Advances in Groundwater Governance

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Chapter 24

Groundwater governance in the United States: a mosaic of approaches

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ABSTRACT

Groundwater is an important water supply for meeting municipal, industrial, and agricultural water demands and for supporting riparian and other ecological systems in the United States (U.S.). Effective groundwater governance is therefore crucial to the wise use of this largely non-renewable resource (recharge rates are slower than extraction rates). While minimum, federally-established drinking-water quality and water-discharge regulations do exist, the framework of the laws and regulations governing groundwater use in this country is highly decentralized. Each state determines its own groundwater priorities and governance approaches, with the further potential for states to delegate significant responsibilities to sub-state jurisdictions. Painting the groundwater governance picture in the U.S. with a single brushstroke is therefore impossible; a more refined analysis is required to characterize the mosaic of groundwater governance priorities and approaches. In this chapter, we report on findings of a nationwide survey on groundwater governance. We address the variation in circumstances and approaches across the country, and provide insights into some challenges identified by survey respondents. To demonstrate the changing nature of groundwater governance and groundwater debates, we consider two Western U.S. states, California and Arizona. Arizona has long practiced groundwater management in designated parts of the state, while California only recently adopted a comprehensive approach to groundwater management. We conclude with a synopsis of ongoing national-scale research and a look to the future of groundwater governance in the U.S.

LIST OF ACRONYMS

ADWR – Arizona Department of Water Resources
AM – Adaptive Management
AMAs – Active Management Areas
CAP – Central Arizona Project
DWR – Department of Water Resources
GMA – Groundwater Management Act
IWRM – Integrated Water Resources Management
SGMA – Sustainable Groundwater Management Act

UA – University of Arizona
WRRC – Water Resources Research Center

24.1 INTRODUCTION

Like elsewhere in the world, water users in the United States (U.S.) are increasing their reliance on groundwater (Maupin *et al.,* 2015). Since the invention of the centrifugal pump after World War II, extraction of groundwater in this country has grown exponentially. Six decades later groundwater is the source for drinking water for about half of the population (Leshy, 2008). However, there are significant variations to this trend, depending on the water-use sector and region of the county. Irrigated agriculture is a major user of groundwater, consuming approximately two-thirds of the groundwater withdrawn in this country, mostly by the mostly arid Western States (Maupin *et al.,* 2015). In general, human needs met by groundwater varies widely by state; groundwater constitutes 80% of Kansas' fresh water supply, whereas Virginia relies on groundwater for less than 5% of its water (Figure 24.1). Human needs include public supply (including irrigation of greenspace), self-supplied domestic, irrigation, livestock, aquaculture, self-supplied industrial, mining, and the generation of thermoelectric power (our percentages are based on the most recently published data from the U.S. Geological Survey; Maupin *et al.,* 2015).

In contrast to governance in most other nations, water governance in the U.S. is highly decentralized. While the federal (*i.e.*, central) government establishes minimum drinking-water and water-discharge standards, individual states are largely responsible for managing their surface-water and groundwater supplies (Leshy, 2008; Megdal *et al.,* 2015). This state-level authority yields a mosaic of priorities for and approaches to both surface-water and groundwater governance. Moreover, many states do not recognize the connection between surface-water and groundwater, leading to different sets of laws and regulations for what is, actually, a single resource (Gerlak *et al*., 2013). As a result, water governance is rendered particularly complex because of variability in reliance on groundwater versus surface water, and due to a near-total lack of uniformity in state-level statutory approaches to implementing and enforcing regulations (Megdal *et al.,* 2015).

Although western states rely on groundwater resources to accommodate growing demands more than states in the rest of the country, groundwater allocation does not follow such an east-west split. Each state has a particular set of laws and regulations regarding groundwater, and that kind of patchwork approach can even vary within the same state, as it does in Arizona, for example. The Groundwater Management Act of 1980 identified areas with heavy use of groundwater, known as Active Management Areas (AMAs). Although all AMAs have to comply with regulations stated in the Groundwater Code, certain regulations are AMA-specific in order to recognize differences in groundwater use and conditions. It is not difficult to imagine, then, particular governance structures and institutions developing as expressions of each state's individual laws and regulations. This is particularly problematic considering the paucity of scholarly focus on this topic until recent years.

But notwithstanding this lack of uniformity, a groundwater-governance framework is very important to managing groundwater over time. Typically, physical limitations are not the major barrier to sustainable groundwater use. Rather, it is

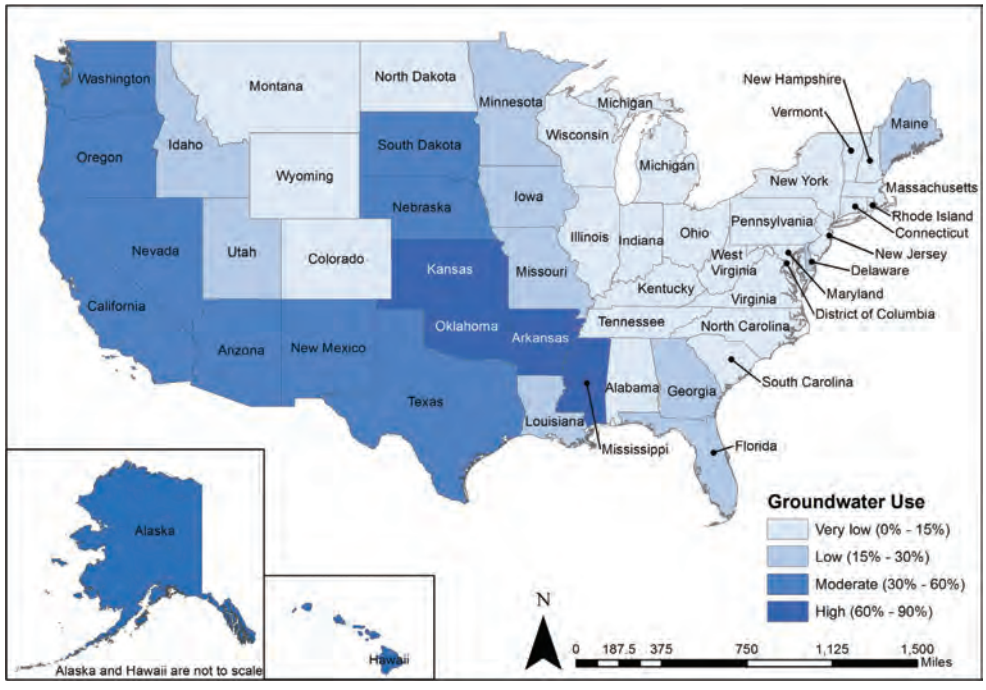

Figure 24.1 Percent of human needs met by groundwater using USGS data for 2010 (Maupin *et al.,* 2015).

ineffective governance regimes (*e.g.*, when some stakeholders are not considered in the decision-making process, or when extractions are not monitored) that often lead to overuse of the resource (Mukherji & Shah, 2005; Varady *et al.,* 2016a). In the past groundwater overexploitation has been exacerbated by a lack of critical evaluation of groundwater-governance structures (GEF *et al.,* 2016). In recent years, however, observers have begun to delve into the complexities associated with creating effective groundwater-governance regimes around the world (Varady *et al.,* 2016a). At the University of Arizona (UA), researchers at the Water Resources Research Center (WRRC) and the Udall Center for Studies in Public Policy have engaged in a multi-phased effort to understand groundwater governance in the country. The work began with a 2013 initial national-scale survey and continues with case-study analysis and a second survey (Gerlak *et al.,* 2013; Megdal *et al.,* 2014; Megdal *et al.,* 2015; Megdal *et al.,* 2016).

