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Key Points:
- States can help or hinder resilient water management across scales
- Knowledge systems, participation, learning, integrated planning and allocation, and flexible institutions support good water governance
- Stationarity assumptions, intractable institutions, and inadequate funding challenge good water governance

Supporting Information:
- Supporting Information S1
- Supporting Information S2

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The role of U.S. states in facilitating effective water governance under stress and change

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Abstract Worldwide water governance failures undermine effective water management under uncertainty and change. Overcoming these failures requires employing more adaptive, resilient water management approaches; yet, while scholars have advance theory of what adaptive, resilient approaches should be, there is little empirical evidence to support those normative propositions. To fill this gap, we reviewed the literature to derive theorized characteristics of adaptive, resilient water governance including knowledge generation and use, participation, clear rules for water use, and incorporating nonstationarity. Then, using interviews and documentary analysis focused on five U.S. states' allocation and planning approaches, we examined empirically if embodying these characteristics made states more (or less) adaptive and resilient in practice. We found that adaptive, resilient water governance requires not just possessing these characteristics but combining and building on them. That is, adaptive, resilient water governance requires well-funded, transparent knowledge systems *combined with* broad, multilevel participatory processes that support learning, strong institutional arrangements that establish authorities and rules *and* that allow flexibility as conditions change, and resources for *integrated* planning and allocation. We also found that difficulty incorporating climate change or altering existing water governance paradigms and inadequate funding of water programs undermine adaptive, resilient governance.

1. Introduction

Despite having complex systems of water governance in place, water systems around the world continue to experience governance failures that undermine effective water management under uncertainty and change [*UNWWAP*, 2003]. Expanding economies, growing populations, and a rapidly changing and uncertain environment challenge the ability of water managers and policy makers' to govern water effectively. Water governance-the "range of political, social, economic, and administrative systems that are in place" to manage water resources at different levels of society-encompasses a wide variety of activities such as planning and allocation, data gathering, and modeling, legislative and judicial processes, and local citizen involvement [*Rogers and Hall*, 2003, p. 7]. A diverse and largely theoretical literature has advanced our understanding of the characteristics of effective water governance under uncertainty and change. This research suggests that, given the complexity of water resources management under uncertainty, more adaptive and resilient governance arrangements are needed [see e.g., *Engle et al*., 2011; *Huitema et al*., 2009; *Huntjens*, 2011; *Huntjens et al*., 2012; *Nelson*, 2011; *Nelson et al*., 2008; *Pahl-Wostl*, 2007, 2009]. Intuitively, the need for adaptive, resilient governance arrangements makes sense; yet, there is little empirical research available that tests these normative propositions. Moreover, most of the research on water governance is at the watershed and international scales. To our knowledge, water governance arrangements at subnational scales have been relatively less examined. For example, despite the fact that U.S. states have broad water governance authority, research analyzing water governance arrangements of individual states within the United States is particularly scarce [although see, *Kirchhoff et al*., 2013; *Megdal et al*., 2014].

In this paper, we address the following questions: (1) How do U.S. states approach water allocation and planning? (2) In what ways do U.S. state water allocation and planning approaches embody (or not) characteristics of adaptive and resilient governance theorized in the literature? (3) What challenges do U.S. states face in employing adaptive, resilient water governance arrangements? To address the research questions, we first develop a normative set of characteristics (e.g., institutional and organizational arrangements and practices) reflective of adaptive, resilient water governance based on an extensive review of the literature. Next, we examine U.S. state governance regimes for water resource planning and allocation and compare observed practices and arrangements to the characteristics of adaptive, resilient governance theorized in the literature. In particular, we tease apart how the different observed practices and arrangements work together to enhance (or undermine) effective water management at the state level and explore the implications for enhancing or diminishing governance capacity at the local level. We also illuminate challenges states face in employing more resilient approaches in practice. We focus our empirical analysis on five U.S. states-Florida, Georgia, Illinois, Maryland, and Texas-drawing upon interviews and documentary analysis.

2. U.S. State Water Allocation and Planning

At the risk of oversimplifying the many varied complexities and dimensions of water allocation in U.S. states, due to space constraints, we highlight the two main systems for water allocation. In most western states, surface water allocation is accomplished through a system of prior appropriation that awards rights to priority users (i.e., first in time, first in right) [*Maloney and Ausness*, 1971]. Most states east of the Mississippi River use a riparian or regulated riparian system where land owners that abut a waterbody (i.e., riparians) have the right to use the water so long as their right does not diminish the rights of other riparians to use the water [*Choe*, 2004; *Deason et al*., 2001; *Maloney and Ausness*, 1971]. Legal doctrines for surface water allocation are generally well established; those for groundwater are both less well developed and less uniform [*Megdal et al*., 2014]. In both eastern and western states, groundwater allocation regimes vary considerably from no restrictions on use to individually permitted rights for specified amounts of water. In addition, under regulated riparian systems, some permitted rights are issued in perpetuity while others have built-in expiration and/or renewal dates [*Schlager*, 2006].

Water planning approaches and motivations for planning are also complex and vary by state. Some states choose not to exercise their authority to plan and do no planning at all. Other states engage in state-led, top-down efforts conducted periodically. Finally, some engage in ongoing participatory planning processes where plans are updated at regular intervals [*Viessman and Feather*, 2006]. Typically, states undertake planning because of some experience with or concern about water shortage—either from drought or from a combination of drought and population or economic growth [*English and Arthur*, 2010], or when concerns about water quantity and quality collide.

