 54(4): 3062-3080.

Brugha, R. and Z. Varvasovszky. 2000. Stakeholder analysis: A review. *Health Policy and Planning* 15(3): 239-246.

Carroll, A. 1991. The pyramid of corporate social responsibility: Toward the moral management of organizational stakeholders. *Business Horizons* 34(4): 39-48.

Carter, N.T., S. Mulligan, and C. Seelke. 2017. *U.S.-Mexican Water Sharing: Background and Recent Developments*. Congressional Research Service Report 7-5000.

Center for Strategic and International Studies (CSIS). 2003. *U.S.-Mexico Transboundary Water Management: The Case of the Rio Grande/Rio Bravo*. A Report of the U.S.-Mexico Binational Council. Washington, D.C.

Coastal Bend Regional Water Planning Group. 2015. Coastal Bend Regional Water Planning Area Region N. Executive Summary and Regional Water Plan. Available at: https://www.twdb.texas.gov/waterplanning/rwp/plans/2016/N/Region_N_2016_RWP.pdf. Accessed July 26, 2022.

Di Baldassarre, G., N. Wanders, A. Aghakouchak, L. Kuil, S. Rangecroft, T.I. Veldkamp, and A.F. Van Loon. 2018. Water shortages worsened by reservoir effects. *Nature Sustainability* 1(11): 617-622.

Dietz, T., E. Ostrom, and P.C. Sterm. 2003. The struggle to govern the commons. *Science* 302(5652): 1907-1912.

Doyle, J. and D. Ford. 1998. Mental models concepts for system dynamics research. *System Dynamics Review* 14(1): 3-29.

Earle, A. (Ed.). 2013. *Transboundary Water Management: Principles and Practice*. Earthscan, London, UK.

Fischhendler, I., E. Feitelson, and D. Eaton. 2004. The short-term and long-term ramifications of linkages involving natural resources: The US-Mexico transboundary water case. *Environmental and Planning C: Government and Policy* 22(5): 633-650.

Gohari, A., S. Eslamian, A. Mirchi, J. Abedi-Koupel, A.M. Bavani, and K. Madani. 2013. Water transfer as a solution to water shortage: A fix that can backfire. *Journal of Hydrology* 491: 23-29.

Grafton, R.Q., J. Williams, C.J. Perry, C. Ringler, P. Steduto, and R.G. Allen. 2018. The paradox of irrigation efficiency. *Science* 361(6404): 748-750.

Gunda, T., B.L. Turner, and V.C. Tidwe. 2018. The influential role of sociocultural feedbacks on community-managed irrigation system behaviors during times of water stress. *Water Resources Research* 54(4): 2697-2714.

Hancock, B., K. Windridge, and E. Ockleford. 2007. An Introduction to Qualitative Research. The National Institute for Health Research, NIHR Research Design Service for the East Midlands/Yorkshire and the Humber.

Hoffman, M., M. Lubell, and V. Hillis. 2014. Linking knowledge and action through mental models of sustainable agriculture. *PNAS* 111(36): 13016-13021.

International Boundary & Water Commission (IBWC). 2021. Treaties between the U.S. and Mexico. Available at: https://www.ibwc.gov/Treaties_Minutes/treaties.html. Accessed July 20, 2022.

International Boundary & Water Commission (IBWC). n.d. Rio Grande near Brownsville, Texas and Matamoras, Tamaulipas. Available at: https://www.ibwc.gov/wad/DDQBROWN.htm. Accessed July 20, 2022.

Kahneman, D. 2011. *Thinking, Fast and Slow*. Farrar, Straus and Giroux, New York, NY.

Kim, D. 1992. *Systems Archetypes I: Diagnosing Systemic Issues and Designing Interventions*. Toolbox Reprint Series. Pegasus Communications Inc., Waltham, MA.

Kim, D. 1994. *Systems Archetypes II: Using Systems Archetypes to Take Effective Action*. Toolbox Reprint Series. Pegasus Communications Inc., Waltham, MA.

Kim, D. 2000. *Systems Archetypes III: Understanding Patterns of Behavior and Delay*. Toolbox Reprint Series. Pegasus Communications Inc., Waltham, MA.

Kim, H. and D. Andersen. 2012. Building confidence in causal maps generated from purposive text data: Mapping transcripts of the Federal Reserve. *System Dynamics Review* 28(4): 311-328.

Kovar, S. 2021. “Corpus Christi City Council Passes Budget Item Allocating $10 Million to Desalination Plant Proposal.” KRIS 6 News, Corpus Christi, September 7, 2021. Available at: https://www.kristv.com/news/local-news/corpus-christi-city-council-passes-budget-item-allocating-10-million-to-desalination-plant-proposal. Accessed July 20, 2022.

Levy, M.A., M.N. Lubell, and N. McRoberts. 2018. The structure of mental models of sustainable agriculture. *Nature Sustainability* 1: 413-420.

Mayagoitia, L., B. Hurd, J. Rivera, and S. Guldan. 2012. Rural community perspectives on preparedness and adaption to climate-change and demographic pressure. *Journal of Contemporary Water Research & Education* 147(1): 49-62.

Moodley, K., N. Smith, and C.N. Preece. 2008. Stakeholder matrix for ethical relationships in the construction industry. *Construction Management and Economics* 26(6): 625-632.

Murdock, M. and J. Brenner. 2016. Texas Coastal Bend Regional Climate Change Vulnerability Assessment. The Nature Conservancy, Houston, TX. Available at: https://www.cbbep.org/manager/wp-content/uploads/CBBEP_VA_TNCFinal_31Mar16.pdf. Accessed July 20, 2022.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press, Cambridge, UK.

