DECENTRALIZED GROUNDWATER GOVERNANCE AND WATER NEXUS IMPLICATIONS IN THE UNITED STATES

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ABSTRACT: Groundwater is essential to meeting water demands across the United States. Effective groundwater governance (making laws, policies, and regulations) and management (implementing governance framework) are needed to ensure its sustainable use. Groundwater governance in the United States is decentralized, resulting in considerable variations in practices across states. This Article reports on two state-level surveys and three regional case studies conducted to better understand groundwater governance strategies and practices. This Article also relates the results of these research efforts to food, energy, and climate. The first survey sampled state agency officials about the extent and scope of groundwater use, groundwater laws and regulations, and groundwater tools and strategies within their states. The second survey focused on groundwater quality, surveying state-level water quality professionals to better understand the diverse strategies and practices for managing groundwater quality. The three case studies highlighted innovations in sub-state approaches to manage groundwater.

This Article explains the study results related to the interconnectivities of groundwater to food, energy, and the climate, along with the strengths and shortcomings of state-level groundwater governance in addressing these interconnectivities. The analysis points to the importance of identifying best practices for addressing nexus challenges for groundwater.

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Providing clean water and sanitation to the world's growing population is a key component of Goal 6—the United Nations' Sustainable Development Goal for clean water and sanitation.[1] Global water challenges include too little water (scarcity), too much water (flooding), poor water quality, and sea level rise. As researchers realized physical water systems must be holistically considered, they increased their focus from the water-energy nexus to the water-energy-food nexus to the water-energy-food-climate nexus. In so doing, these

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1. WORLD BANK GRP., ATLAS OF SUSTAINABLE DEVELOPMENT GOALS 22 (2018), https://openknowledge.worldbank.org/bitstream/handle/10986/29788/9781464812507.pdf?sequence=5&isAllowed=y [https://perma.cc/M9H2-4XYA].

researchers started to ask whether it is realistic to expect governance systems to address critical water challenges in a holistic way? Further, what are the prospects for addressing key national or global priorities when water governance is decentralized and national and state-level legal systems may not recognize the connection between surface water and groundwater? These questions can be difficult to answer, particularly when little is known about water governance and management frameworks for the location in question.

While water challenges are at the forefront of global discussions, water can also be a regional or local resource and is subsequently managed and governed as such. This is particularly true for groundwater, the invisible water that is increasing in importance. Groundwater has important linkages with food, energy, and climate. Many farmers use groundwater as a primary source of water for irrigating crops. Groundwater has been used in and has experienced impacts from mining, more recently through hydraulic fracturing of rock for natural gas. Groundwater is also connected to surface water and riparian ecosystems in many cases, though those links are still unknown or poorly understood in certain areas. Governance and management approaches are not necessarily designed to recognize these linkages.

This Article reports on findings from multiple groundwater governance studies in the United States. The absence of clearly articulated national food, energy, climate, and water policies means addressing the nexus issues is largely left to individual states or sub-state jurisdictions. These studies identify both similarities and differences in legal underpinnings for addressing the nexus challenges. The analysis concludes that lack of formulation of national policies, coupled with strong authorities at the state level, makes identifying best governance practices imperative.

I. DEFINING GROUNDWATER GOVERNANCE

Groundwater governance, like other areas of water governance, is receiving global attention. The Global Environmental Facility (GEF), partnering with the Food and Agriculture Organization of the United Nations (FAO), the United Nations Educational, Scientific and Cultural Organization (UNESCO) and others, undertook a project (GEF Project) earlier in this decade to develop a framework for action to raise awareness of the importance of good groundwater governance and to identify best governance practices.[2] To help participating experts and stakeholders understand the highly decentralized approach to groundwater governance in the United States, a team of researchers at the University

2. *See About the Project*, GROUNDWATER GOVERNANCE, http://www.groundwatergovernance.org/about-the-project/en/ [https://perma.cc/69JJ-AZMC]. Not long afterwards, the Organisation for Economic Co-operation and Development (OECD) began its Water Governance Initiative, which focuses on governance for all types of water, not just groundwater. *The OECD Water Governance Initiative*, OECD, http://www.oecd.org/cfe/regional-policy/water-governance-initiative.htm [https://perma.cc/WR3D-BJKD]. Its purpose is to bring stakeholders together twice a year "to share good practices in support of better governance in the water sector." *Id.*

of Arizona undertook a survey of U.S. states' groundwater governance and management practices.[3] The "Initial Survey" was completed in 2013 and presented at the GEF Project's March 2013 Regional Consultation.[4]