3. Water Governance Under Stress and Change

A diverse and largely theoretical body of research on water governance, climate change adaptation, and resilience of social-ecological systems suggests that, given the complexity and uncertainty of water resources management and the impacts of climate change, more reflexive and adaptive governance arrangements are needed. At its most basic level, as *Milly et al*. [2008] suggest, managing water resources under stress and change requires water managers to no longer assume stationarity in climate, patterns of growth, or societal values. While this is an important first step, incorporating nonstationarity into management is insufficient if the governance context itself is not flexible and adaptive. For example, conventional hierarchical governance approaches-arranged to facilitate top-down decision making-are routinely criticized for being inefficient, unresponsive, and not conducive to learning and adaptation [*Huitema et al*., 2009; *Pahl-Wostl*, 2007; *Johnson*, 1999]. While top-down approaches still dominate the water governance landscape, more participatory variations such as Adaptive Water Governance (AWG) and Integrated Water Resources Management (IWRM) are gaining traction. While IWRM aims to improve governance through integration of water demands and uses, information, and participation [*Davis*, 2007; *Rouillard et al*., 2013], AWG aims to improve governance under uncertainty by emphasizing management as learning. To enhance learning, AWG prioritizes flexibility, generating knowledge to help learn from past events, and building trust through collaboration, coordination, and deliberation among diverse stakeholders across scales (e.g., jurisdictional, managerial) [*McLain and Lee*, 1996; *Johnson*, 1999; *Dietz et al*., 2003; *Olsson et al*., 2004; *Folke et al*., 2005; *Huitema et al*., 2009; *Mostert and Pahl-Wostl*, 2010; *Ison et al*., 2011; *Rouillard et al*., 2013]. Finally, integrative, adaptive, collaborative, and transparent water governance is hypothesized to be more effective under stress and change [*Godden and Kung*, 2011; *Foerster*, 2011; *Huntjens et al*., 2012; *Pahl-Wostl*, 2007; *Knüppe and Pahl-Wostl*, 2011; *Nelson et al*., 2008; *Miller*, 2011].

Table 1. Theorized Characteristics Associated With Adaptive and Resilient Water Governance

Characteristic	Definition	Literature Source
Knowledge	Ongoing generation and distribution of scientific information to understand and characterize the quantity and quality of water resources and demands on those resources	*Adger et al.* [2005]; *Armitage and Plummer* [2010]; *Berkes* [2009]; *Davidson-Hunt and O'Flaherty* [2007]; *Folke* [2006]; *Huitema et al.* [2009]; *Lebel et al.* [2005]; *Reid et al.* [2006]; *van Kerkhoff and Lebel* [2006]
Flexible, policy learning	Ongoing mechanisms and processes to integrate new knowledge into policy and decision-making. Responsive to changing conditions in the natural and social environment	*Nelson et al.* [2008]; *Adger et al.* [2011]; *Godden and Kung* [2011]; *Foerster* [2011]; *Huntjens et al.* [2012]; *Pahl-Wostl* [2007, 2009]; *Knüppe and Pahl-Wostl* [2011]
Multilevel interactions	Multilevel interactions of actors or systems within and across scales	*Folke et al.* [2005]; *Huntjens et al.* [2010]; *Rouillard et al.* [2013]
Collaboration and deliberation	Diverse and representative participation, collaboration, and deliberation that builds trust, transparency, and taking a broad view	*Folke et al.* [2005]; *Huntjens et al.* [2010]; *Rouillard et al.* [2013]
Clear boundaries or rules	A system for water use that clearly defines who has access to water and that includes an equitable means for adjustment in response to stress	*Huntjens et al.* [2012]
Nonstationarity	Not assuming stationarity in climate, patterns of growth, or societal values	*Milly et al.* [2008]

Concerns about maladaptation and the potential need for transformation have led some scholars to suggest that water governance must go beyond being simply integrative and adaptive to create governance structures that build resilience rather than undermine resilience as a result of too-short adaptation time horizons, too narrow geographic considerations, or ignoring ecosystem or other common pool considerations [*Adger et al.*, 2011; *Nelson*, 2011]. The concept of resilience adds another dimension to AWG by enabling not only adaptation within the existing system, but also the ability to transform the system to an entirely new state [*Nelson et al.*, 2008; *Adger et al.*, 2011]. That is, adding resilience brings a greater emphasis on governance arrangements and practices that enable science supported policy change and that provide clear boundaries or rules for managing the use of water resources under scarcity [*Adger et al.*, 2005; *Armitage and Plummer*, 2010; *Berkes*, 2009; *Davidson-Hunt and O'Flaherty*, 2007; *Folke*, 2006; *Huitema et al.*, 2009; *Ison et al.*, 2011; *Lebel et al.*, 2005; *Reid et al.*, 2006; *van Kerkhoff and Lebel*, 2006]. On the one hand, science supported policy change enables governance systems to make ongoing adjustments in response to short-term stresses and to facilitate transitions and transformations in response to longer-term changes [*Nelson et al.*, 2007]. On the other hand, articulating clear and transparent rules for water allocation under scarcity [*Huntjens et al.*, 2012] enables the articulation of built-in governance mechanisms to fairly and equitably adjust use to avoid systemic breakdown, as conditions change (e.g., less water becomes available). Table 1 summarizes the theorized characteristics associated with adaptive and resilient water governance.

