Only uncertainty is certain: local responses to changing water conditions in the Rio Grande Basin

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Abstract:
As the impacts of climate change become prevalent, water availability in the Southwestern US will become more variable and uncertain, creating challenges for communities that depend on water. Literature on adaptation has often focused on responses to single impacts, such as drought, becoming more extreme. However, increased variability from climate change on water systems could result in conditions never before experienced, such as flooding, that are at odds with existing adaptation strategies focused on a particular range of conditions. These trade-offs create vulnerabilities that increase the need to understand what, if any, adaptations are utilized to respond to changing conditions at the local level. The Rio Grande River Basin is an ideal setting for this study, as adaptations have focused on the drought conditions of the last 20 years, and a variety of governance and management arrangements exist. This project relies on a unique data set of coded articles from local newspapers on issues of drought and flooding and responses to those issues. We confirm our expectations that the adaptations implemented will be traditional types of infrastructure and management responses, rather than more flexible or collaborative projects. Results will increase understanding of existing efforts to manage changing water availability and have implications for future planning and management of water in the Rio Grande Basin.

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Introduction

Patterns of water use in the Southwest United States have been able to remain relatively consistent over the last approximately 100 years. However, due to changing environmental conditions (including climate change) and greater demands for water from urban areas, the conditions under which water is used will not remain constant. Areas that previously experienced drought, could experience flooding as a result of intense heavy storms, or experience drought conditions at different times of the year than in the past. These changes create trade-offs in water management, especially at the local level when resources are limited. How communities respond to these changes will have lasting effects for the community and the environment.

The responses of these communities will take the form of adaptation, which in relation to climate change is defined as adjustments made to actual or expected climate stimuli (IPCC 2014). These adjustments occur within a larger social and environmental context that is relevant for the success or failure of chosen responses. This larger context involves coupled infrastructure systems (CISs) which consist of the coupling of natural and human-made infrastructures (Anderies et al. 2016). Additionally, local communities are nested within larger systems of governance, such as polycentric or multilevel arrangements. These governance types influence the actions that will be taken to respond to changing conditions and lead to collective action problems in coordinating responses (DeCaro, et al 2017). Using a dataset of coded local newspaper articles from the Rio Grande River Basin, this paper aims to analyze how adaptation to changing conditions occurs on the local level, specifically with reference to collective action in a coupled system.

Literature Review

Adaptation at the local level: what do we know?

Adaptation at the local level varies in quality across the US and the world. Factors influencing adaptation include: the structure and function of local authorities, ability to participate in regional or national networks of information, and availability of financial and human resources (including from higher levels of government) (Westerhoff et al. 2011). In terms of the occurrence of adaptation activity in water management, the perceived risk of global and local water quality, surface water reliance, provision of other services (besides water), degree of impact from the current drought, and communication with climate change experts has been found to be associated with adaptation responses (Ekstrom et al. 2017). Authority and autonomy of local authorities is also important for facilitating adaptation (Westerhoff et al. 2011). Finally, participation is important for long-term success and community resilience—this means including all stakeholders in decision making and responsibilities, especially traditionally disadvantaged groups (Sultana and Thompson 2017).

Planning strategies also influence adaptation. Sterle and Singletary (2017) found that when exposed to continuous climate stressors, local adaptation began to focus more on long-term strategies of enhancing water supply instead of short-term strategies to manage water demand in a snowmelt dependent water system. Integrating technology with adaptation planning can also result in success when technologies are low cost, such as rainwater harvesting or conservation agriculture (Trærup and Stephan 2015). While planning is important and more planning has occurred at local levels than other levels, implementation lags significantly behind (Kettle and Dow 2014).

The lag in implementation is due to a number of barriers to adaptation. Limitations at the local level include insufficient resources, locally relevant information, uncertainty, short-term time horizons, and lack of support from higher levels of government (Fidelman et al. 2013). Interference (good and bad) from higher levels of government also often influences capacity on the local level. Local communities want the best of both worlds when interacting with state or higher governments—they want financial and human resources for their planning activities, but also want to maintain control of the process on their level (Kettle and Dow 2014; Urwin and Jordan 2008). Institutional factors also contribute to limitations. Local conflicts can be exacerbated by resource governance regime changes, and institutional arrangements or norms can preclude certain users from participation (Sultana and Thompson 2017). Existing institutions, such as components of the prior appropriation system, present challenges due to overallocation and issues with enforcement of environmental and water quality regulations (Sterle and Singletary 2017).

Uncertainty plays a large role in adaptation outcomes. Uncertainty comes in different forms, such as a lack of information about how a policy intervention may affect a shared resource to the stochastic nature of many ecological systems (Schlager and Blomquist 2008). It extends beyond just resource availability, and also concerns financial resources availability and determining the best technological solution to use (Sterle and Singletary 2017; Trærup and Stephan 2015; Westerhoff et al. 2011). As a result, local adaptation plans typically do not address uncertainty well (Woodruff and Stults 2016). Information is another source of uncertainty, especially in determining what information to trust. Local knowledge has shown to be important, as has information from state government agencies (Eckstrom et al. 2017; Sultana and Thompson 2017). The relationships between different actors further complicate the issues associated with uncertainty and trusted information.