The present chapter is designed to improve knowledge about the variation of groundwater-governance challenges and approaches in a single (in this case, large) nation and to explore in greater depth the approaches of two states for which groundwater is a crucial water resource for all water-using sectors. Specifically, we use the most recent national data available to provide a picture of state-by-state dependence on groundwater across the nation and provide additional analysis of our 2013 survey results, in which we assessed groundwater governance across the country. We report those survey findings regarding the adoption of effective groundwater-governance approaches in each state, including Integrated Water Resources Management (IWRM) and Adaptive Management (AM).

IWRM, as defined by the U.S. Global Water Partnership (GWP) as "a process that promotes the coordinated development and management of water, land and related resources in order to maximize the social and economic welfare equitably without compromising the sustainability of vital ecosystems" (GWP 2000). IWRM promotes decentralized governance that ensures stakeholder participation and integrates social and ecological systems, as well as surface water and groundwater (Varady *et al.*, 2016b).

AM, by comparison, can be understood as a "systematic approach that builds on trial and error utilizing feedback loops to allow us to learn from experience and to adjust our water management practices to address evolving issues and conditions … (and) typically focuses on developing and understanding of the baseline physical (*e.g.*, climate/hydrological), legal and socioeconomic aspects of a region or basin" (AWRA 2016). AM incorporates uncertainty into water management by monitoring outcomes over the long term and revisiting objectives and action plans in an iterative process. Both IWRM and AM have the potential to lead to more equitable and sustainable outcomes (Varady *et al.*, 2016b).

We also analyse the relationship between groundwater exploitation and governance approaches, identifying states with declining subsurface levels as a priority. We overlay survey results with state-level data on groundwater use released in 2015 by the U.S. Geological Survey, and we also include new analysis of the 2013 survey results. We then investigate groundwater governance in two particular states—Arizona and California—whose groundwater governance frameworks are commonly cited nationally and internationally for their innovation and challenges. Arizona can be considered an "early adopter" of comprehensive groundwater governance. In 1980 it enacted arguably the most rigorous and forward-looking groundwater regulations and governance structure in the United States. California, by contrast, can be seen as a "late adopter". It took until 2014 for that state to legislate comprehensive groundwater governance. Arizona was an early adopter of a comprehensive groundwater governance approach because its long history of groundwater overdraft caused land subsidence. Groundwater regulation was a pre-condition to obtaining federal funding to convey Colorado River water into the region. Recently, severe drought conditions and curtailment of surface water supplies have resulted in significant overdrafting of groundwater, which in turn led to state adoption of groundwater use regulations. The summaries are evidence of the complexities and challenges associated with groundwater governance and how it has been customized to address state-level conditions.

We conclude with a synopsis of ongoing research and speak to the future of groundwater governance in the U.S.

24.2 EXPLORING VARIATION IN GROUNDWATER GOVERNANCE IN THE U.S.

24.2.1 Methodology and approach to the 2013 survey

At the time the survey was conducted in 2013, there existed no compendium or analysis of groundwater-governance or management practices in the United States. A large body of work examined legal regimes in specific cases (*e.g.*, Bryner & Purcell, 2003; Torres,

2012; Dellapenna, 2012; Stevens, 2013), but few analysts had examined trends and commonalities in governance across the country. The 2013 UA study was designed to begin to address that knowledge gap. This preliminary study had three goals: (1) to understand each state's broad groundwater-governance framework, (2) to clarify the factors driving changes to groundwater governance, and (3) to assess state-by-state priority for groundwater governance.

While this book defines *groundwater governance* elsewhere (and includes variations among chapter authors), it is helpful to understand the definition we used to guide our design of the 2013 survey. We defined groundwater governance as "the overarching framework of groundwater use laws, regulations, and customs, as well as the process of engaging the public sector, and civil society" (p. 678) (Megdal *et al.,* 2015). It is important to differentiate water governance from water management. In the same study, we defined groundwater management as "the actions to implement those laws, policies, and decisions. It consists of the routine, practical, and effective ways that enable us to achieve predetermined goals and objectives" (p. 678) (Megdal *et al.,* 2015).

Groundwater governance includes coordinating administrative actions and decision-making among different jurisdictions, which may include: federal, state, tribal, county, or local (*i.e.*, municipal) governments; private business, individuals, and non-governmental institutions. In addition, there are other jurisdictional units that directly or indirectly affect groundwater governance such as Active Management areas (AMAs), U.S. Forest Service, Bureau of Reclamation, Bureau of Land Management, U.S. Fish and Wildlife Service, National Park Service, U.S. Amy Corps of Engineers special regions and protected areas, and other units of administration. A groundwater governance framework typically includes four dimensions: political, socio-cultural, economic, and ecological (Varady *et al.,* 2013). Also important to the survey design was consideration of *groundwater management*. While governance largely consists of the sets of laws, regulations, and customs in each state, groundwater management refers to the expression of governance in the routine practice of groundwater administration (Varady *et al.,* 2013). The 2013 survey was designed with these definitions in mind, and contained questions addressing the *de-jure* groundwater governance in each state, as well as the *de-facto* groundwater management conducted in the state on a day-to-day basis.

Specifically, the survey, employing the online service Survey Monkey, featured questions regarding the extent and scope of groundwater use, groundwater laws and regulations, and groundwater tools and strategies. The targeted respondents were largely identified through the network of federally authorized Water Resources Research Institutes at universities across the country (See NIWR.info). A single state-level respondent filled out the survey for each of the 50 states and the District of Columbia, for a total of 51 responses. The state agencies represented included: 22 water-quality agencies, 19 water-quantity agencies, and seven that managed both water quality and quantity in their state. In three states a representative could not be identified, so instead a researcher from the state's Water Resources Research Institute responded. Of the respondents: 8 identified as mid-level manager, 20 as manager, 5 as director/political appointee, 12 as engineer, 4 as hydrologist/geologist, 3 as planner, and one each identified as lawyer, researcher, or public-relations specialist.

The question-by-question results were posted on-line in "Groundwater Governance in the U.S.: Summary of Initial Survey Results" (Gerlak *et al.,* 2013), and

Table 24.1 Summary of key survey responses.

Questions	*Yes*	*No*	*No resp.*
States have groundwater laws (formal or informal)	50	0	1
State law recognizes the connection between surface-water & groundwater	25	23	3
State law recognizes groundwater quality	43	5	3
State law recognizes groundwater conservation	36	12	3
State law recognizes groundwater-dependent ecosystems	25	21	5
State agencies have groundwater oversight & enforcement authority	48	0	3
Local agencies have groundwater oversight & enforcement authority	31	1	19
Different state agencies oversee water quantity & water quality	36	15	0
State agencies have sufficient capacity to carry out responsibilities	25	23	3
Respondents have observed substantial changes in groundwater management	35	15	1

the survey questions are shown in Appendix A. The 2015 article, "Groundwater Governance in the United States: Common Priorities and Challenges" (Megdal *et al.*, 2015), expounded upon the fragmented nature of groundwater governance identified in the original survey, and identified three common priorities for groundwater governance: water quality and contamination, conflicts between users, and declining groundwater levels.

In this chapter, we offer summary results along with more in-depth and additional analysis of the 2013 survey results. We report findings regarding how the states categorize their groundwater-governance approaches, including their deployment of IWRM and AM. We also analyze the relationship between groundwater exploitation and governance approaches, identifying states with declining groundwater levels as a priority.