4. Methodology

We use a case study approach [*Yin*, 2003] to examine governance regimes for water planning and allocation in five states: Florida, Georgia, Illinois, Maryland, and Texas. To inform our selection, we reviewed all 48 contiguous states' approaches to water planning especially, states' consideration of climate change in water planning circa 2010. We selected these five states for analysis because they represent a variety of approaches to state water planning (e.g., state led with regional planning or no or limited planning) and allocation (e.g., strong allocation programs or no or limited allocation), experience varying stresses (e.g., drought, very high or low growth rate), and vary in their consideration of the impacts of climate change on water resources. We were particularly interested in examining states in the south, Midwest, and eastern United States where tremendous growth in irrigated agriculture is adding new pressures on water resources [*Levin and Zarriello*, 2013; *Schaible and Aillery*, 2012]. Data collected for this research included both documents (e.g., state policies governing water allocation and planning, state water planning reports, and information from state water agency websites) and semistructured phone interviews.

Sampling for the semistructured interviews was nonrandom and purposeful [*Morse et al.*, 2001]. We made every effort to select practitioners and experts who would bring a mixture of perspectives and who represent the range of governance processes and functions being analyzed. The approximately hour-long interviews were structured to elicit the interviewee's perspectives about: (1) critical water resources management issues and objectives; (2) water resource planning and allocation decision making processes and institutional arrangements; and (3) information sources used in planning and to inform allocation decisions and water policy making. The interview protocol is included in supporting information as Text S1. In total, 50 interviews were conducted during January–July, 2011. These are summarized in Table 2.

Table 2. Number and Affiliation of Interviewees

State	Interviewee Affiliation (Number of Interviewees)	Subtotal
Texas	State (4); Academic (2); Nongovernmental (2); Private (2)	10
Georgia	State (3); Federal (1); Academic (2); Nongovernmental (1)	7
Maryland	State (5); Interstate (2); Federal (1); Academic (3)	11
Florida	State (7); Academic (1); Nongovernmental (1); Private (2)	11
Illinois	State (5); Academic (5); Nongovernmental (1)	11

Anonymity was guaranteed to all interviewees and consequently interviewees are referred to by code: XX-#, where the "XX" is the state abbreviation and the "#" is a number assigned to an interviewee.

For accuracy, interviews were recorded and transcribed [*Galletta*, 2013] and each coauthor independently reviewed and analyzed the transcripts. To address the first research question, data analysis focused on determining the regulatory framework for allocation and planning, specific authorities and agencies involved, and the practices and arrangements for allocation and planning in each state. For the second research question, data were examined to compare observed practices and arrangements for planning and allocation to those associated with adaptive and resilient governance identified in the literature (Table 1). Finally, for the third research question, the data were analyzed to identify impediments to implementing more adaptive, resilient governance arrangements in practice.

5. State Allocation and Planning Approaches

The institutional arrangements in each state establish the regulatory frame and authority for water allocation and planning while the organizational frameworks establish both who is involved in allocation and planning (i.e., governmental, nongovernmental, and public actors) and the respective roles they play. For example, for allocation, Texas is the only case in our study that adheres to the prior appropriation doctrine for surface water and absolute dominion for groundwater. Georgia, Maryland, and Florida all employ the riparian doctrine for water allocation. Finally, in Illinois there is no state-wide administrative system for water allocation although the state does regulate surface water withdrawals from Lake Michigan. For planning, by law, both Texas and Georgia employ a science-based, participatory, state, and regional planning process involving state agencies and regional planning groups. While Florida also engages in ongoing, science-based, regional planning, the process focuses on stressed water resources (i.e., rather than state-wide or region-wide plans) and offers limited opportunities for participation. Moreover, differently than other states, in Florida, both planning and allocation authorities are carried out by the state's five regional Water Management Districts (WMDs). The planning process is also somewhat unique in Maryland wherein counties undertake water planning. Finally, in Illinois, while there is a state water plan (IL-1), planning is primarily relegated to local jurisdictions. Illinois experimented with a short-lived, regional planning process for two Illinois watersheds (IL-2; IL-3; IL-5), but authority and funding waned and the process collapsed after 2009. According to state water managers, "It is up to the municipalities and water districts to do their own planning" (IL-1). A summary of state water allocation and planning approaches is included in supporting information as Table S1.

6. Adaptive and Resilient Characteristics and Challenges

6.1. Knowledge and Linking Knowledge to Action

A commitment to support knowledge development helps state agencies, legislatures, regional groups, and local decision makers foster a comprehensive view of water availability and use. Despite its importance, states vary in their support for ongoing data and knowledge generation for water management—an important characteristic of adaptive, resilient governance [*Adger et al.*, 2005; *Armitage and Plummer*, 2010; *Armitage et al.*, 2015]. Among our case studies, Texas, Georgia, and Florida exhibited the greatest capacity and support for knowledge development, while Illinois and Maryland had less support (for a summary of adaptive and resilience characteristics across all cases, see Table 3). For example, the Texas legislature provides both authority and financial resources to the Texas Water Development Board (TWDB) to collect water use data and to develop surface and groundwater models for use in planning and allocation decisions across the state (TX-1; TX-2). Like Texas, the Georgia legislature also funded the development of surface water availability and assimilative capacity models to support the regional planning process (GA-1). And, in