Multilevel adaptation and polycentricity

In many areas, multiple actors and jurisdictions are at play and they are constantly interacting to respond to water issues. Polycentric systems are "characterized by multiple governing authorities at different scales rather than a monocentric unit" (Ostrom 2010b, 3). Each unit is independent, but is nested within an overlapping structure. Some units are general purpose while others are special purpose, such as irrigation systems. Multilevel governance is a similar related concept, seen as the "process of continuous interactions among governments and private entities, operating at, and between, several administrative levels and ultimately aiming at the realization of collective goals" (Termeer et al. 2010). The difference between the two concepts is the nested and overlapping nature of polycentricity is not emphasized in multilevel governance, and multilevel governance involves private entities in addition to public entities.

These types of structures affect the management of resources in different ways than centralized arrangements. In general, the underlying normative assumption is that dispersing governance across multiple jurisdictions is more efficient, especially in the provision of public goods and services (V. Ostrom et al. 1961; Termeer et al. 2010). Information sharing is enhanced, as the structure of the system facilitates transmission of knowledge, especially local knowledge, and builds trust over time (Baldwin et al. 2018; Marshall 2009; Ostrom 2005). The nested nature of polycentric systems provides protection for all citizens and backup when smaller units fail, allowing for policy experimentation (Marshall 2009; Ostrom 2005). These types of systems are particularly well suited to manage environmental issues across scales and the interrelationships between social and environmental systems (Heikkila et al. 2018).

Despite these benefits, polycentric and multilevel governance systems present unique challenges. There are more clashes between levels in multilevel governance, and conflict can exist due to the interdependence of units at multiple levels in a polycentric system (Ostrom 2005; Urwin and Jordan 2008). Short term plans can undermine long-term plans and conflicts can occur between conservation practices and adaptation planning if they are not considered together (Urwin and Jordan 2008). Coordination dilemmas can arise between levels and transaction costs can rise when navigating the multiple nested structures (Termeer et al. 2010).

These structures provide benefits to adaptation solutions. When a problem is affecting multiple scales, diverse solutions organized at multiple scales provide benefits to people at multiple scales (Ostrom 2010b). Polycentric systems specifically do this by enhancing innovation and learning and increasing trust among actors, leading to outcomes that are more effective, equitable, and sustainable (Ostrom 2010b). These types of arrangements also facilitate collective action, as has been shown in water governance (Baldwin et al. 2018).

Theory and Hypotheses

Despite the benefits of polycentric arrangements and multilevel governance structures, the current trends in local level adaptation indicate that the benefits of these arrangements are not being realized or utilized in the pursuit of adaptation responses, especially at the local level. This is likely due to the complex relationships not only between different actors, but within the larger infrastructure and resource system within which they act. As a result of this context and the difficulties of collective action, actors will likely identify and use response that avoid collective action dilemmas.

Coupled infrastructure systems (CISs) consist of the combination of natural, hard human-made, and soft human-made infrastructures, or natural resource systems, technology, and protocols, respectively (Baggio et al. 2016). Natural infrastructure can have varying degrees of mobility or be stationary and hard human infrastructure has varying degrees of intensity (Baggio et al. 2016). Utilizing a CIS approach considers the CIS as the unit of analysis in evaluating the success of various CPR systems by determining combinations of system components that lead to success, as well as exploring the feedback effects generated by linked infrastructures (Anderies et al. 2016). In this view, governance is an emergent feature of a CIS.

Due to these relationships between human-made and natural infrastructures, both must be considered when developing adaptive responses to changing water conditions. The specific characteristics of the resources may determine the types of institutional components that work better in a given context. For example, clearly defined social boundaries are more important when the resource is mobile and monitoring is more important when the resource is less mobile (Baggio et al. 2016). Water is both mobile and stationary—surface water is highly mobile both across the land and back into the air in the form of evaporation, but water can be stored in both above and below ground reservoirs (a form of human infrastructure). Thus, the complexities of the resource and its interactions with human made infrastructure will present a challenge to decision makers, especially in the face of information costs and future uncertainty.

Other challenges can arise in CIS systems that make adaptation difficult. With any long-lasting, hard human-made infrastructure (such as dams) path dependence in management techniques is a possibility. Once the infrastructure is built or put in place, it influences future management decisions, each one cementing the path more. This inertia can also occur with investment by individuals and groups of actors. Investment from large groups of people is needed to create shared infrastructure and requires continued investment (Anderies et al. 2016). The initial investment must overcome the challenge to collaborate and there must be ways to keep the collaboration going.

These difficulties in getting groups to invest and maintain investment in CISs are a collective action problem. Despite the potential for better joint outcomes with cooperation, actors typically make high cost decisions themselves due to the potential risks in cooperation (Ostrom 2010a; 2010b; Feiock 2013). When the stakes are high, as in water management, the collective action dilemma creates issues for water managers attempting to guarantee a secure supply. Factors leading to successful or unsuccessful outcomes identified in the collective action literature apply here: trust building through reciprocity and reputation and information about past actions; heterogeneity of participants, their resources, information, and payoffs; and the ways in which actors are linked (Ostrom 2010a). Due to the contentious nature of water rights management and the heterogeneity among water users, collective action dilemmas will occur in this context.

Thus, we would expect that the collective action needed to invest in the CIS is high cost and difficult, so actors will prefer to choose responses that do not require collaboration. In other words, actors will prefer solutions that can be implemented unilaterally over collaborative responses requiring collective action. The dilemma presented by changing conditions in water management is a situation in which the context is important but it involves multiple areas by the nature of the problem—there are multiple irrigation districts, cities, states, and the federal government involved in the management of a CIS that includes the natural infrastructure of the river basin and the numerous forms of human infrastructure. However, due to collective action problems, solutions that take into account the nature of the CIS will be more difficult as they involve multiple actors at multiple levels.