24.2.2 Key findings of the 2013 survey

Results of the survey show the decentralized nature of groundwater governance in this country, where most states have groundwater laws and agencies that oversee and enforce these laws (Table 24.1).

24.2.2.1 Groundwater use

As expected, the survey results show wide variation in groundwater use across and within states. Respondents offered a broad spectrum when asked to estimate the percentage of human demands met by groundwater in their state. "Human demands", as defined in the survey, include domestic, commercial, industrial, and agricultural – all uses except groundwater dependent ecosystems (see Appendix A). The percentages provided by these experts often did not coincide with the numbers developed by the U.S. Geological Survey (whose results can be seen in Figure 24.1). This discrepancy suggests a data-collection issue or respondents' incorrect perceptions of their state's reliance on groundwater. There was, however, strong agreement that groundwater reliance varied within each state. Two-thirds of respondents noted that reliance on groundwater varies by region within their state, and 88% said that the proportion of groundwater use by

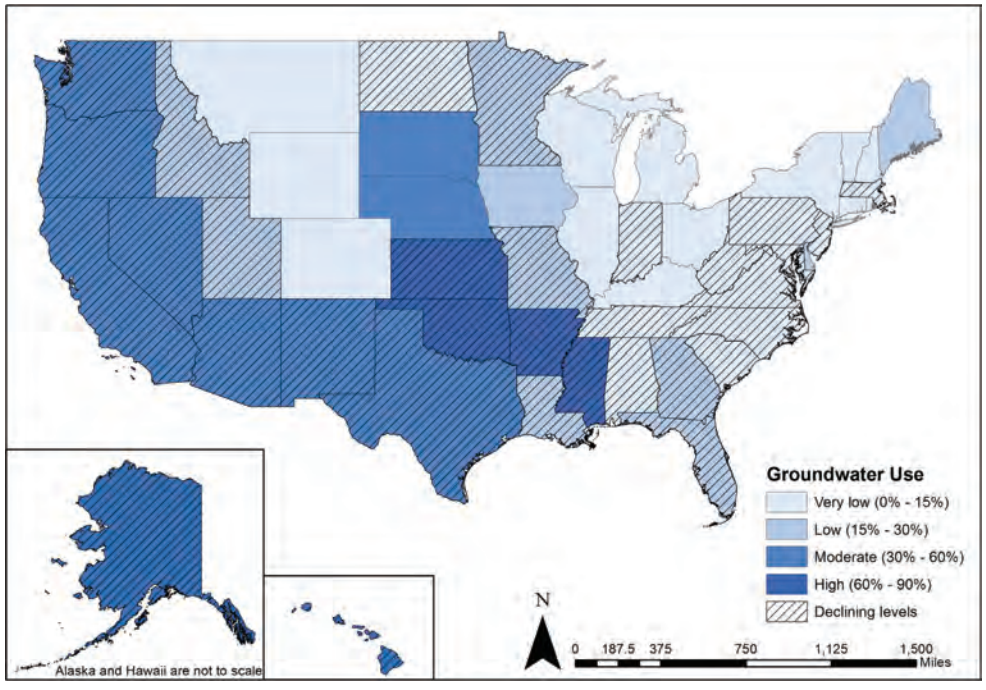

Figure 24.2 Percent of withdrawals from groundwater (USGS, 2010) combined with reported declining levels in aquifers (data from survey).

each major water-use sector (municipal, industrial, and agricultural) varies spatially within their states.

But not all states use groundwater resources in the same proportion. Our results are based on expert opinion and show that the 16 states that use groundwater for more than 30 percent of their human needs are located in both the eastern and western parts of the U.S (see "moderate" and "high" in Figure 24.1). Responses to our survey also revealed 32 states that have declared maintaining groundwater levels as a governance priority. Reliance on groundwater for their human needs combined with declining levels of groundwater suggests a "potential critical condition" of groundwater resources—that is, high reliance and decreasing supply (Figure 24.2).

Our analysis identified 13 states in this potential critical condition (Figure 24.3). Four of these (Arkansas, Kansas, Mississippi, and Oklahoma) rely on groundwater for more than 60 percent of their human uses (high) and they reported declining levels of groundwater. The remaining nine states in potential critical condition (Alaska, Arizona, California, Hawaii, Nevada, New Mexico, Oregon, Texas, and Washington) depend on groundwater for between 30 and 60 percent (moderate) of their human uses and report declining groundwater levels as a priority concern. Most of these are western states. It is important to acknowledge that this "critical" condition is likely to vary inside each state. Some regions within a state, for instance, may not be moderately or highly reliant on groundwater, or it may be that not all aquifer levels are declining.

Figure 24.3 States that face a potential critical condition in their groundwater resources—more than 30 percent of human needs are met by groundwater (USGS, 2010) and reported declining aquifer levels (data from survey).

24.2.2.2 Groundwater-governance framework

As expected, the survey responses revealed considerable variation in existence and types of groundwater laws and regulations, though some uniformity did emerge. Ninety-six percent of respondents indicated that there exist formal groundwater policies, rules, or regulations in their state. While nearly all states have formal groundwater-governance structures in place, the structure can range from formal and explicit to a patchwork that is only indirectly applied to protect groundwater. Illinois and Nebraska, for example, have explicit laws protecting groundwater quality and quantity, while Pennsylvania does not have policies designed explicitly to protect groundwater; it relies instead on a piecemeal approach, using specific statutes or regulations for various activities to work for groundwater-quality protection.

Whatever the structure, the respondents generally agreed that this state of affairs had developed during the last few decades. Fully 70% of respondents had observed changes in the way groundwater is managed in the state, with the most common being: the passage of new legislation, changes in permitting processes, aquifer modelling, aquifer storage and recovery, and greater integration in management of groundwater and surface water.

While the responses showed significant attention to groundwater priorities, the survey also revealed areas of need. One of the biggest impediments to effective, sustainable groundwater governance is likely the continued lack of explicit recognition

Table 24.2 State groundwater governance priorities (N = 48).

Priorities	*Count of states*
Water quality/Contamination	45
Conflicts between water users (e.g., well interference)	36
Declining groundwater levels	32
Quantification of water rights	20
Regulatory disputes	12
Access	9
Other	8
Inter-agency jurisdictional conflict	3
There have been no clearly articulated priorities	2

of the inescapable connection between surface and groundwater in state water laws. Only half the respondents indicated that their state unequivocally recognized this connection. Additionally, 49% said that the courts are active in groundwater issues in their states, and 29% indicate existence of programs or settlements addressing Native American groundwater. Just more than a majority of respondents (54%) note that state law considers the water needs of groundwater dependent ecosystems.

The survey disclosed widely differing priorities regarding successful groundwater governance and management. Top priorities included: water quality/contamination, conflicts between users—*e.g.*, well interference, and declining groundwater levels (Table 24.2).

The survey showed that the application of groundwater regulation varied among water user groups. Twenty-nine respondents (59%) said that regulation applied to industrial users and publicly-owned community water systems; 28 (57%) indicated that it applied to privately-owned community water systems; 31 (63%) believed that it applied to all user groups. Of course, the nature of the regulation differed according to the type of water user. Some are exempt (*e.g.*, domestic household users), some have fewer restrictions (*e.g.*, agriculture users), while others face more stringent regulations (*e.g.*, users of public, industrial drinking water).