Table 3. Summary of Adaptive, Resilient Governance Practices in U.S. States

	TEXAS	GEORGIA	FLORDIA	MARYLAND	ILLINOIS
Knowledge	State wide water use data, population projections, information, and models about surface and groundwater availability and demands.	State wide water use data and population forecasts as well as information and models about surface water availability and assimilative capacity.	Water use data, population projections, information and models about surface and groundwater availability and demands in areas under water stress.	State wide water use data and well-drilling data but limited modeling (in area under water stress).	Limited water use data. Limited modeling primarily in areas already under water stress.
Linking knowledge-to-action	TWDB and TCEQ aim for comprehensive modeling with ongoing improvements to support planning and allocation decisions.	EPD aims for comprehensive modeling with ongoing improvements to support planning and allocation decisions.	WMDs strong data and information development helps identify water management issues particularly in areas under stress.	Decision support tool aims to provide knowledge to support allocation decisions in Coastal Plain. CWSP review informs permit decisions.	Limited authority for ISWS means limited opportunities for linking knowledge to action.
Policy learning with flexibility	Ongoing state water planning process generates policy recommendations that inform new state water policies enacted by the state legislature.	Limited opportunities for regional planning process to promote policy learning. Drought/crisis created policy window for state legislature to enact new water planning requirements.	Limited opportunities for local or WMD planning to promote ongoing policy learning and change at the state level.	Ongoing CWSP process and information development contributed to MDE policy learning; limited opportunities for ongoing policy learning at the state level.	Limited opportunities to promote policy learning and change at the state level.
Multilevel interactions, participation, and learning	Diverse, multilevel participation in ongoing planning processes facilitates learning and behavior change at state, regional, and local level.	Diverse, multilevel participation in planning processes facilitates learning by regional and local water managers and state agencies.	With limited participation in planning, there is less opportunity for fostering learning and behavior change across levels.	With limited participation in planning, there is less opportunity for fostering broader learning and behavior change at the local.	With no participation in planning, there is limited opportunity for fostering learning and behavior change at the local, regional, or state level.
Clear boundaries (or rules)	Surface water allocations offer little opportunity for adjustment. Groundwater mostly unregulated.	Permits offer limited opportunity for adjustment	Permits issued with renewal date; renewals provide opportunity for WMDs to adjust permits.	Permits issued with renewal date; renewals provide opportunity for MDE to adjust permits.	None. When conflicts arise, typically handled in the judicial system.
Incorporating nonstationarity	Water availability models rely on historical data and planning focuses on drought of record.	Water availability models rely on historical data.	WMDs primarily rely on historical data; political environment makes direct action on climate change difficult.	MDE relies on historical data; political environment supportive of climate change; no process in place to translate climate information for water resources decision-making.	A short-lived regional planning process produced climate change impacts analysis for two regions. No ongoing process to translate that information for decision making.

Florida, individual WMDs support data generation and modeling of surface and groundwater for planning and allocation (FL-1; FL-2). For these states, developing a comprehensive, ongoing view of their water resources is the necessary first step to support more proactive management aimed at achieving long-term water management objectives (although there can be disconnects between knowledge and action as described in the next paragraph). In contrast, Illinois and Maryland's knowledge development for water decisions is more limited. Rather than state-wide model development, both Illinois and Maryland focus more intensive modeling efforts only in areas of high water use (IL-2; IL-3) and in areas already under stress (MD-1), respectively. And in Illinois' case, water use data are only collected when funds are available. Given these circumstances, it is more difficult for Illinois water agencies to understand changing conditions; this contributes to water management that is more reactive and crisis-driven. One planning official put it this way: "It seems to take a crisis for tough decisions to be made or for action to be taken that might actually move things down a path towards better water management" (IL-6). Illinois is not alone; a recent *GAO* [2014] report identified lack of information on water availability and use as a major factor complicating water planning in the United States. On the other hand, while modeling of water resources is limited in Maryland, Maryland Department of the Environment (MDE) routinely collects water use data and monitoring information across the state that counties use in planning and MDE uses in allocation decisions (MD-1). This state-wide monitoring enables MDE to understand how the resources and uses change over time, which helps mitigate less comprehensive modeling (and a lack of state-wide planning).

While ongoing, comprehensive knowledge development is important, knowledge alone is insufficient [*Folke et al*., 2005; *Lejano and Ingram* 2009]. For water governance to be both adaptive and resilient, water governance systems must link knowledge to action [*Huitema et al*., 2009; *Huntjens et al*., 2010; *Nelson et al*., 2007; *Pahl-Wostl*, 2007]. This is especially true for linking information about resource availability and use to allocation decisions; when states fail to make these links (or links break down), management failures arise. Our case studies revealed mixed success with linking knowledge to allocation decisions. For example, prior to initiation of the state-wide planning effort, Georgia experienced management failures:

> *Prior to the state-wide comprehensive planning effort that gave the Environmental Protection Division the tools to evaluate permits, permitting for surface or groundwater withdrawals was accomplished without any systematic analysis. Hence, the state walked permit by permit into a situation when more permits have been granted than there is water to fill them particularly in times of drought. (GA-1)*

In contrast, management failures have mostly been avoided in Maryland and Florida where there is a longer history of linking ongoing monitoring information to permitting decisions. For example, Maryland recently, enhanced its decision support capabilities with the development of an Aquifer Management System (AMS) for the coastal plain aquifer. The AMS enables MDE staff to quickly examine new permit requests and review existing permits to aid allocation decisions (MD-3). Similarly, in Florida, water managersrely on water use and monitoring data together with integrative surface and groundwater models to assess new permit requests (FL-6). These more comprehensive efforts to review the demands on a resource relative to the cumulative impacts from all permitted uses helps avoid overallocation (FL-3; FL-6; MD-3).