Hypothesis 1: There will be fewer collaborative solutions overall than unilateral solutions.

In terms of water management, unilateral solutions would be expected to be preferred at all levels. These types of solutions are those that can be more easily implemented by an actor without having to work with others for resources or worry about the effects and interactions with other levels of government. For example, these types of response can include disaster assistance, construction of new infrastructure or rehabilitation of existing infrastructure, management decisions, enactment of laws and regulations, court cases, and water conservation. More collaborative solutions will include public meetings, market-incentives, provision of public information, habitat restoration, and monitoring. Of all of these responses, water conservation is expected to be the most common solution, and being a unilateral solution, this will provide support for the overall theory.

Hypothesis 2: Water conservation will be the most common response employed.

As noted above, the ways in which actors are linked is one factor influencing the success of collective action. Within a single river basin, there are numerous actors at different levels, leading to polycentric or multilevel arrangements in certain areas of the basin. These linkages are already established, in some cases very formally, which makes collaboration more likely in these cases.

Hypothesis 3: When actors from multiple governance levels and jurisdictions are involved in an issue, collaborative solutions will be more likely.

Finally, at the local level unilateral solutions will be preferred. Cities and irrigation districts will have strong interests in protecting their supplies and maintaining ownership of their water rights and their ability to manage their water. Additionally, local actors may be afraid of encroachment on their rights and responsibilities by higher level actors (Bednar 2009).

Hypothesis 4: Local level actors will prefer more unilateral solutions.

Rio Grande River Basin

The Rio Grande is an approximately 1,900-mile river that flows from the San Juan Mountains in Colorado, through New Mexico and Texas, then crosses into Mexico and flows into the Gulf of Mexico. For approximately 1,255 miles it forms the border between the U.S. and Mexico (IBWC 2018). The river is heavily utilized for agriculture. Approximately 80 percent of the water below the Elephant Butte Reservoir in New Mexico goes to irrigated agriculture (Michaelsen 2004) and 87 percent of water rights belong to agriculture (Rister et al. 2011). Four reservoirs provide storage for water, a number of dams, canals, and ditches divert water, and three hydroelectric plants provide electricity to the area (IBWC 2018; Rister et al. 2011; US BOR n.d.). There are approximately 32 irrigation districts in Texas and several in New Mexico that manage distribution of water to agricultural interests.

In terms of water levels, the average flow rates in northern New Mexico are typically around 43 m3 s-1 but this dwindles downstream as the water is used up and becomes wastewater and irrigation return flows, down to an average annual flow of 3 m3 s-1 before the confluence of the Rio Conchos. After this the flow is about 30 m3 s-1 (Woodhouse et al. 2012). Water levels have been as low as 74 percent of the long-term average flow in the upper Rio Grande in one of the longest droughts in the area in 1873-1883 (Woodhouse et al. 2012).

Figure 1: Map of Rio Grande River Basin

The U.S. and Mexico cooperate in the governance and distribution of water from the Rio Grande through several international and interstate agreements. The 1906 Convention between the U.S. and Mexico for the Equitable Distribution of the Waters of the Rio Grande allocated 60,000 acre-feet (af) annually to Mexico according to a monthly schedule while Mexico waived claims to water between the Mexican Canal and Fort Quitman, Texas (Vick 2012). Within the U.S., in 1938, the Rio Grande Compact divided water between Colorado, New Mexico, and

Texas, at a rate proportional to the amount of water in the river (Rister et al. 2011). Another treaty was signed in 1944 between the U.S. and Mexico—the Treaty for the Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande; this treaty divided the water of the Rio Grande from Fort Quitman to the Gulf of Mexico between Mexico and the U.S. and gave the International Boundary and Water Commission (IBWC) authority over border water (Rister et al. 2011; Vick 2012). In terms of local governance, the water in the Rio Grande Project of the U.S. Bureau of Reclamation in south-central New Mexico and west Texas has been allocated between irrigation districts such as the Elephant Butte Irrigation District (EBID) and the El Paso County Water Improvement District No. 1 (EPWID) (Rister et al. 2011).

Water in this area has been a source of contention for some time and the conflicts continue into the present. For example, Mexico accumulated a water deficit to the U.S. of over 1.5 million af between 1992-2002 which was finally repaid in 2005. During this time, many farmers unsuccessfully tried to file for compensation with the Mexican government (Rister et al. 2011). Cities and agriculture have also clashed. The city of El Paso initially did not think it needed water from the Rio Grande Project, but as the city grew this was no longer the case. Litigation led to an agreement to make conservation and water efficiency improvements, in addition to an exchange of river water for treated city waste water (Rister et al. 2011). States have also fought over water in the Rio Grande. Following a severe drought in the early 2000s, EBID and EPWID were no longer receiving their full allotments of water from Elephant Butte Reservoir, so New Mexico farmers began pumping more groundwater. New Mexico began to regulate groundwater, but the two irrigation districts and the Bureau of Reclamation negotiated a new operations plan in 2008. New Mexico claimed that the agreement violated their authority to regulate groundwater, so they sued EBID and the Bureau of Reclamation. Texas then sued New

Mexico over not complying with the compact due to the increased groundwater pumping. These cases are ongoing and have not yet received resolution (Garrick et al. 2016).

Data and methods

Data collection

The data for this analysis was collected through newspaper articles on issues surrounding flooding and drought in the Rio Grande River Basin. A search of Lexis Nexis using these terms, coupled with “Rio Grande”, to generate an initial set of articles. A coder went through each set of articles to cull any that either did not focus on the Rio Grande River or were clearly unrelated to the issues related to the river. This resulted in the dataset from which articles were coded.