The term *groundwater governance* has no single or simple definition. During the early stages of the GEF Project, a thematic paper on groundwater governance policy noted the multiple definitions in the literature and offered the following definition: "Groundwater governance is the process by which groundwater is managed through the application of responsibility, participation, information availability, transparency, custom, and rule of law. It is the art of coordinating administrative actions and decision making between and among different jurisdictional levels—one of which may be global."[5] When we reported on our Initial Survey in the literature, we modified this into a single-sentence definition: groundwater governance is "the overarching framework of groundwater use laws, regulations, and customs, as well as the processes of engaging the public sector, the private sector, and civil society."[6] In its final documents, the GEF Project settled on yet another definition: groundwater governance "comprises the enabling framework and guiding principles for responsible collective action to ensure control, protection and socially-sustainable utilisation of groundwater resources for the benefit of humankind and dependent ecosystems."[7] Thus, groundwater governance is more than the legal structure for regulation and monitoring government, but all definitions include the legal framework as part of groundwater governance.[8] Governance is distinct from groundwater management, which is the actions taken that are predicated on the governance framework.[9] For example, the governance framework may allow for water banking, but individual water providers are the ones who then decide when and where to bank water.

3. *See generally* ANDREA K. GERLAK ET AL., GROUNDWATER GOVERNANCE IN THE U.S.: SUMMARY OF INITIAL SURVEY RESULTS (2013), https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/pdfs/GroundwaterGovernanceReport-FINALMay2013.pdf [https://perma.cc/EWD6-S3UA] [hereinafter INITIAL SURVEY].

4. Sharon B. Megdal et al., *Groundwater Governance in a Federal Framework: Results of a Survey of the 50 States of the USA*, WATER RESOURCES RES. CTR. (Mar. 20, 2013), https://docs.google.com/viewerng/viewer?url=http://www.fao.org/fileadmin/user_upload/groundwatergovernance/docs/Hague/Presentations/Day2/P5A_Megdal_20Mar2013_FINAL_USAStates19Mar2013.pdf [https://perma.cc/8TBL-P9KJ].

5. ROBERT G. VARADY ET AL., GROUNDWATER GOVERNANCE: A GLOBAL FRAMEWORK FOR COUNTRY ACTION: GROUNDWATER POLICY AND GOVERNANCE 7 (Glob. Env't Facility ID 3726, 2013), http://www.groundwatergovernance.org/fileadmin/user_upload/groundwatergovernance/docs/Thematic_papers/GWG_ThematicPaper5_APr2013_web.pdf [https://perma.cc/873L-UV7Z].

6. Sharon B. Megdal et al., *Groundwater Governance in the United States: Common Priorities and Challenges*, 53 GROUNDWATER 677, 678 (2015).

7. *See* Maria-Helena Semedo et al., *Foreword to* FOOD & AGRIC. ORG., SHARED GLOBAL VISION FOR GROUNDWATER GOVERNANCE 2030 AND A CALL-FOR-ACTION (2016), http://www.fao.org/3/a-i5508e.pdf [https://perma.cc/5W6K-DPN4].

8. *See* Sharon B. Megdal, *Invisible Water: The Importance of Good Groundwater Governance and Management*, NPJ CLEAN WATER, Sept. 3, 2018, at 1, 2.

9. VARADY ET AL., *supra* note 5, at 8.

II. DECENTRALIZED GROUNDWATER GOVERNANCE IN THE UNITED STATES AND NEXUS IMPLICATIONS

As explained by Megdal, her coauthors, and others, water governance—and particularly groundwater governance—is delegated to the states in the United States.[10] Moreover, within states, groundwater governance may be split across different state agencies.[11] The availability of water varies by state, with the focus on water quantity versus water quality depending on the water abundance of the state, among other factors.[12] In addition, groundwater governance may vary considerably within states.[13]

At the national level, U.S. water policy sets minimum drinking water standards through the Safe Drinking Water Act and standards for discharges to rivers and streams through the Clean Water Act, the Comprehensive Environmental Response, Compensation and Liability Act, and the Resource Conservation and Recovery Act.[14] While many federal government agencies touch water,[15] there is no single federal water regulation agency. In addition, there is difficulty in generalizing groundwater's connection to energy policy, food policy, or climate policy in part because, arguably, there are no clearly articulated policies at the national level or the policies that exist are in a state of flux. Despite the periodic passage of the U.S. Farm Bill,[16] there is no national food policy in the United States. Construction of energy facilities by type and location is largely at the discretion of U.S. energy producers, with some federal regulation of nuclear