6.2. Policy Learning and Flexibility

Adaptive, resilient governance systems deal with complexity and uncertainty with institutions that are capable of changing and policy learning to inform and support those changes [*Huntjens et al*., 2011]. Policy learning relies on evidence of consequences of past policies and related information as a basis for changing frames of reference or setting new or adjusting existing policies to achieve better outcomes [*Hall*, 1993; *Hargrove*, 2002; *Huntjens et al*., 2011]. Changes may be incremental improvements—not fundamentally altering the way water is managed—or transformative, radically altering water management [*Huntjens et al*., 2011].

Texas' ongoing water planning effort and Maryland's permitting process provide the strongest evidence for policy learning among our cases. In Texas, with each 5 year planning cycle, the state water plan paints a state-wide picture of water availability and demands out to 2050, identifies issues and needs, and proposes a set of legislative recommendations to resolve issues and support better management (TX-1). For example, legislative recommendations from the 2007 and 2012 plans informed actions by the Texas legislature that supported the creation of new institutions for groundwater management and planning, authorized the TWDB to collect water use data, and created a sustainable funding stream for water projects [*TWDB*, 2007, 2012]. These changes exhibit a range of policy learning from incremental, single loop learning, with new data collection efforts, to more transformative triple loop learning through the creation of groundwater management institutions [*Argyris and Schön* 1996; *Huntjens et al*., 2011; *Pahl-Wostl*, 2009]. In Maryland, opportunities for policy learning arise out of mechanisms for ongoing data collection and review and renewal of permits (MD-1). For example, ongoing monitoring data and reporting via the permitting program helped MDE track drought conditions in 2007. The onset of the 2007 drought just 5 years after a prior severe drought spurred concerns about future water availability and prompted MDE to adopt a new requirement for a drought factor of safety that effectively reduced water availability in new permits and permit renewals (MD-1). This drought factor of safety represents a shift in MDE's frame of reference (double loop learning) about how much water is actually available long-term. In both Texas and Maryland, ongoing drought and other pressures on water supplies spur policy learning by keeping water issues high on the political and legislative agendas and creating policy windows [*Kingdon*, 1984] that enable transformative change.

Where states often struggle, is when strategic or other considerations inhibit even incremental (single loop) policy learning. For example, in Georgia and Florida water law gives state agencies the authority to restrict or adjust water allocations based on new information. Though these agencies have the authority to change allocations, they often resist taking action in part from a desire to protect the agency from scrutiny and in part from not wanting to be perceived as limiting opportunities for growth, a priority in these states (for more discussion of adjusting allocations see section 6.4).

6.3. Multilevel Interactions, Participation, and Learning

Multilevel interactions between different levels of government and the public or other nongovernmental participants in water-related decision making is critical to adaptive, resilient governance [*Adger et al*., 2005; *Huitema et al*., 2009; *Huntjens et al*., 2011; *Olsson et al*., 2007; *Kok and de Coninck*, 2007]. Multilevel interaction and participation is important not only because it increases compliance with and effectiveness of decisions, but also because it engenders learning and capacity building that may improve water governance over the long-term [*Gerlak and Heikkila*, 2011; *Pahl-Wostl*, 2009]. Beyond stakeholder participation, public participation is important because participation increases public understanding and contributes to making the process more transparent and democratic [*Huitema et al*., 2009; *Sabatier et al*., 2005].

Despite its importance, the states in our study varied in the amount and diversity of multilevel interactions and in public or other participation in state-wide planning efforts. Much of that variation stems from differences in state legislative frameworks for planning that establish who is involved and how they interact which create more (or fewer) opportunities for learning. For example, by law, the Georgia planning process includes advisory committees and public town hall meetings that together open a dialogue between the different governmental and nongovernmental actors and the public about water resources limits and potential responses. Information shared through this planning process creates opportunities for learning which help to build a "constituency for good management of water resources throughout the state" (GA-2). In Texas, where the water planning framework mandates diverse, multilevel interaction and participation, some local water managers that participate in the planning process begin to think about issues they might not have thought about on their own, such as modifying their estimates of firm yield out of their reservoirs (TX-3). At the other extreme is Illinois, where planning is left entirely to the local level with very little support or guidance from the state. As a result, according to one interviewee, rather than becoming more resilient, local water systems cycle in and out of crisis (IL-3). The situation in Florida is more mixed. On the one hand, state law requires that WMDs engage local governments in planning. While this is a less diverse set of participants than mandated in Texas and Georgia, in the best cases, those interactions do help local water managers learn about resource limitations and discover options to address them (FL-5). In these cases, as local water managers gain a better understanding of the management issues at stake, it opens up new possibilities for improving regional management [*Mostert et al*., 2007]. But in other cases, the planning process falls short. For example, though a water manager at one WMD expressed interest in promoting a participatory planning model, they described a more limited process that involved looking at local water suppliers' water supply plans, incorporating those into their regional plans, and then requesting public comments on the plan (FL-1). Social [*Pahl-Wostl*, 2009; *Tippett et al*., 2005] and collaborative learning [*Gerlak and Heikkila*, 2011; *Newig et al*., 2010] research suggests that this type of process, characterized by successive one-way interactions, provides little opportunity for learning and public engagement. Likewise, the state governance framework in Maryland offers limited opportunities for participation by only requiring counties to collaborate with local jurisdictions and the state on CWSPs. Because the state legal frameworks in Florida and Maryland define participation more narrowly, elements that foster learning including broad engagement (e.g., with the public, nongovernmental organizations, or other water interests) and incorporation of diverse sources of information and knowledge are more limited [*Gerlak and Heikkila*, 2011; *Keen and Mahanty*, 2006]. This in turn, limits opportunities for: building a constituency for good water management beyond the water managers who are involved; achieving broader state water management goals, as local and county level priorities take precedence; increasing public understanding; and, fostering more democratic decision making normally associated with more adaptive, resilient governance approaches.