Two coders read through the articles and coded certain criteria. First, the main issues of the article as identified in the first three paragraphs were coded as present or absent (see Appendix for a list of issues). Then, each of the actors mentioned in the article was coded according to their organization according to a coding scheme that identified their type—local government, federal government, educational institution, private citizen, etc. Formalized conflicts and agreements between actors were also coded, such as lawsuits, formal complaints, or formal agreements. Finally, the responses to issues identified were coded according to type and according to their phase—proposed, planned/in progress, or implemented. More than one response could be recorded for each article. This yielded a total of 131 coded articles on the issues of drought and flooding in the Rio Grande.

Several other data sources were utilized to provide control variables for the statistical analysis. Data on drought at the county level, by percent of the county in at least moderate drought, was obtained from the U.S. Drought Monitor for all the years and locations covered in the dataset. Water use data was also utilized to control for usage by the public supply and irrigation through data obtained from the U.S. Geological Survey at the county level in five-year increments. Because the location data in the articles was not as fine-grained as the drought or water usage data, the data from these two sources was aggregated by the location codes used in the media coding (see Appendix for location coding). A number of cases concerned state-wide or basin-wide issues; rather than aggregate up to the state or basin-level, these cases were dropped for the logit regression analysis, resulting in a total of 113 coded articles.

Methods

The main dependent variable in this analysis is the type of responses mentioned in response to the main issue of an article. These responses are grouped by unilateral, collaborative, and water conservation solutions. The unilateral category includes disaster assistance, new or rehabilitated infrastructure, water infrastructure management, laws and regulations, court cases, and resources. The collaborative solutions include collaboration, public meetings, market incentives, public information, habitat restoration, and monitoring. Water conservation solutions are simply their own category. Further details on these categories can be found in the coding scheme included in the appendix. Independent variables include the controls mentioned above on water usage and drought, as well as the independent variables of interest—the types of government actors involved in the issue discussed in the article.

In order to test the hypotheses above, descriptive statistics were first examined. Several associational comparisons were made to determine support for hypotheses. This was followed by a logit regression analysis to dig deeper into the relationships between the actors and responses. Interactions between pairs of government actor types were also examined to test the effects of collaboration among actors on responses.

Results

Overall, the number of articles with a response mentioned as either proposed, planned/in-progress, or implemented was higher than anticipated. Of the 131 coded articles, 117 included a response and only 14 did not mention a response. Implemented responses appeared in 63 of the articles. Types of responses were as expected with the majority of responses being unilateral solutions or water conservation. There were 98 articles mentioning unilateral responses, 38 discussing water conservation, and 43 indicating collaborative solutions. This provides support for Hypothesis 1, as there are fewer collaborative solutions than unilateral. The categories of response types were also disaggregated, as seen in Table 1. Individually, the unilateral solutions generally occurred more often than collaborative solutions, and water conservation occurred more often than any collaborative solution when including all stages of responses. When only looking at implemented responses, water conservation occurs more often than any other individual response, confirming Hypothesis 2.

The relationships between the actors and responses is less clear. Table 2 shows the number of articles that a given type of governmental actor appears in. Federal and special district actors appear most involved based on this data. The first dependent variable, unilateral solutions, is not significantly affected by any of the independent variables (Table 3). Seven models were run to test each of the combinations of interactions among the actors, and none of these interactions were significant for unilateral solutions. Each type of actor individually has a positive effect on the likelihood of a unilateral solution, which fits with the expectation that unilateral solutions would be preferred overall, and provides an indication that there may be some promise to Hypothesis 4 with local actors having a positive effect on the likelihood of a unilateral solution.

Table 1: Number of responses by type

Type of response	Total number of cases	Number of cases with implemented responses
Disaster assistance	16	11
New/Rehabilitated infrastructure	35	7
Water Infrastructure Management	55	14
Laws and regulations	8	1
Court cases	10	1
Resources	20	6
Unilateral solutions	**98**	**36**
Collaboration	13	5
Public meeting	5	4
Market incentive	4	0
Public information	14	10
Habitat restoration	6	0
Monitoring	12	10
Collaborative solutions	**42**	**26**
Water conservation	**38**	**16**
Other	9	--

Table 2: Cases with government actors

Actor type	Number of cases
Federal	79
State	45
Local	40
Special district	69
All 4 categories	3
Any 3 categories	24
Any 2 categories	53
Only 1 category	43
No government actors	8

Collaborative solutions (Table 4) are also not significantly affected by the independent variables. Directionally, state and special district actors have a negative relationship with collaborative solutions, indicating that they may be less likely to engage in these types of solutions. Federal and local actors are inconsistent in whether they positively or negatively affect the likelihood of collaborative solutions, depending on the interactions included. None of the interactions are significant and are mixed directionally, meaning no conclusive effect can be determined for the involvement of multiple governance levels and jurisdictions on the likelihood of a collaborative response, leading to no support for Hypothesis 3.

The final set of logit regression models attempts to determine the likelihood of water conservation as a response (Table 5). Similar to the other models, significant results are lacking with the exception of special districts. These actors have a positive, significant effect on the likelihood of a water conservation response in all seven models. This indicates that special districts prefer this type of response as compared to the other categories of responses. The interactions between actors is mixed as with the other dependent variables, except for a negative, significant coefficient on the interaction between local and special districts. This may at first appear puzzling, but may make sense as water conservation is not necessarily a type of response that benefits from collaboration. Water conservation, as typically mentioned in the coded articles, refers to regulations that restrict the usage of water by individual users during set times. These types of measures can be implemented by a single government actor over their jurisdiction, and attempting to collaborate on water conservation may actually slow down the implementation of these measures.