10. Sharon B. Megdal et al., *Groundwater Governance in the United States: A Mosaic of Approaches*, *in* ADVANCES IN GROUNDWATER GOVERNANCE 483, 484 (K. Villholth et al. eds., CRC Press 2017); Robert Haskell Abrams, *Legal Convergence of East and West in Contemporary American Water Law*, 42 ENVTL. L. 65, 69 (2012); R. Quentin Grafton et al., *An Integrated Assessment of Water Markets: A Cross-Country Comparison*, 5 REV. ENVTL. ECON. & POL'Y 219, 224 (2011); Nathan Weinert, *Solutions for Interstate Groundwater Allocation and the Implications of Day*, 44 TEX. ENVTL. L.J. 105, 107 (2014).

11. *See* Megdal et al., *supra* note 10.

12. Future research might delve into determining why the focus varies from water quantity to water quality in each state. *See generally* INITIAL SURVEY, *supra* note 3.

13. *See* Sharon B. Megdal et al., *Innovative Approaches to Collaborative Groundwater Governance in the United States: Case Studies from Three High-Growth Regions in the Sun Belt*, 59 ENVTL. MGMT. 718, 721–30 (2017) (discussing three case studies of groundwater management at the sub-state level). Michael Kiparsky et al., *The Importance of Institutional Design for Distributed Local-Level Governance of Groundwater: The Case of California's Sustainable Groundwater Management Act*, 9 WATER 755, 756 (2017).

14. Kimberly Bick, *Contaminated Groundwater as a Resource in California*, 24 HASTINGS ENVTL. L.J. 97, 98, 104 (2018); Peter J. Martinez et. al., *Environmental Crimes*, 43 AM. CRIM. L. REV. 381, 414 (2006).

15. *See, e.g.*, *About the Office of Water*, EPA, https://www.epa.gov/aboutepa/about-office-water [https://perma.cc/GSP2-PVC2]; *About Us*, U.S. FISH & WILDLIFE SERV., https://www.fws.gov/fisheries/fac_program.html [https://perma.cc/LG97-4JBM]; *About Us*, NOAA FISHERIES, https://www.fisheries.noaa.gov/about-us [https://perma.cc/H3RK-TM2T].

16. PARKE WILDE, FOOD POLICY IN THE UNITED STATES: AN INTRODUCTION 10 (2d ed. 2018).

power, for example.[17] State regulatory agencies have oversight of renewable energy requirements.[18] Carbon emissions policy and U.S. participation in the United Nations Framework Convention on Climate Change is at the discretion of the federal government.[19] Issues surrounding groundwater and its connection to food, energy, and climate also tend to be localized, making state, regional or national policies more difficult to craft.

The lack of national groundwater policy makes it more difficult to contemplate addressing nexus challenges with the management of transboundary aquifers, whether across state lines, tribal nations, or international boundaries. Almost all aquifers in the United States are shared between countries, states, tribes, counties, or cities.[20] This leads to different management and governance practices between jurisdictions, including different definitions of aquifer boundaries and varied data collection practices and methodologies.[21] While several interstate compacts govern surface water basins,[22] there are no interstate compacts specifically governing an aquifer in the United States. The federal government could get involved in "interstate disputes . . . . [with] equitable apportionment cases in the Supreme Court,"[23] congressionally approving "new or amended interstate compacts,"[24] "restrict[ing] water exports . . . via the [largely] dormant Commerce Clause,"[25] or adopting a "federal regulation [system] of, or oversight over, interstate and international water markets."[26] The assessment and governance of transboundary aquifers is more likely to be effective if parties consider and respect national sovereignties, including tribal nations, and the different regulatory frameworks and cultures.[27]

States guard against infringement of their authorities, especially when it comes to water. This reality, coupled with limited federal water, energy, food, and climate policies, means innovations and solutions often emerge from state actions rather than from federal actions. Our groundwater study results provide some insights about what the states are focusing on with respect to improving groundwater governance and the prospects for connecting state priorities with

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17. *What FERC Does*, FERC, https://www.ferc.gov/about/ferc-does.asp [https://perma.cc/7SHV-6C6C].

18. *See State Renewable Energy Resources*, EPA, https://www.epa.gov/statelocalenergy/state-renewable-energy-resources [https://perma.cc/E285-HNQG].

19. *See* Rashmeen Kaur, *U.S. Participation in Global Climate Change Resolutions: Analysis of the Kyoto Protocol*, 13 MCNAIR RES. J. SJSU 77, 78–81 (2017).

20. Megdal et al., *supra* note 6.

21. *See id.* at 679.