The survey also showed frequent delegation of groundwater-governance authority from state to local government levels. While nearly all respondents identified state agencies as responsible for oversight and enforcement, fully two-thirds mentioned that local agencies also have oversight and enforcement responsibilities. Groundwater oversight typically rests with environmental and natural-resources agencies and departments, water-resource boards and departments, and health departments—at both state and local governance levels.

24.2.2.3 Groundwater management

In addition to explaining groundwater-governance frameworks in each state, the survey considered variations across the nation. Common focal areas for the agencies surveyed included: permitting (88% of respondents), monitoring (80%), planning (70%), and protected areas (54%). Monitoring, both of groundwater quality and quantity, is widely practiced across water-use sectors, including municipal, industrial,

and agricultural. Tools that are widely utilized by the agencies include public education programs, and increasing public access to data on water rights, groundwater use, and groundwater supply.

Holding governance power and having the ability to use it were seen to be very different attributes in the survey. While many state and local agencies theoretically hold groundwater-enforcement power, only half the respondents said that agencies had sufficient capacity to carry out mandated responsibilities. Insufficient staffing and/or programmatic money were the most commonly cited reasons for insufficient capacity to enforce laws and regulations. Where capacity fails, many states place their trust in voluntary measures to address groundwater issues. Eighty-eight percent of respondents say their state encourages the use of such measures for such actions as contamination clean-up, technical guidance, and information and education.

24.2.3 IWRM and AM in the U.S. states

Even though IWRM and AM are widely acclaimed by scholars, and in theory are portrayed as effective governance approaches that can be implemented to groundwater (Lemos, 2015; Varady *et al.,* 2016b), U.S. practice shows a big gap. Survey results suggest that neither IWRM nor AM governance approaches are commonly employed. Sixteen states reported using IWRM, while 14 states claim they are adhering to an AM approach. From these states, only nine reported using both IWRM and AM (California, Colorado, Connecticut, Hawaii, Massachusetts, Nebraska, Nevada, New Mexico, Oregon, Washington and Wyoming; Figure 24.4).

It is possible, however, that states may in fact be implementing principles from both IWRM and AM without referring to these practices with these terms; alternatively, it may be that some state representatives who responded did not recognize one or both of the terms. We asked the question *"In your state, are any of these groundwater management strategies in use? (check all that apply)."* Answer options included both IWRM and AM—along with other strategies such as aquifer recharge and storage programs, engagement of regional-planning or management organizations, economic incentives, public education programs, and "other." Interestingly, not all the states that reported using the IWRM approach (16 out of 51 or 31.3 percent) also reported having a law that recognized explicitly the surface-water/groundwater connection, an essential element of IWRM. Survey results show the 10 states (California, Colorado, Connecticut, Hawaii, Massachusetts, New Mexico, Oregon, Washington, West Virginia, and Wyoming) that reported having this law reportedly use the IWRM approach. Six states (Florida, Louisiana, Nebraska, Nevada, and New Jersey) reported using IWRM in spite of lacking a law that recognizes the surface-water/groundwater connection. It is important to note that to fully validate and update our reported findings; there needs to be substantially more research on the issue of recognizing this connection.

As with IWRM, a minority of states reported using an AM approach to groundwater governance (14 out of 51, or 27.4%) (Figure 24.4). Essential elements of AM are monitoring and flexible planning, so that learning can occur even in the face of uncertainty. However, only five of the 14 agencies that reported using AM (representing Connecticut, Hawaii, Nebraska, Nevada, and North Carolina) also stated that they plan and monitor both groundwater quality and quantity. The other nine agencies (from California, Colorado, Idaho, Kansas, Massachusetts, New Mexico, Oregon,

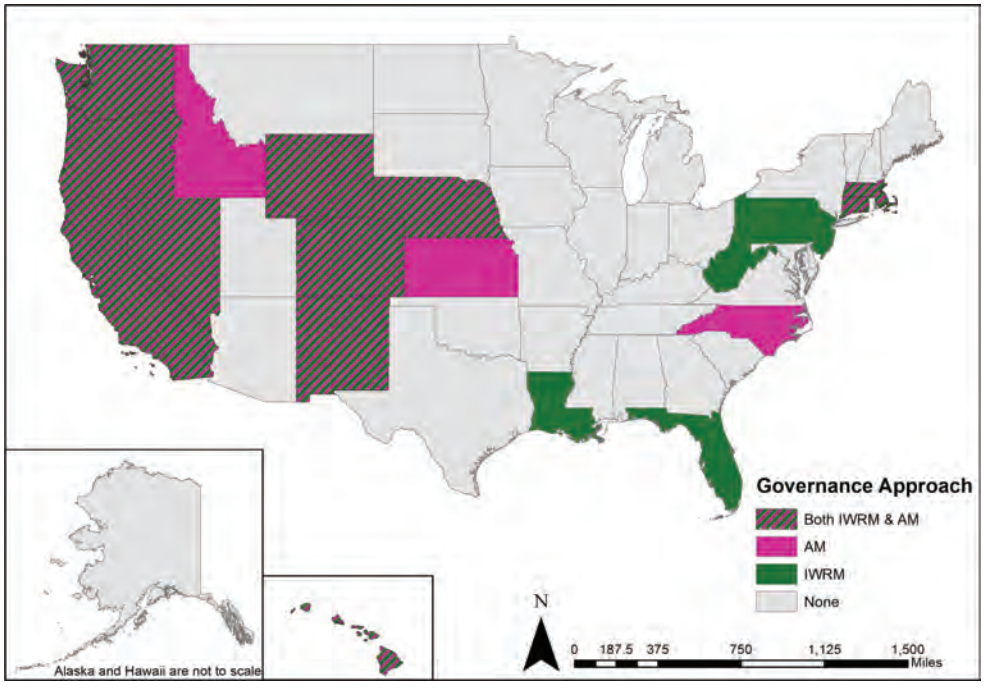

Figure 24.4 States that have adopted IWRM, AM, or both.

Washington and Wyoming) state that they employ AM, but do not plan or monitor groundwater quality and quantity.

Obviously, given the vast geographic diversity of the country, not all states face the same water-resources challenges. To examine more closely the espousal of IWRM and AM, we identified which of the states reporting a "potential critical condition in the groundwater resources" (*i.e.*, depending on groundwater for more than 30% of human use and experiencing declining aquifer levels) have actually implemented either IWRM or AM, or both approaches (Table 24.3). At the time of our survey, of the 13 states with critical conditions, six (California, Hawaii, Nevada, New Mexico, Oregon, and Washington) adopted both IWRM and AM. One additional state (Kansas; using AM), as identified and based on the survey, has carried out one of the effective governance approaches (IWRM or AM). Alaska, Arizona, Arkansas, Mississippi, Oklahoma, and Texas reported a potential critical condition of groundwater resources, yet did not report adopting either IWRM or AM.

24.3 RECENT DEVELOPMENTS IN GROUNDWATER GOVERNANCE IN ARIZONA AND CALIFORNIA

As is apparent from the survey results, groundwater governance and management can vary greatly across state lines. Transboundary groundwater governance issues between states and neighbouring countries are critical but were not within the scope of this

Table 24.3 States that reported a critical condition in their groundwater resources and type of management approach.