Finally, Table 6 displays the types of solutions mentioned in the articles by actors involved in the issues. Overall, all four types of government actors preferred unilateral solutions over collaborative solutions or water conservation, but the amounts for collaborative solutions and water conservation were much closer together. This suggests an avenue for future research, in that the combination of collaborative solutions and water conservation may be complementary tools in adapting to changing conditions.

Table 3: Unilateral solutions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Percent area in drought	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Public water supply (Mgal/d)	-0.014	-0.014	-0.014	-0.011	-0.014	-0.013	-0.014
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
Irrigation water (Mgal/d)	-0.008*	-0.008*	-0.008*	-0.009*	-0.008	-0.008*	-0.008*
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Federal actor	0.186	0.175	0.225	0.544	0.194	0.191	0.186
	(0.461)	(0.524)	(0.546)	(0.737)	(0.465)	(0.462)	(0.461)
State actor	0.399	0.367	0.386	0.411	0.360	0.626	0.394
	(0.553)	(0.905)	(0.563)	(0.555)	(0.625)	(0.767)	(0.561)
Local actor	0.552	0.555	0.629	0.555	0.515	0.593	0.525
	(0.530)	(0.535)	(0.795)	(0.532)	(0.597)	(0.541)	(0.771)
Special district actor	0.305	0.305	0.304	0.639	0.294	0.442	0.290
	(0.529)	(0.529)	(0.529)	(0.753)	(0.536)	(0.616)	(0.614)
Federal*State		0.049					
		(1.099)					
Federal*Local			-0.137				
			(1.049)				
Federal*Special district				-0.594			
				(0.961)			
State*Local					0.181		
					(1.356)		
State*Special district						-0.455	
						(1.054)	
Local*Special district							0.051
							(1.058)
Constant	1.800*	1.807*	1.791*	1.576	1.796*	1.693*	1.815*
	(0.975)	(0.987)	(0.979)	(1.029)	(0.973)	(1.004)	(1.023)
Observations	113	113	113	113	113	113	113
Log Likelihood	-60.896	-60.895	-60.887	-60.704	-60.887	-60.803	-60.894
Akaike Inf. Crit.	137.791	139.789	139.774	139.409	139.773	139.606	139.789
Note:	*p**p***p<0.01						

Table 4: Collaborative solutions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Percent area in drought	-0.005	-0.006	-0.005	-0.005	-0.005	-0.005	-0.005
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Public water supply (Mgal/d)	0.018	0.018	0.018	0.014	0.018	0.018	0.019
	(0.017)	(0.017)	(0.017)	(0.018)	(0.017)	(0.017)	(0.017)
Irrigation water (Mgal/d)	0.001	0.0005	0.0004	0.002	0.0001	0.001	0.001
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Federal actor	0.047	-0.133	0.279	-0.479	0.001	0.045	0.042
	(0.426)	(0.491)	(0.537)	(0.664)	(0.432)	(0.426)	(0.426)
State actor	-0.360	-0.877	-0.427	-0.359	-0.094	-0.167	-0.414
	(0.490)	(0.880)	(0.498)	(0.491)	(0.593)	(0.671)	(0.501)
Local actor	0.086	0.133	0.457	0.082	0.296	0.123	-0.178
	(0.455)	(0.461)	(0.688)	(0.458)	(0.528)	(0.463)	(0.670)
Special district actor	-0.145	-0.119	-0.147	-0.669	-0.079	-0.019	-0.332
	(0.482)	(0.488)	(0.483)	(0.701)	(0.492)	(0.570)	(0.591)
Federal*State		0.773					
		(1.049)					
Federal*Local			-0.648				
			(0.905)				
Federal*Special district				0.902			
				(0.880)			
State*Local					-0.832		
					(1.088)		
State*Special district						-0.412	
						(0.986)	
Local*Special district							0.488
							(0.908)
Constant	-0.808	-0.698	-0.895	-0.496	-0.833	-0.907	-0.644
	(0.815)	(0.832)	(0.824)	(0.866)	(0.811)	(0.851)	(0.867)
Observations	113	113	113	113	113	113	113
Log Likelihood	-68.829	-68.545	-68.573	-68.303	-68.525	-68.740	-68.684
Akaike Inf. Crit.	153.658	155.090	155.145	154.606	155.050	155.481	155.368
Note:	*p**p***p<0.01						