While on the whole state legislative frameworks that mandate and support more diverse multi-level interactions and participation create more opportunities for learning and foster more transparent and democratic decision making, such outcomes are not automatic. For example, in Georgia some participants felt that the planning process lacked transparency and that the resulting regional water plans were not legitimate. Issues with transparency centered on perceptions that EPD did not provide objective information to the regional planning groups (GA-3). Rather, these participants felt that the models and data that EPD provided, while important for opening a dialog about water uses and limits, also constrained the dialog because it essentially determined both the acceptable range of scenarios of the future (GA-3) and the range of possible solutions (GA-2). This approach essentially stifled open deliberation by limiting consideration of alternative views and approaches and fostering, in some participants, the feeling that the process did not adequately reflect their views and values (hence lacked legitimacy). This example raises an important concern for planning processes to attend to the value and character of public science to promote informed, transparent debate [*Jasanoff*, 2006].

Though better decisions, buy-in, and learning are all potential benefits of participatory planning, a pernicious challenge is that the process is resource (time, personnel, and financial) intensive for all involved [*Pahl-Wostl*, 2009]. And, while central authorities (e.g., state legislatures and water agencies) can help to offset some of the costs by helping to bring people together and by providing funds, information, and guidance [*Bardhan*, 2002], local governments, for example, must still weigh their own cost of participation with whatever perceived benefits they think might accrue. And, because benefits are diffuse and resources are constrained, local governments (and other water interests) may need additional incentives to participate. Some states do incentivize participation by linking state funding for water projects to planning and linking planning to allocation decisions. For example, in Texas, if a water system's new water strategy "is not consistent with the way the water plan recommends that the system meet their water needs, then they are not eligible" to receive support from the state (e.g., funding or a permit) (TX-2). Conversely, if a water system documents implementation of the regional plan (e.g., improving water conservation efforts) they are more competitive when seeking grant money from the state (TX-3). Similarly, Florida and Georgia employ explicit connections between planning, allocation and funding to encourage participation in planning and to promote learning. For example, in Georgia, requests for new permits must be consistent with the regional water plans or state funding for water projects may be denied [*GWC*, 2008]. And, in Florida, WMDs tie both funding for water supply projects and water permit decisions to the regional planning process (FL-1; FL-3; FL-4). Finally, in Maryland, water managers link CWSPs with allocation decisions. As a result of these explicit connections between planning and allocation decisions and between planning and financial support for water projects, local and regional water managers have to pay attention to the planning process which creates opportunities for learning and change.

6.4. Clear Boundaries (or Rules)

Our empirical data support the notion that setting clear boundaries or rules-that is, defining who has access to water particularly when the amount of water available is limited by drought-is an important component of adaptive, resilient governance [*Huntjens et al.*, 20ll]. States' administrative systems for water allocation generally establish both a clear authority for the right to use a quantity of water and a process for conflict resolution. Among our cases, Texas (surface water only), Georgia, Maryland, and Florida have administrative systems for water allocation and built-in mechanisms for conflict resolution between water rights holders, while Illinois does not (see Table 3). Because Illinois does not set clear administrative rules for water with a process for conflict resolution, comprehensive water management is illusive and conflicts between water rights holders often lead to costly, time-consuming court fights (IL-5).

While setting clear rules is a critical first step, our data suggest that rules by themselves are insufficient for adaptive, resilient governance. States also need to monitor, enforce and adjust those rules as conditions change. These additional steps require capabilities that are nontrivial. On one hand, they require that states have the ability to monitor water sources and uses over time and to link that information to allocation decisions (see earlier discussions in sections 6.1-6.2). On the other hand, they require states to not only have the flexibility and authority to make adjustments to those allocation decisions, but to also have the willingness to take action, if warranted.

Of the states examined, Florida, Georgia, and Maryland all have the means to make allocation adjustments; yet, only Maryland water managers exhibited a willingness to act when conditions merited a change. For example, in Florida, water permits are issued with a 10 year reopener (of 20 year duration permits) and with the proviso to "not cause environmental harm" (FL-3; FL-6). The reopener and proviso provide the WMDs the means to examine water use and water availability and to adjust the permit or require mitigation to reduce adverse environmental impacts, if conditions warrant (FL-3; FL-6). Yet, according to one interviewee, "telling people 'no' is not the goal of the [permitting] process" (FL-6). And in Georgia, while state water law gives EPD water managers the means to restrict or adjust water allocations based on new information, they look to the legislature to legislate water restrictions rather than exercising their own authority to reduce use (GA-3). Only when water resources were on the brink—such as, when a coastal aquifer came very near to irreparable damage from saltwater intrusion—did EPD act (GA-3). Unlike Florida and Georgia, MDE has both denied permits when permit requests exceeded the amount the resource could support and issued building moratoria when communities could not demonstrate they had adequate sources of supply (MD-1; MD-4). What this data suggest is that even when rules are clear, state agencies sometimes find it difficult to enforce those rules especially when doing so competes with broader state priorities such as those that promote economic growth (FL-6; IL-2; IL-4; IL-5; TX-4) or when taking action may make the agency a political target (MD-5).