Ostrom, E., R. Gardner, and J. Walker. 1994. *Rules, Games, and Common-pool Resources*. University of Michigan Press, Ann Arbor, MI.

Preston, S. 1975. The changing relation between mortality and level of economic development. *Population Studies* 29(2): 231-248.

Reed, M.S., A. Graves, N. Dandy, H. Posthumus, K. Hubacek, J. Morris, C. Prell, C.H. Quinn, and L.C. Stringer. 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management* 90(5): 1933-1949.

Sansom, A. 2008. *Water in Texas*. University of Texas Press, Austin, Texas.

Seager, R., M. Ting, I. Held, Y. Kushnir, G. Vecchi, H. Huang, N. Harnik, A. Leetmaa, N. Lau, C. Li, J. Velez, and N. Naik. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. *Science* 316(5828): 1181-1184.

Senge, P. 1990. *The Fifth Discipline: The Art and Practice of the Learning Organization*. Doubleday/Currency, New York, NY.

Stave, K.A. 2003. A system dynamics model to facilitate public understanding of water management options in Las Vegas, Nevada. *Journal of Environmental Management* 67(4): 303-313.

Sterman, J.D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Irwin-McGraw-Hill, Boston, MA.

Sturdivant, A.W., C.S. Rogers, M.E. Rister, R.D. Lacewell, J.W.B. Norris, J. Leal, J.A. Garza, and J. Adams. 2007. Economic costs of desalination in south Texas: A case study. *Journal of Contemporary Water Research & Education* 137(1): 21-39.

Sweeney, L.B. and J. Sterman. 2000. Bathtub dynamics: Initial results of a systems thinking inventory. *System Dynamics Review* 16(4): 249-286.

Texas A&M University. 2014. Groundwater Conservation Districts. Available at: https://texaswater.tamu.edu/groundwater/groundwater-conservation-districts.html. Accessed July 20, 2022.

Texas State Library and Archives Commission. 2016. Water in Texas. Available at: https://www.tsl.texas.gov/lobbyexhibits/water#:~:text=Water%20law%20in%20Texas%20began,how%20that%20water%20was%20used. Accessed July 20, 2022.

Texas Water Development Board. 2021a. Water Data for Texas. State Well Number 6950302 is 43.00 Feet Below Land Surface on 2021-10-12. Available at: https://waterdatafortexas.org/groundwater/well/6950302. Accessed July 20, 2022.

Texas Water Development Board. 2021b. Water Data for Texas. Falcon Reservoir. Available at: https://www.waterdatafortexas.org/reservoirs/individual/falcon. Accessed July 20, 2022.

Texas Water Development Board. 2022. Water Data for Texas. State Well Number 7702509 is 413.16 Feet Below Land Surface on 2022-02-03. Available at: https://waterdatafortexas.org/groundwater/well/7702509. Accessed July 20, 2022.

Turner, B.L., M. Wuellner, T. Nichols, and R. Gates. 2014. Dueling land ethics: Uncovering agricultural stakeholder mental models to better understand recent land use conversion. *Journal of Agriculture and Environmental Ethics* 27(5): 831-856.

Turner, B.L., H.M. Menendez, R. Gates, L.O. Tedeschi, and A.S. Atzori. 2016a. System dynamics modeling for agricultural and natural resource management issues: Review of some past cases and forecasting future roles. *Resources* 5(4): 40. DOI: 10.3390/resources5040040.

Turner, B.L., V. Tidwell, A. Fernald, J.A. Rivera, S. Rodriguez, S. Guldan, C. Ochoa, and A. Cibils. 2016b. Modeling acequia irrigation systems using system dynamics: Model development, evaluation, and sensitivity analyses to investigate effects of socio-economic and biophysical feedbacks. *Sustainability* 8(10): 1019.

Turner, B.L., M. Goodman, R. Machen, C. Mathis, R. Rhoades, and B. Dunn. 2020a. Results of Beer Game trials played by natural resource managers versus students: Does age influence ordering decisions? *Systems* 8(4): 37. DOI:10.3390/systems8040037.

Turner. B.L. 2020b. Model laboratories: A quick-start guide for design of simulation experiments for dynamic systems models. *Ecological Modelling* 434: 109246.

Uitto, J.I. and A.M. Duda. 2002. Management of transboundary water resources: Lessons from international cooperation for conflict prevention. *Geographical Journal* 168(4): 365-378.

U.S. Geological Survey (USGS). 2022. Surface Water Data for USA: USGS Surface-Water Monthly Statistics, USGS 08210000 Nueces Rv nr Three Rivers, TX. Available at: https://waterdata.usgs.gov/nwis/uv?site_no=08210000. Accessed July 20, 2022.

Uvalde County Underground Water Conservation District (UCUWCD). 2015. Groundwater Management Plan: 2016-2021. Available at: https://www.twdb.texas.gov/groundwater/docs/GCD/ucuwcd/ucuwcd_mgmt_plan2016.pdf. Accessed July 20, 2022.

Vargas, K. 2019. "Solutions to Rio Grande River Pollution." Local 23 News, Valley Central, December 25, 2019. Available at: https://www.valleycentral.com/news/local-news/solutions-to-rio-grande-river-pollution/. Accessed July 20, 2022.

Wilmer, H. and J. Sturrock. 2020. "Humbled by nature": A rancher's mental model of adaptation in the Great Plains. *Great Plains Research* 30(1): 15-33.

Wilmer, H., M. Fernandez-Gimenez, S. Ghajar, P. Taylor, C. Souza, and J. Derner. 2020. Managing for the middle: Rancher care ethics under uncertainty on Western Great Plains rangeland. *Agriculture and Human Values* 37(3): 699-718.