Table 5: Water Conservation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Percent area in drought	0.002	0.002	0.002	0.002	0.002	0.002	0.003
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Public water supply (Mgal/d)	0.042**	0.043**	0.042**	0.042**	0.042**	0.042**	0.041*
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.022)
Irrigation water (Mgal/d)	0.008	0.008	0.008	0.008	0.008	0.008	0.009
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Federal actor	0.551	0.376	0.669	0.468	0.554	0.551	0.571
	(0.501)	(0.572)	(0.606)	(1.224)	(0.510)	(0.501)	(0.508)
State actor	0.708	0.199	0.657	0.708	0.695	0.622	0.953
	(0.593)	(1.024)	(0.611)	(0.593)	(0.728)	(1.139)	(0.635)
Local actor	0.211	0.271	0.441	0.210	0.201	0.200	2.046
	(0.543)	(0.551)	(0.853)	(0.543)	(0.639)	(0.556)	(1.283)
Special district actor	2.211***	2.266***	2.199***	2.141*	2.207***	2.158**	3.436***
	(0.658)	(0.676)	(0.657)	(1.144)	(0.668)	(0.882)	(1.154)
Federal*State		0.775					
		(1.247)					
Federal*Local			-0.392				
			(1.122)				
Federal*Special district				0.099			
				(1.345)			
State*Local					0.037		
					(1.275)		
State*Special district						0.115	
						(1.302)	
Local*Special district							-2.347*
							(1.422)
Constant	-5.166***	-5.084***	-5.148***	-5.104***	-5.168***	-5.117***	-6.503***
	(1.285)	(1.295)	(1.272)	(1.526)	(1.288)	(1.393)	(1.686)
Observations	113	113	113	113	113	113	113
Log Likelihood	-52.965	-52.766	-52.904	-52.962	-52.965	-52.961	-51.416
Akaike Inf. Crit.	121.930	123.531	123.809	123.925	123.929	123.922	120.831
Note:	*p**p***p<0.01						

Table 6: Solutions by actor

Actor	Unilateral solutions	Collaborative solutions	Water conservation
Federal	60	25	25
State	36	11	11
Local	33	15	10
Special district	52	22	33

Discussion and conclusion

While these preliminary results do not provide definitive answers about how communities respond to changing conditions, it is clear there is potential for further exploration of these data. While the regression results do not indicate a strong preference for types of solutions among the different governmental actors, this may indicate they prefer a more diverse set of solutions. Diversifying responses to changing conditions can increase robustness and enhance long-term sustainability. Analyzing the diversity of solutions considered in each article will be included in the next steps from this data. In terms of trade-offs between competing changing conditions (such as flooding and drought), this data does not analyze whether different issues lead to different types of solutions. Looking at the responses by issue and over time will also be included in the next iteration of this analysis in order to see if there are trade-offs between types of responses and if these trade-offs change over time. The current analysis indicates a dominance of traditional infrastructure solutions, but as more infrastructure is completed, there is less that can be done from this angle and decision makers may be forced to turn to other types of solutions.

The data do indicate the polycentric nature of the system, suggesting this form of management is beneficial on the Rio Grande. The basin is a polycentric system with multiple overlapping jurisdictions and special districts. These special districts are highly active in their responses, as seen in Table 6 and the water conservation logit regression in Table 5. These are largely irrigation districts and water utilities in this data—organizations with a special purpose and jurisdiction acting within and around the other governmental levels. These districts may be better able to implement solutions, especially unilateral ones, than other levels of government because they are single purpose jurisdictions, so they do not have other responsibilities to balance with water management activities like a city or state would. Exploring the role of these special districts in local responses to changing conditions would be a promising avenue of future research.

In terms of CISs, the analysis demonstrates the path dependence of hard human-made infrastructure in making adaptation difficult. Unilateral solutions, including physical infrastructure, dominate the responses, but it is not clear how well these solutions fit and interact with natural infrastructures. The lack of collaborative solutions may also indicate a lack of development of soft human-made infrastructure or social infrastructure which may fit and interact with the natural system in different ways. The lack of development of social infrastructure also indicates a lack of investment in this infrastructure by individual actors and groups, meaning collective action is still likely an obstacle. The costs of collective action may be high enough that less responses occur as a result of working together, and less collaborative responses occur overall. There may also be issues with trust and reciprocity as a result of past interactions and conflicts, leading certain individual actors or types of actors to be less likely to engage with each other or other types of actors if they anticipate negative consequences as a result of the interactions. Future analysis could trace the role of specific actors over time in the dataset to determine if there are pairings that occur more or less often.

There are several limitations in the data and analysis. First, the current operationalization may not accurately capture the nuance in the types of responses and the actors as it aggregates across response types and phases. The continued collection of data may remedy this by increasing the number of responses in each response type. Also, the interactions may not actually capture the collaboration between actors or government levels as it is simply determining if the presence of these pairs of actors together in a case are affecting the response types. Finally, more than one response may be coded for each article—decision makers may be taking more than one action to respond to changing conditions and certain combinations of responses may be more effective than single responses. As mentioned previously, exploring the diversity in solutions and combinations of solutions may prove fruitful.

In conclusion, the data presented in this paper provide a suggestion of how changing conditions are managed in the Rio Grande River Basin. Currently, more unilateral solutions are preferred in response to changing conditions and collaboration does not appear to have a strong effect on response type. Additionally, there is no clear preference for certain types of solutions by actor, with the exception of special districts being more likely to use water conservation than all other response types. Future research can further explore the interactions between actors, particularly from a federalism angle, as encroachment or shirking by actors at different levels may influence the interactions and solutions (Bednar 2009). This analysis has implications for policy and decision makers, as it provides a picture of the range of solutions that are put into place and who utilizes them, providing knowledge and information on where to look for strategies or who may be potential partners in collaborative projects. With the continued collection of data in this project, we should gain more insight into how communities manage changing conditions in water dependent environments.