States with a critical condition (more than 30 % of uses come from groundwater combined with declining levels)	*Integrated Water Resources Management (IWRM)*	*Adaptive management (AM)*
Alaska		
Arizona		
Arkansas		
California	✓	✓
Hawaii	✓	✓
Kansas		✓
Mississippi		
Nevada	✓	✓
New Mexico	✓	✓
Oklahoma		
Oregon	✓	✓
Texas		
Washington	✓	✓
Total	6	7

analysis. In order to delve a bit more into detail for a few states, for further analysis we selected Arizona, the authors' home state (Box 24.1), and California, the most recent state to approve comprehensive groundwater legislation (Box 24.2). While the two states share a border and some similarities in climate and geology, their respective approaches to groundwater governance have been very different.

Arizona, an arid, inland state, has long relied on groundwater and imported surface water. As such, it has often taken a comprehensive approach to groundwater regulation in designated areas of the state, passing in 1980 the Arizona Groundwater Management Act (GMA), widely regarded as one of the nation's most progressive groundwater-governance laws, where within the five AMAs there is a mandate that developers and water providers demonstrate a 100-year assured water supply to support community growth and there exist other regulations designed to reduce or eliminate groundwater overdraft. While groundwater stresses continue to emerge, large-scale, progressive programs such as groundwater-recharge/recovery and water reuse have allowed Arizona to limit overdraft problems and address groundwater level declines for regulated areas of the state.

Box 24.1 Arizona: early adopter of comprehensive groundwater governance—but only in parts of the State

As Arizona's population grew from less than 2 million in 1970 to 7 million in 2017 (http://worldpopulationreview.com/states/arizona-population/), the state became increasingly reliant on groundwater to meet its human needs (WRRC, 2007). As in California, Arizona afforded landowners the right to pump essentially unlimited groundwater. This led to widespread extraction, subsidence, and

the dubious distinction of featuring the nation's largest metropolitan area that was solely reliant on groundwater (Tucson). These facts led Arizona leaders to attempt to bring surface water from the Colorado River—which forms Arizona's western boundary with California—to the heavily populated central portion of the state. The process of obtaining approval for planning and building the US$4.7 billion 541 km (336 mi) long Central Arizona Project (CAP) canal is an entire book in itself. One of the most important points of Arizona's water history is the passage of the 1980 Arizona Groundwater Management Act (GMA). Prior to funding the CAP, the federal government insisted that Arizona control its groundwater-overdraft problem, and the GMA was the result (Colby and Jacobs, 2007; Megdal, 2012; Ferris *et al.*, 2015).

The GMA's goal was to eliminate severe overdraft in areas where this was a problem. The Act created four Active Management Areas (AMAs), which were populated areas of the state where groundwater overdraft was to be managed or halted (Figure 24.5). Later legislation split the one of the AMAs (Tucson) into two parts. Management goals were specified in legislation for each of the AMAs, and a new state agency, the Arizona Department of Water Resources (ADWR), was to implement and enforce the new law's provisions. For four of the five AMAs, safe-yield, which requires AMA-wide balance between groundwater withdrawals and natural and artificial recharge, is the goal. Only the management goals for the largely agricultural Pinal AMA (see Figure 24.5) allows for declining groundwater levels.

The GMA mandated conservation by the agricultural, industrial, and municipal sectors in AMAs. Every 10 years, the ADWR is to adopt a management plan for each AMA that codifies these mandatory conservation regulations and measures progress toward meeting the AMA's management goal. Farmers were not permitted to increase their irrigated area, as measured in acres (0.4 hectare per acre), and they are expected to adhere to irrigation efficiency requirements and/or implement best management practices. Municipal providers were also required to adopt conservation practices. Early management plans established target per-capita volumes (in gallons) per day for users of municipal water, targets that have largely been replaced by best management practices.

Another innovative component of the GMA designed to reduce municipal water use is the Assured Water Supply Program. This rules-based program requires new residential developments to demonstrate that there is sufficient water to meet the need of existing and new residents for 100 years. Water supplies relied upon to serve new community needs must meet water-quality standards and be physically, continuously, and legally available for 100 years, and water utilization must be consistent with the statutory water management goal for the AMA. The management plans assess progress made toward meeting GMA management goals and these provisions have reduced groundwater mining considerably in the state, leading to forward-thinking programs designed to increase Arizona's water sustainability.

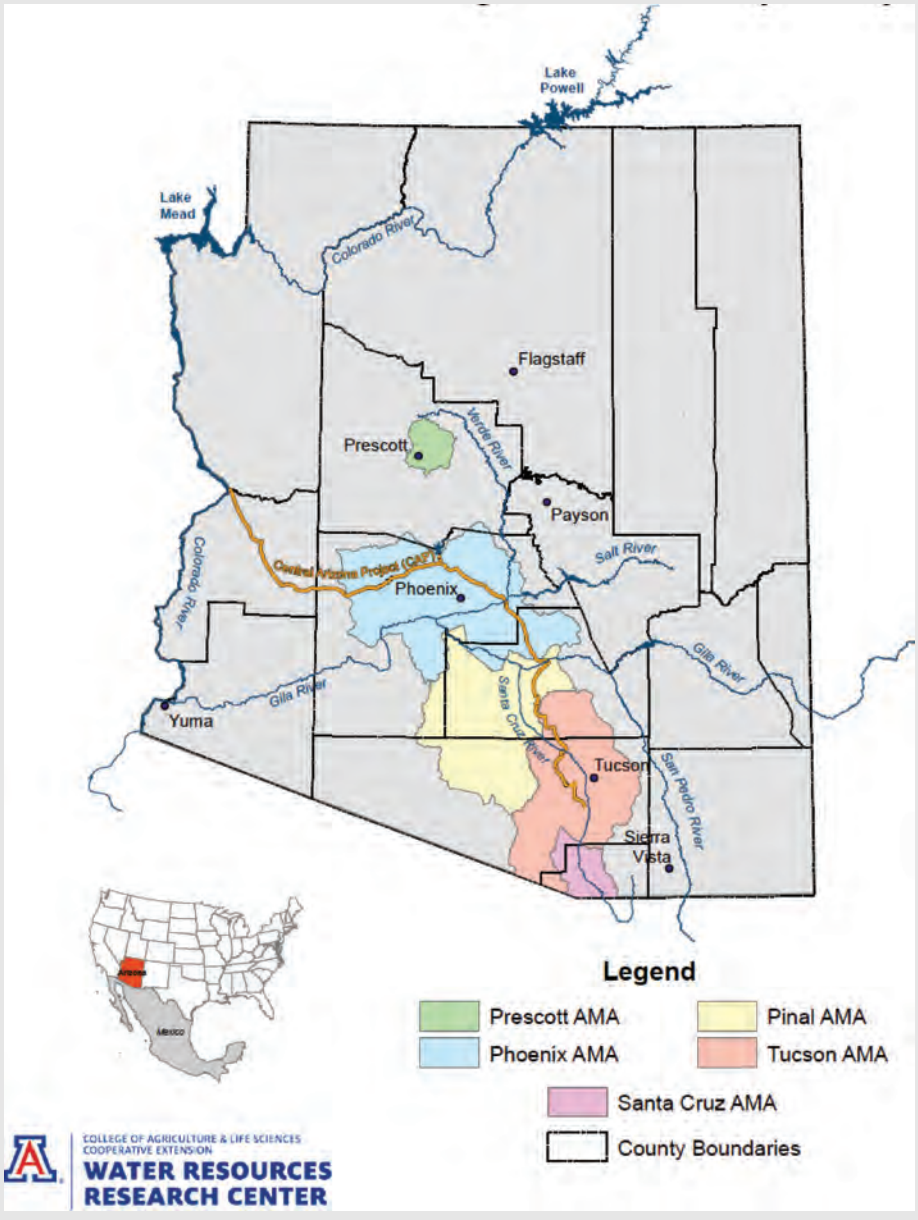

Figure 24.5 Active Management Areas (AMAs) in Arizona (map created by the WRRC).