6.5. Nonstationarity

Despite increasing calls that adaptive, resilient governance should take climate (and other) nonstationarities into account [*Adger et al*., 2005; *Milly et al*., 2008; *Rogers*, 2008], consistent with *Kundzewicz and Stakhiv* [2010] and *Kirchhoff* [2013] our findings show that water managers continue to struggle to incorporate climate change information. Even when there is interest in using climate change projections, negative perceptions about information and the politicization of "climate change," reinforce stationarity approaches. For example, in Georgia, water managers at EPD considered using climate change projections but did not ultimately do so because they felt the information was unreliable (GA-3). While in Florida and Texas, water managers perceived credible, regional-scaled climate predictions were unavailable (FL-4; TX-1). Beyond information, the politicization of "climate change" also makes taking action difficult. For example, in Texas, water managers expressed interest in addressing climate change, but noted doing so was politically untenable because "climate change" is a political lightning rod (TX-3). In Florida, water managers acknowledged that the recent shift in the political climate (e.g., the transition in the Governor's Office) meant that it is now much more difficult to take action on climate change (FL-1).

Rather than incorporate nonstationarity in climate directly, our empirical data suggest that states incorporate historical climate information and rely on ongoing planning to accommodate potential future adjustment for climate-related uncertainty. For example, Texas employs a historical worst case drought (generally the 1950s drought) for planning purposes (TX-4, TX-1), Georgia EPD incorporates 70 years of historical variability in its watershed models, and Florida WMDs almost universally rely on historical data (in some cases going back to the 1800s) to bound future conditions in their plans. While states rely on the past for allocation and planning, water managers in Texas argue that they deal with climate change with their ongoing planning effort and "in our adaptive process" (TX-2). Similarly, a water manager in Florida said that their ". . .[20 year] planning horizon is probably sufficient to deal with climate change. . . [as] changes are likely to be sufficiently gradual that we should be able to stay out in front of them" (FL-4). These strategies reflect a conscious choice to institutionalize a long-term planning horizon as a "soft" strategy for adapting to uncertain climate change [*Gleick*, 2003; *Hallegatte*, 2009]. What remains unanswerable today is whether or not a long-term planning horizon is sufficient to expose the dynamics of vulnerability [*Dilling et al*. 2015].

7. Other Challenges to Adaptive, Resilient Water Governance in U.S. States

7.1. Resistance to Institutional Change

Though defining who has access to water is important for adaptive, resilient governance, states face challenges in trying to change existing water governance paradigms. Sometimes this resistance comes from government agencies interested in protecting regulatory turf or from existing water rights holders who favor the status quo [*Thompson*, 2011]. In our cases, not unlike in other parts of the world [*Marshall* 2010], the struggle states most often faced was trying to establish regulations where none existed previously. For example, in Georgia, according to one interviewee, resistance to more stringent regulations on agricultural withdrawals nearly derailed the state water planning effort altogether (GA-2). And in Texas, resistance to enacting groundwater regulations have prompted some legislators to introduce bills that would ". . .take what little power the underground water districts have back from them and re-establish groundwater ownership as a private right" (TX-4). Finally, in Illinois, while water managers recognize the need for better planning and management of water resources especially for conflict management, there is resistance to initiating broader planning measures or changing water policy (IL-2, IL-4).

7.2. Whither Water for the Environment

Even when rules for how to deal with water during scarcity are clearly articulated, consistent with *Megdal et al*. [2011] and *Pahl-Wostl et al*. [2013] our data suggests that those rules almost uniformly aim to protect human water uses at the expense of environmental needs. For example, in Texas, critics of the state water planning process argue that the process is a plan for growth that does not foster a critical examination of "the necessity or desirability of any particular [water development] project" (TX-4). Similarly, in Florida, the state legislature wants the WMDs to be as accommodating as possible to new water uses; "telling people 'no' is not the goal of the process"(FL-6). This mind set means that districts "allocate water right up to the limit of what is available long term" (FL-3) which has contributed to increasing issues with lowering lake levels, degradation of wetlands, and declining spring flows (FL-6). The situation is similar in Texas and Georgia where years of overemphasizing development and undervaluing the environment has left many aquatic ecosystems at risk particularly during droughts (TX-6). While ignoring the environment in water allocations is a known challenge [*Megdal et al*., 2011], states are beginning to tackle these issues (e.g., Texas Senate Bill 3 regarding determining environmental flows with further information available at http://www.twdb.texas.gov/surfacewater/flows/environmental/index.asp) though clear and systematic approaches for determining environmental flows are not yet established [*Pahl-Wostl et al*. 2013]. These efforts are welcome news as the consequences of ignoring the environment (together with other good governance principles) are in stark view for the world to see in California where "untrammeled growth" has finally run up "against the limits of nature" [*Nagourney et al*., 2015].