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Appendix

Table A. Unilateral solutions with only planned/in progress and implemented responses

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Percent area in drought	0.003	0.002	0.003	0.003	0.003	0.003	0.003
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Public water supply (Mgal/d)	-0.005	-0.004	-0.004	-0.002	-0.005	-0.004	-0.006
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
Irrigation water (Mgal/d)	-0.008*	-0.009**	-0.007*	-0.008*	-0.008*	-0.008*	-0.007*
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Federal actor	0.014	-0.406	-0.109	0.362	0.016	0.013	0.024
	(0.407)	(0.484)	(0.497)	(0.655)	(0.411)	(0.408)	(0.409)
State actor	-0.028	-0.986	0.012	-0.025	-0.038	0.171	0.085
	(0.459)	(0.749)	(0.468)	(0.461)	(0.551)	(0.656)	(0.470)
Local actor	0.432	0.553	0.212	0.436	0.422	0.471	1.066
	(0.445)	(0.457)	(0.675)	(0.446)	(0.527)	(0.454)	(0.693)
Special district actor	-0.234	-0.192	-0.232	0.100	-0.236	-0.099	0.147
	(0.460)	(0.466)	(0.461)	(0.673)	(0.467)	(0.557)	(0.552)
Federal*State		1.521					
		(0.937)					
Federal*Local			0.383				
			(0.890)				
Federal*Special district				-0.573			
				(0.846)			
State*Local					0.035		
					(1.006)		
State*Special district						-0.383	
						(0.901)	
Local*Special district							-1.115
							(0.905)
Constant	1.108	1.386*	1.147	0.887	1.109	1.001	0.782
	(0.793)	(0.823)	(0.797)	(0.852)	(0.793)	(0.830)	(0.836)
Observations	113	113	113	113	113	113	113
Log Likelihood	-73.720	-72.365	-73.627	-73.490	-73.719	-73.629	-72.946
Akaike Inf. Crit.	163.439	162.729	165.255	164.981	165.438	165.258	163.892
Note:	*p**p***p<0.01						

Table B. Collaborative solutions with only planned/in progress and implemented responses

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Percent area in drought	-0.009	-0.009	-0.008	-0.009	-0.009	-0.009	-0.009
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Public water supply (Mgal/d)	0.026	0.027	0.025	0.019	0.026	0.026	0.026
	(0.019)	(0.019)	(0.019)	(0.020)	(0.019)	(0.019)	(0.019)
Irrigation water (Mgal/d)	0.0004	-0.0002	-0.0001	0.002	0.0001	0.0004	0.0003
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Federal actor	-0.496	-0.753	-0.196	-1.557**	-0.520	-0.500	-0.498
	(0.454)	(0.531)	(0.567)	(0.770)	(0.460)	(0.454)	(0.453)
State actor	-0.144	-0.790	-0.243	-0.136	-0.018	0.041	-0.179
	(0.538)	(0.899)	(0.549)	(0.544)	(0.658)	(0.781)	(0.552)
Local actor	0.020	0.096	0.459	0.017	0.120	0.055	-0.142
	(0.488)	(0.498)	(0.694)	(0.498)	(0.575)	(0.500)	(0.752)
Special district actor	0.276	0.330	0.269	-0.589	0.313	0.388	0.167
	(0.525)	(0.536)	(0.528)	(0.713)	(0.538)	(0.631)	(0.646)
Federal*State		1.061					
		(1.116)					
Federal*Local			-0.862				
			(0.979)				
Federal*Special district				1.706*			
				(0.977)			
State*Local					-0.380		
					(1.170)		
State*Special district						-0.350	
						(1.078)	
Local*Special district							0.284
							(0.996)
Constant	-1.043	-0.900	-1.130	-0.535	-1.053	-1.136	-0.945
	(0.884)	(0.900)	(0.888)	(0.926)	(0.880)	(0.933)	(0.947)
Observations	113	113	113	113	113	113	113
Log Likelihood	-60.893	-60.419	-60.501	-59.318	-60.839	-60.840	-60.852
Akaike Inf. Crit.	137.786	138.838	139.003	136.636	139.679	139.680	139.705
Note:	*p**p***p<0.01						

Table C. Water conservation with only planned/in progress and implemented responses

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Percent area in drought	0.005	0.005	0.005	0.005	0.005	0.005	0.007
	(0.007)	(0.008)	(0.007)	(0.007)	(0.007)	(0.007)	(0.008)
Public water supply (Mgal/d)	0.049**	0.052**	0.054**	0.051**	0.049**	0.050**	0.048**
	(0.023)	(0.024)	(0.024)	(0.024)	(0.023)	(0.023)	(0.024)
Irrigation water (Mgal/d)	0.011	0.011	0.014*	0.011	0.010	0.011*	0.013*
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Federal actor	-0.212	-0.720	-0.736	0.505	-0.279	-0.209	-0.235
	(0.520)	(0.610)	(0.654)	(1.234)	(0.531)	(0.520)	(0.525)
State actor	0.574	-1.078	0.805	0.584	0.841	0.967	0.738
	(0.615)	(1.287)	(0.641)	(0.618)	(0.746)	(1.181)	(0.640)
Local actor	0.696	0.920	-0.186	0.698	0.910	0.740	2.082
	(0.564)	(0.591)	(0.887)	(0.566)	(0.662)	(0.576)	(1.307)
Special district actor	1.381**	1.486**	1.462**	1.963*	1.465**	1.610*	2.310**
	(0.662)	(0.690)	(0.672)	(1.164)	(0.680)	(0.908)	(1.132)
Federal*State		2.384					
		(1.502)					
Federal*Local			1.569				
			(1.193)				
Federal*Special district				-0.900			
				(1.368)			
State*Local					-0.844		
					(1.370)		
State*Special district						-0.522	
						(1.337)	
Local*Special district							-1.769
							(1.443)
Constant	-5.526***	-5.491***	-5.785***	-6.044***	-5.435***	-5.742***	-6.649***
	(1.476)	(1.540)	(1.587)	(1.731)	(1.446)	(1.596)	(1.878)
Observations	113	113	113	113	113	113	113
Log Likelihood	-49.383	-47.887	-48.481	-49.152	-49.191	-49.307	-48.550
Akaike Inf. Crit.	114.767	113.775	114.963	116.304	116.382	116.614	115.099
Note:	*p**p***p<0.01						