The delivery of Colorado River water through the CAP and restrictions on groundwater withdrawals prompted development of a statewide recharge and recovery program. The statutory framework, which was last revised in 1994, requires permitting of recharge facilities, storage activities, and the recovery of

stored water. Significant annual storage capacity has been permitted in the region served by the CAP. Utilization of the storage and recovery framework has provided flexibility in how water providers have met the requirements of the GMA. The Arizona legislature allowed water suppliers to use water recharged in one place within an AMA as the fulfilment of the Assured Water Supply requirements related to use of renewable supplies, lending flexibility to water providers who do not have direct access to renewable supplies such as the CAP. The state legislature created the Central Arizona Groundwater Replenishment District as a vehicle to facilitate meeting the Assured Water Supply Rules' requirement that water use be consistent with the management goal of the AMA. Additionally, the Arizona Water Banking Authority was created to utilize on an annual basis any unused Colorado River water entitlement (Megdal, 2012).

Arizona has a long history of progressive groundwater management, and continues to be a leader in development of innovative ways to accommodate growth while limiting overdraft of its groundwater resources.

In contrast, for much of its history California largely allowed unregulated groundwater pumping. This decision permitted massive agricultural development in the Central Valley—a vast region stretching some 350 km (220 mi) northward and southward from Fresno—and contributed to municipal growth. But the practice led to land subsidence and ongoing concerns about the additional impacts of drought and climate

Box 24.2 California: late adopter of comprehensive groundwater governance—but too early to assess success

Historically, groundwater in California was managed under the correlative rights doctrine, which requires equitable sharing of all groundwater users overlying an aquifer by comparing demands of other overlying rights. Each person with land overlying an aquifer was allowed a "reasonable amount" for his/her use; however, California had no comprehensive statutory framework to regulate groundwater, so much of the correlative rights doctrine was open to interpretation (Thompson Jr. *et al.*, 2012).

Beginning in 2012 drought hit California and much of the state has remained under various levels of drought conditions. These conditions prompted increased reliance on groundwater that exacerbated overdraft and subsidence in many areas. For many in the state, it became clear that something had to be done to better manage groundwater. The Sustainable Groundwater Management Act (SGMA) is the amalgamation of three legislative bills (SB 1168, SB 1319, and AB 1739), and was approved by Governor Jerry Brown on September 16, 2014 (California Department of Water Resources 2016a).

The SGMA authorizes that groundwater resources in California will be managed for sustainable, long-term reliability and for economic, social, and environmental benefits for current and future beneficial uses. In order to

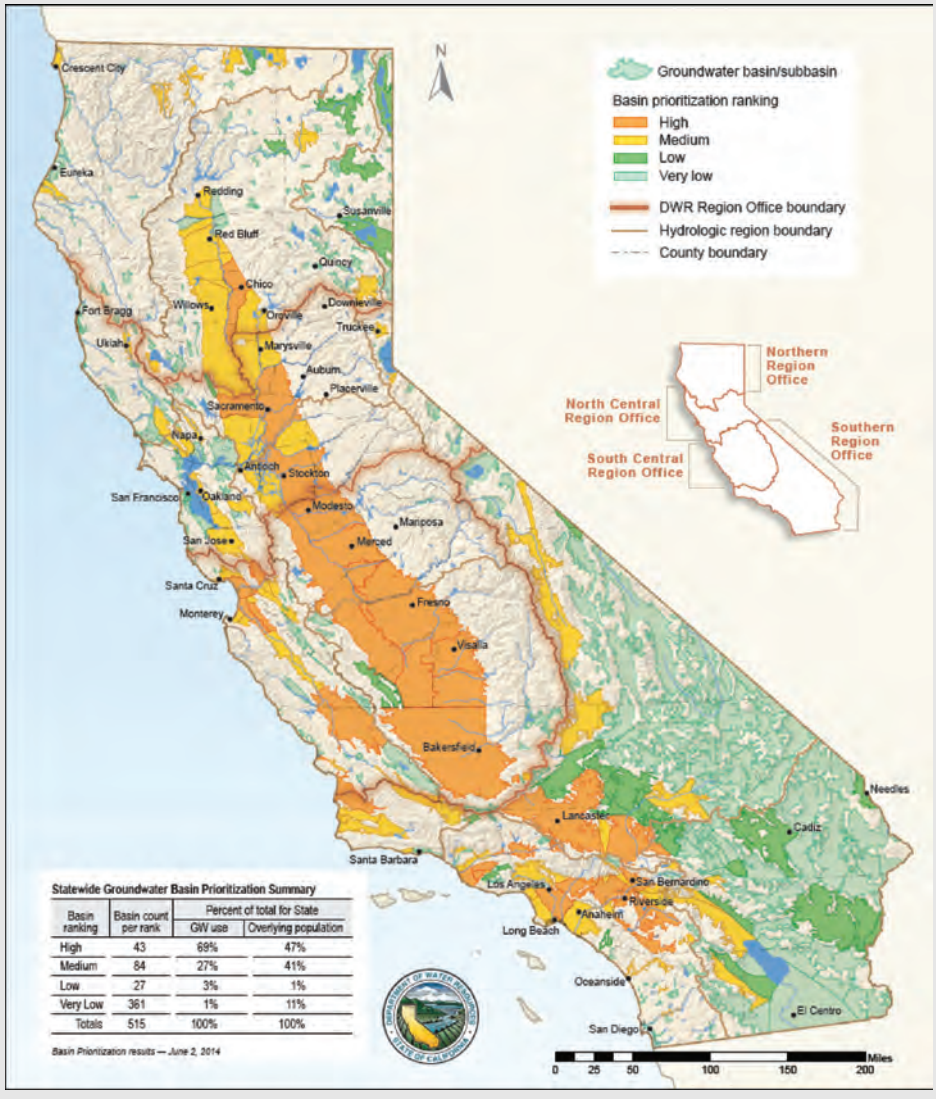

Figure 24.6 California Statewide Groundwater Basin Prioritization (California Department of Water Resources 2016a).

accomplish this, it requires the California Department of Water Resources (CDWR) to assign each groundwater basin to one of four priority categories based on condition of long-term overdraft and inadequate groundwater sustainability plan, among other conditions: high, medium, low, and very low (Figure 24.6). A timeline is assigned to each basin based on these priorities and whether the basin has been determined to be in critical overdraft by

CDWR. Higher priority basins with critical overdraft must be managed under a groundwater-sustainability plan or coordinated groundwater sustainability plan by 2020 (California Assembly 2014; California Senate 2014a, California Senate 2014b). Due to the regional management structure of groundwater in California, each groundwater basin must create its own plan to be reviewed by CDWR (Nishikawa, 2016). The coordinated groundwater sustainability plan concept reflects the idea that groundwater does not necessarily follow political boundaries, so multiple agencies can agree upon a single sustainability plan. High- and medium-priority basins that do not have critical overdraft must be managed under one of these plans by 2022. Recognizing that having groundwater basins create their own sustainability plans could be like having the fox in charge of the hen house, these plans must be reviewed by CDWR, which will determine if the plans will be able to achieve groundwater sustainability as per the specified timelines. Sustainability is achieved when withdrawals are equal to recharge, and must be achieved within 20 years of the plans' acceptance (California Assembly 2014; California Senate, 2014a, 2014b).