7.3. Financial and Human Resource Constraints

Adequate resources are necessary to support effective water planning and allocation programs. For example, historically Florida's WMDs enjoyed significant resources; however, water managers note that recent budget reductions have forced cutbacks that, if severe enough, could greatly diminish water management capabilities (FL-1; FL-2; FL-8). In particular, reduced staffing and funding for data collection and monitoring could negatively impact the availability of data and information that WMDs rely on to evaluate new permit requests (FL-6) and that WMDs provide to local governments for updating their local comprehensive plans (FL-9). Maryland water managers face a similar challenge. Recent state budget cuts resulted in underfunding of and delayed timelines for the development of science to aid allocation and planning (e.g., the coastal plain aquifer studies and the piedmont fractured rock studies) (MD-2). These budget cuts add to past budget cuts that already reduced MDE planning staff (MD-5). According to one water manager, past budget cuts reduced "the state's ability to provide the big picture view and to support water planning and allocation efforts" (MD-1). Reduced staffing has also made it difficult for MDE to oversee existing appropriation permits and ensure compliance. As a result, during the drought of 2007, a number of residential wells went dry on the eastern shore of Maryland before MDE discovered that a few large water users were overdrawing their appropriation permits (MD-2).

8. Conclusions

States are important actors in the challenge to manage water across the landscape under a changing climate. In this paper, we set out to examine empirically how theorized characteristics of adaptive, resilient water governance fare in practice. To accomplish this aim, we focused on the important role U.S. states play in water governance, specifically, in water allocation and planning. Using interviews and documentary analysis, we examined states' allocation and planning approaches and assessed how those approaches embody characteristics of adaptive and resilient governance theorized in the literature. Through this examination, we uncovered important enabling conditions and dependencies that enhanced or undermined adaptive, resilient governance, challenges U.S. states face in employing more adaptive, resilient water governance arrangements, and implications for enhancing water governance going forward.

Our review of the literature pointed to six theorized characteristics associated with adaptive, resilient water governance. These six characteristics include: supporting knowledge generation, distribution, and use for policy and decision making; enabling multilevel interactions, collaborations, and broad participation; establishing clear rules for water use and adjustment under stress; and, not assuming stationarity in the climate.

First, our examination of five U.S. states revealed that many of the adaptive, resilient characteristics are conditioned by underlying institutional arrangements in each state. These institutional arrangements establish authorities, rules, and resources for water allocation and planning, data collection, and knowledge development, and they establish who participates and in what capacity. As such, these institutional arrangements set the enabling conditions for states to employ more (or less) adaptive, resilient water governance arrangements.

Second, our empirical analysis showed how theorized adaptive, resilient governance characteristics support better water management in practice. For example, we found that states with ongoing water resources data collection and knowledge development programs had the tools to more proactively manage water resources, whereas states that lacked ongoing data and knowledge systems, were more likely to employ more reactive and crisis-driven management. We also found that knowledge systems had transferable benefits across scales of decision making. When state-wide knowledge systems were in place, water management was enhanced from the state to the regional to the local level and when they were absent, water management tended to be worse (more crisis-driven) across the board. Similarly, we found states that enabled and incentivized broad multilevel participation in planning, created both opportunities for learning (from the public to local and regional water manager to business and environmental groups) and more democratic decision making, and that multilevel participation built capacity for improving water governance over the long-term. On the other hand, states with less participatory planning processes created fewer opportunities for learning and generated weaker support for achieving broader state water management goals.

Third, our analysis suggests that competing state priorities can get in the way of effective water governance even when states possess characteristics associated with being more adaptive and resilient. For example, even in states that establish clear rules for who can use water under what conditions and that have a comprehensive system in place to monitor those water resources over time, resilience may be undermined when water managers do not take action when conditions warrant. In seeking to understand why this happens, we found that in these cases water managers find it difficult to enforce the rules when doing so competes with broader state priorities such as those that promote economic growth at the expense of protecting water resources or when taking action may make their agency a political target.

Finally, we uncovered several challenges U.S. states face in employing more adaptive, resilient water governance arrangements. First, despite increasing pressure to incorporate climate change into long-term water management [*Milly et al*., 2008], states struggle to do so because of perceptions about the information itself and the politicization of climate change. Instead, states rely on ongoing planning processes to accommodate climate-related uncertainty. This means that states nearly universally lack a statewide strategy for managing climate change impacts on water resources and that local jurisdictions must fend for themselves. Beyond finding, it difficult to take action on climate change, states face challenges trying to alter existing water governance paradigms to be more adaptive and resilient when they are deeply ingrained and well-supported by political or interest groups. Last, states struggle to adequately fund and staff water programs during tight budgetary times and to support environmental as well as human needs for water. Unfortunately, most states in our study reported downward trends for funding and staffing of water programs. This suggest that unless states and their citizens invest more in water management programs, it will be increasingly difficult to support more adaptive resilient water governance going forward.

While empowering local actors is often emphasized for building resilience to climate change, our results show that state actors can play an important role in supporting capacity for resilient water management across scales. However, more comparative work is needed to further test and explore this proposition. For example, research is needed that examines a broader number and variety of state water policies and planning mechanisms and their connections to regional or local water management efforts to elucidate where advancements in adaptation and resilience could be most effectively supported as water becomes an even more limited resource across the landscape. In addition, future research should delve deeper into particular governance conditions or approaches to explore underlying mechanisms and motivations in more detail. For example, new insights could emerge from a deeper exploration of underlying conditions necessary to support (or not) making adjustments to water allocations.

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