Rio Grande Media Codebook

Variable Name	Definition	Format
Coder_ID	ID number for each coder	Starts at 100
Article_ID	Unique numerical identifier for each new article; see Article ID master list to prevent duplicates	Texas 1000-1999; New Mexico 2000-2999; Colorado 3000-3999; other 4000-4999
Date	Publication date of article	MM/YYYY
Issues: Drought_shortage; Groundwater; Flooding; Pollution_quality; Species_habitat; Infrastructure; Water_pay_alloc; Water_mgmt; Water_rights; Other	Main issues discussed in first 3 main paragraphs of the articles; may be more than one per article. See definitions of issues below.	1=main issue 0=not main issue
Location	Geographic location; use the main location of the article discussed in the first 3 paragraphs; use only one code	1=San Luis Valley, CO 2=CO-NM border to Santa Fe, NM 3=Middle Rio Grande, NM (between Santa Fe and Elephant Butte Reservoir) 4=Elephant Butte to El Paso, TX including El Paso 5=Between El Paso and Amistad Reservoir, TX (Lost Reach) 6=Amistad Reservoir to mouth of the Rio Grande 7=New Mexico 8=Texas 9=Rio Grande River Basin 10=Mexico
Actor1, Actor2, etc.	All proper names are considered actors; code the name of the organization the actor belongs to. Code specific state agencies unless not specified, then code the state; i.e. code “state officials” as Texas. Note: If proper name is not performing an action, being quoted, or is for descriptive purposes, do not code.	Refer to Actor ID master list for existing 4-digit actor codes or to assign a new ID per list instructions. If more than one actor from the same organization is included in the article code the ORGANIZATION for each actor.
Disagree	Actors publicly and actively disagreeing, including court cases, public meetings, damage or theft; do not include opinions from those not involved directly	1=disagreement 0=no disagreement
Disagree_actor1, Disagree_actor2, through 5	Code the actors involved in the disagreement	Code with 4-digit Actor ID; once per organization
Agree	Actors formally or publicly agreeing to actively work together or provide support with a mutual interest in the outcome	1=agreement 0=no agreement
Agree_actor1, Agree_actor2, through 5	Code the actors involved in the agreement	Code with 4-digit Actor ID; once per organization
Responses: Disaster_assist; New_rehab_infras; Water_infras_mgmt; Laws_regs; Court_case; Resources; Collaboration; Public_meet; Market_incentive; Water_conservation; Public_info; Habitat_restore; Monitoring; Other	Response to the issues or problems coded in the article; can include proposed actions, independent actions, or coordinated efforts. Do not include ideas or speculation. See response definitions below.	Code by status of response: 0=no response 1=suggest/proposed: concrete, thought out ideas 2=planned or in progress: clear action will be implemented (e.g. dates set) 3=implemented

Definitions of Issues:
Drought_shortage: Drought/Water shortage; Issues related to lack of precipitation over period of time or shortage due to human demand or human actions
Groundwater: Issues related to access, use, abuse, or lack of groundwater
Flooding: Issues related to flooding events and their consequences
Pollution_quality: Pollution/Water quality; Contamination of surface or groundwater. Includes issues affecting water quality
Species_habitat: Invasive/Endangered Species or Habitats; Issues related to native species or intrusion of non-native species (flora or fauna) and their habitats. Includes habitat management and efforts at reconstruction
Infrastructure: Issues related to existent or proposed water infrastructure. Water infrastructure could be pipes, waste water treatment plants, irrigation equipment, or referring to the construction of levees or reservoirs
Water_pay_alloc: Water payment/allocation; Issues related to delivery of water according to treaties and compacts
Water_mgmt: Management issues related to permits, operation of infrastructure, and provision of water
Water_rights: Issues related to the legal basis for diverting and using water and disagreements over who uses the water and how
Other: An issue not captured in these categories. Name of the issue instead of using the 1/0 coding.

Definitions of Responses:
Disaster_assist: Disaster declaration, emergency declaration, evacuations, aid provided
New_rehab_infras: New infrastructure works constructed or existing rehabilitated; includes measures to clean up and prevent pollution
Water_infras_mgmt: Management decisions related to water and infrastructure, including releases and payments; this also includes water planning, such as state water plans
Laws_regs: Enactment of new regulations, laws, or legislation or changes to existing, including enforcement or implementation
Court_case: An issue is taken to, resolved, or tied up in court
Resources: Includes experts to study or examine the issue or money, loans, and grants
Collaboration: Actors sharing information or consulting with one another or creating groups to manage resources
Public_meet: Invite public/stakeholder participation or input
Market_incentive: Responses related to buying, selling, or leasing water or measures to influence behavior of water users
Water_conservation: Proposed, planned, or implemented measures to reduce usage and/or consumption
Public_info: Providing information to public to help respond to, prepare for, or alleviate issues; also raising awareness; this includes websites
Habitat_restore: Actions to restore habitats dependent on the river for survival or benefitting the river and its uses; includes Endangered Species Act applications
Monitoring: Conducting formal observations of the issue including the actions of other actors or environmental conditions
Other: A response not included here. Name the response instead of coding 1/0.