The act places further restrictions on groundwater basins, and provides a state "backstop" if basins are unable to meet requirements. Starting in 2025, groundwater basins that are designated high or medium priority can be placed in a probationary status by the State Water Resources Control Board (Board) if groundwater extractions result in significant depletions of interconnected surface waters. Areas in a basin where this occurs can be exempt if they meet the sustainability goal. If a basin is found deficient at creating an acceptable sustainability plan or following the approved one, the Board is also authorized to make interim plans for probationary basins in coordination with CDWR. If actions are not taken to rectify the problem, the interim plan may be adopted by the Board after notice and a public hearing (California Assembly 2014; California Senate 2014a, California Senate 2014b).

Groundwater management is highly decentralized in California (Nishikawa, 2016). In order to bring the various facets of management under one roof, the SGMA authorizes local agencies to elect a groundwater sustainability agency. Areas that are not managed by a groundwater sustainability agency will be managed by the encompassing county. These agencies empowered by the act to: (1) require registration of a groundwater extraction facility, (2) require an extraction facility to be measured with a water-measuring device, and (3) regulate groundwater extraction. The agency may also obtain inspection permits, conduct inspections, and impose fees. These powers come with a significant caveat: they can only be applied in consultation with the cities and counties. Extraction regulations must be consistent with the general plan of cities and counties unless there is insufficient sustainable yield to meet those purposes. Obversely, however, planning agencies for cities and counties must take groundwater sustainability plans into account when making changes to general plans (California Assembly 2014; California Senate 2014a, 2014b). These stipulations ensure that agencies do not regulate groundwater without good reason, and that entities

within their jurisdiction do not make plans that are not in line with the goal of sustainability.

The Act is paid for with money from the Water Rights Fund after appropriation by Legislature, but all of the money expended must be eventually recovered from fees. Some of this money will be recovered by levying fines for violations of cease and desist orders that are issued by the Board (California Assembly 2014; California Senate 2014a, 2014b). The Act is California's first attempt at regulating groundwater, and its degree of success remains to be seen; even the highest priority basins are not required to meet groundwater sustainability goals for nearly 25 years.

change. In 2014 California passed the Sustainable Groundwater Management Act. This law is designed to limit groundwater mining (*i.e.*, non-replenished extraction) and return groundwater withdrawals to sustainable levels across the state.

In the present section, to better understand the contexts in which states are governing groundwater use, we examine in greater detail recent developments in governance in these two states.

Discussion of two state-level approaches shows the importance of drivers for enactment of major groundwater legislation. Arizona experienced groundwater challenges over several decades. Population growth combined with increasing reliance on groundwater resources led to subsidence and aquifer depletion. Arizona leaders worked hard to bring water from the Colorado River via the CAP canal. Securing funding to construct the CAP led to adoption of the GMA. The 1980 law created AMAs that included the most populated areas in the state. The GMA also includes an Assured Water Supply Program, which requires that the water supply new development have enough water supply for its residents for the next 100 years in a manner consistent with statutorily established groundwater management goals.

Multiyear drought in California combined with diminishing surface water supplies exacerbated groundwater overdraft and subsidence in the state. Public attention focused on the rapidly increasing reliance on aquifers to supplement diminished surface water supplies. As a consequence, groundwater governance in California shifted from the correlative rights doctrine to the 2014 approval of the SGMA. The law's intent is for long-term sustainable management of aquifers. The overall sustainability goal is to have equal amount of withdrawals and recharge in all basins by 2022. Local agencies are authorized to select a groundwater sustainability agency; areas not managed by one of these agencies are managed by the county.

24.4 GROUNDWATER GOVERNANCE: LESSONS FROM THE U.S.

Governance and management of groundwater across the U.S. is decentralized, uneven, complex, and dynamic. From the completeness of groundwater laws and regulations, to the most basic recognition of the connection of surface and groundwater, to the recognition of the water needs of the environment, governance structures differ radically across state lines. While some similar priorities exist across states, the differences

and gaps in governance frameworks are apparent through even a cursory examination of the survey results.

States have different mixtures of regulatory authority over groundwater, with some states delegating more to local governments than others. On the one hand, some respondents indicated that different agencies have regulatory authority over different portions of water-use sectors in different regions of a state, further fragmenting governance and management. For a common resource such as groundwater, fragmentation can lead to gaps in regulation, overlapping and sometimes contradictory rules, and lack of attention to larger environmental problems (Doremus, 2009). On the other hand, some degree of fragmentation can be beneficial, because it can lead to responsive, local governance that can increase efficiency (Blomquist & Schlager, 2005). Determining a proper balance between central and local authority is an ongoing challenge for many states.

The difficulty in establishing appropriate roles for state and local regulatory bodies is exacerbated by state groundwater laws that do not codify basic hydrologic facts. Many states fail to recognize the surface-water/groundwater connection (n = 24), the interplay between groundwater quality and quantity (n = 13), or the water needs of the environmental sector (n = 26). Most state laws do not acknowledge that surface waters infiltrate and feed aquifers, and that groundwater basins often provide base flow to rivers. And typically, quantity and quality are overseen by different state agencies, complicating coordination of data and information. Groundwater-dependent ecosystems such as springs preserve biodiversity and are important to tourism and quality of life. Yet many legal and regulatory frameworks fail to recognize these linkages, making it difficult to implement sustainable groundwater management structures.

We found that groundwater challenges span the entire nation. We identified 13 states having what we termed critical condition in their groundwater resources (listed in Table 24.3). These are places where groundwater reliance is considerable (more than 30 percent of human uses) while supply is decreasing (declining levels are a national priority as reported by 32 states). From these states, six have adopted what are generally considered effective governance approaches (IWRM and AM)—most of these in the continental western part of the country (except Hawaii).

In spite of this lack of integrated management, many states aim to use groundwater sustainably by maintaining levels and limiting contamination. States also largely use complementary management tools—such as permitting, monitoring, and encouragement of voluntary activities by water users—to try to achieve those goals. Employing such tools to address common goals is sure to become more important as human population growth and climate change continue to alter the hydrologic cycle (Georgakakos *et al.*, 2014). Perhaps most encouraging is the fact that many survey respondents felt their state's groundwater governance had evolved over the last few decades. If that trend continues, states may be able to develop and apply appropriate tools and techniques to meet critical groundwater-governance priorities.

Our analysis shows that both Arizona and California face potential critical conditions in their groundwater resources. However, Arizona did not report adopting either IWRM or AM, while California reported adopting both. But regardless of how these states refer to their management approaches, both states *have* addressed their challenges by significantly changing their groundwater governance frameworks.

On the one hand, Arizona is recognized as an early adopter of a comprehensive groundwater management approach by securing water from the Colorado River for aquifer recharge, and by creating active management areas in the most populated regions (Colby & Jacobs, 2007; Megdal, 2012). California, on the other hand, has been a late adopter of a comprehensive groundwater management approach, but it has done so throughout the entire state. Both states have realized the importance of managing their groundwater resources sustainably and have taken clear steps toward this direction. In time we will learn the results of California's actions.

24.5 NEXT STEPS

Additional research on the very complex topic of groundwater governance in the U.S. is needed. Survey responses can fill in only part of the mosaic. Surveying a larger sample of representatives of each state and delving more deeply into actual governance practices can assist in developing a more complete and more refined picture. Updates are needed because the mosaic changes over time, as is evident by the discussion of California.

UA researchers at the Water Resources Research Center and Udall Center for Studies in Public Policy have engaged in more in-depth case-study analysis, as well as additional survey work. A second survey, largely aimed at groundwater quality, is expected to yield a much more nuanced understanding of variations in groundwater-quality governance and management. It will build on initial results by probing more closely themes of groundwater concerns and use, such as quality management and monitoring, and regulation; quality-quantity connections; and extent of resources, research, and collaboration in each state.

Our research to now has built on vital knowledge gained from our 2013 survey. But much remains to be done. In-depth analysis of groundwater-quantity laws and regulations, further investigation into centralization vs. fragmentation (including the relative value of each type of governance), and regulatory adaptation to growing threats such as population growth, urbanization, and climate change are all areas of groundwater governance and management research that require further investigation.

Similarly, groundwater governance across state and international borders has been inadequately studied and remains poorly understood, with the exception perhaps of the Memphis Sand Aquifer underlying Arkansas, Mississippi, Tennessee and Kentucky (Fried and Ganoulis 2016). Aquifer-assessment work at the border between the U.S. and Mexico is one effort that has been proceeding (Callegary *et al.,* 2016) and we believe that analogous initiatives would be a welcome addition to the literature and to the arsenal of practical applications.

In this essay, we have documented that groundwater governance across the United States is fragmented, uneven, non-static, and almost certainly ripe for change. Further research along the lines we have suggested would go a long way to enhancing understanding of promising approaches. These would identify best practices that could be shared to promote conservation and effective governance of groundwater—not just in the U.S., but in other areas of the world facing groundwater challenges.

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APPENDIX A: 2013 SURVEY

Introduction: This is a short questionnaire intended to acquire first-hand knowledge from state agency personnel about your state's groundwater governance practices, including the institutions and laws involved.

The study aims to describe the state of the practice in the U.S. and produce a national-scale report identifying the range of approaches to groundwater governance.

This questionnaire should take approximately 15 minutes to complete.

Please note: Data or comments obtained in this survey project will not be attributed to particular individuals. Respondents may skip questions, as necessary.

1. Basic Information

State you represent: _____

Name of the agency you represent: _____

Part I: Groundwater Use

1 In an average year, what approximate percentage of total human demands (*i.e.* domestic, commercial, industrial, and agricultural) are met through use of groundwater supplies in this state?

% of all water withdrawn for human demands in the state that comes from groundwater: _____

2 Is the importance of groundwater use consistent throughout the state or does it vary by region in terms of relative reliance on groundwater to supply human demands? Check only one.

__Reliance is consistent throughout the state

__Reliance varies by region

3 Is the proportion of groundwater use by each major groundwater-using water sector consistent throughout the state or does it vary by region? Check only one.
__Proportions of use by each sector consistent throughout the state
__Proportions of use by each sector varies by region

Part II: Groundwater Laws and Regulations

1 Are there formal groundwater policies, rules, or regulations in the state?
__Yes
__No
Please provide names and dates of relevant statute/rule(s):
_____

2 Have you observed substantial changes in how groundwater is managed in the state over the past few decades?
__Yes
__No
Please explain: _____

3 In what agencies do authorities for groundwater oversight/enforcement reside? Please list all.
Local agencies: _____
State agencies: _____

4 Do separate agencies deal with water quantity and water quality? Yes____No____

5 What are the state's groundwater governance priorities? Check all that apply.
__Declining groundwater levels
__Conflicts between water users (*e.g.* well interference)
__Access
__Quantification of water rights
__Water quality/Contamination
__Regulatory disputes
__Inter-agency jurisdictional conflict
__There have been no clearly articulated priorities
__Other

6 Are there programs or settlements addressing international, interstate or Native American groundwater issues in the state?
__Yes
__No
Please explain: _____

7 Are there programs or settlements addressing Native American groundwater issues in the state?
__Yes
__No
Please explain: _____

8 Are there water conservation regulations applicable to groundwater use in the state law?
__Yes

__No
Please provide names and dates of relevant statute(s): _____

9 Does state law explicitly recognize or address the connection between surface water and groundwater?
__Yes
__No
If yes, how? Please provide names and dates of relevant statute(s):
_____

10 Does state law explicitly address groundwater quality?
__Yes
__No
If yes, how? Please provide names and dates of relevant statute(s):
_____

11 Does state law consider the water needs of groundwater dependent ecosystems?
__Yes
__No
If yes, how? Please provide names and dates of relevant statute(s):

12 Do enforcement agencies have sufficient capacity to carry out policies and responsibilities?
__Yes
__No
Comments: _____

13 Are the courts active in groundwater issues in the state?
__Yes
__No
Please list relevant court decisions: _____

14 To which of the following user groups do groundwater regulations apply? Check all that apply.
__Household/domestic wells
__Industrial Users
__Privately owned community water systems
__Publicly owned community water systems
__Irrigation associations
__All of these
__Other

15 Do regulations differ for each water user types listed above (*e.g.* municipal use vs. irrigation)?
__Yes
__No
If yes, please explain: _____

16 Does your state encourage the use of voluntary measures for addressing groundwater issues?
__Yes
__No
If yes, please explain: _____

Part III: Groundwater Tools and Strategies

1 Which tools do the state use to manage groundwater use/quantity? Check all that apply.
__Permits
__Planning
__Land use development laws/regulations
__Protected areas
__Pricing
__Extraction fees
__Monitoring
__Other

2 For which water sectors is groundwater use metered or monitored? Check all that apply.
__All water sectors
__Municipal
__Industrial
__Agricultural
__Other

3 What aspects of groundwater are monitored? Check all that apply.
__Groundwater levels
__Groundwater abstractions
__Amount in storage
__Conductivity properties
__Groundwater quality
__Rates of recharge
__Rates of discharge
__Other
__None

4 Which tools does the state use to manage groundwater quality? Check all that apply.
__Permits
__Planning
__Land use development laws/regulations
__Protected areas
__Pricing
__Extraction fees
__Monitoring
__Other

5 How are the activities of groundwater management agencies (*e.g.* permit reviews, monitoring) funded? Check all that apply.
__User fees
__Taxes
__State general fund
__Mitigation fees
__Other

6 How widely is information about groundwater resources and rights reported? Check all that apply.
__Information about groundwater supplies is publicly available
__Information about groundwater use is publicly available
__Information about water rights of all users is publicly available
__Information about groundwater supplies is provided directly to water users
__Information about groundwater use is provided directly to water users
__Information about water rights of all users is provided directly to water users
__Information about groundwater resources and water rights including access to water rights registers is not reported

7 To what extent is groundwater information publicly accessible?
__Extremely accessible
__Somewhat accessible
__Not publicly accessible at all

8 In your state, are any of these groundwater management strategies in use? Check all that apply.
__Integrated Water Resources Management (IWRM)
__Aquifer recharge and storage programs
__Regional planning or management organizations
__Economic incentives
__Adaptive management
__Public education programs
__Other

Part IV: Future Research and Contacts

1 Contact information (optional)
Your name (optional) _____
Telephone (optional) _____
Email (optional) _____

2 May we contact you with additional questions in the future?
Yes___
No___

3 Please indicate which of the following categories best describes your professional title.
__Engineer
__Economist
__Planner
__Mid-level administrator
__Manager
__Political appointee/Director
__Researcher/Academic
__Lawyer
__Other (please specify)

Thank you for taking our survey!