22. *See* Tanya Heikkila et al., *The Role of Cross-Scale Institutional Linkages in Common Pool Resource Management: Assessing Interstate River Compacts*, 39 POL'Y STUD. J. 121, 125 (2011).

23. Robert W. Adler, *Climate Change and the Hegemony of State Water Law*, 29 STAN. ENVTL. L.J. 1, 49 (2010).

24. *Id.* at 49–50.

25. *Id.* at 50.

26. *Id.* at 51.

27. *See, e.g.*, James Callegary et al., *Findings and Lessons Learned from the Assessment of the Mexico-United States Transboundary San Pedro and Santa Cruz Aquifers: The Utility of Social Science in Applied Hydrologic Research*, 20 J. HYDROLOGY: REGIONAL STUD. 60 (2018), https://www.sciencedirect.com/science/article/pii/S2214581817301799 [https://perma.cc/EU6E-V3EB] (follow "Download PDF" hyperlink).

nexus issues. In the subsections below, the study methodology and insights related to the water-energy-food-climate nexus are discussed.

A. State Survey Methodology

The Initial Survey, conducted in 2013, was designed to examine responses from a state agency official from each state about the extent and scope of groundwater use, groundwater laws and regulations, and groundwater tools and strategies.[28] Respondents represented all fifty states and the District of Columbia.[29] Survey respondents were identified using the network of federally authorized Water Resource Research Institutes at universities across the United States.[30] Twenty-two respondents were from water quality agencies, nineteen represented water quantity or allocation agencies, and seven respondents either listed a state agency that addresses both water quantity and quality or listed two agencies.[31]

The results of a subsequent survey with a focus on water quality are compiled in a report[32] (Second Survey).[33] Responses from a water professional were again gathered in all fifty states.[34] The Second Survey, completed in 2017,

> was designed to focus on six substantive elements: (1) groundwater concerns and use; (2) groundwater quality management and monitoring; (3) the scopes of groundwater quality regulatory programs; (4) groundwater quality-quantity connections; (5) the scope of resources available and needed, and research and collaboration between local, state, and federal agencies; and (6) exploring future trends in groundwater management.[35]

Like the Initial Survey, the Second Survey was pilot tested, in this case by multiple groundwater quality professionals from different states to inform the designers about the time the survey would require and improve survey design.[36] Participants were "identified through online searches of [state] agencies with authority for water quality" and by consultations with water quality experts.[37] "In states where the agency declined or failed to respond," officials at the state-

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28. INITIAL SURVEY, *supra* note 3.
29. *Id.*
30. *Id.*
31. Megdal et al., *supra* note 10, at 487.
32. *See generally* SHARON B. MEGDAL ET AL., STATE-LEVEL GROUNDWATER GOVERNANCE AND MANAGEMENT IN THE U.S.: SUMMARY OF SURVEY RESULTS OF GROUNDWATER QUALITY STRATEGIES AND PRACTICES (2017), https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/attachment/GWREF_Report_and_appendix_6_6_18.pdf [https://perma.cc/PR6B-R9P5] [hereinafter SECOND SURVEY]. Whereas the Initial Survey was self-funded with the help of University of Arizona Technology Research Initiative Funds, the Second Survey was funded by the Ground Water Research and Education Foundation, a foundation affiliated with the U.S.-based Groundwater Protection Council. *Id.* at 1.
33. Jacob D. Petersen-Perlman et al., *Critical Issues Affecting Groundwater Quality Governance and Management in the United States*, 10 WATER 735 (2018).
34. SECOND SURVEY, *supra* note 32, at 2.
35. *Id.*
36. *Id.*
37. *Id.*

level U.S. Geological Survey (USGS) Water Science Center or "state level employee[s] at the federally authorized [state] Water Resource Research Institutes" were asked to complete the survey.[38]

B. Findings from the State Surveys

This section reports survey results most relevant to the groundwater-food-energy-climate nexus. The Initial Survey indicated that states are concerned about their capacity to address priority issues and declines in groundwater levels.[39] The top state groundwater concerns were water quality (45 states), conflict among water users (36 states), and declining groundwater levels (32 states).[40] Responses showed that similar tools were used to address both groundwater quality and groundwater quantity concerns, with the two most common being monitoring and permitting (as shown in Figure 1).[41] However, twenty states reported metering or monitoring all key water sectors.[42] While 28 state respondents reported that their state meters or monitors the municipal sector and twenty states meter or monitor the industrial sector, only 13 state respondents reported that their states meter or monitor the agricultural sector.[43]

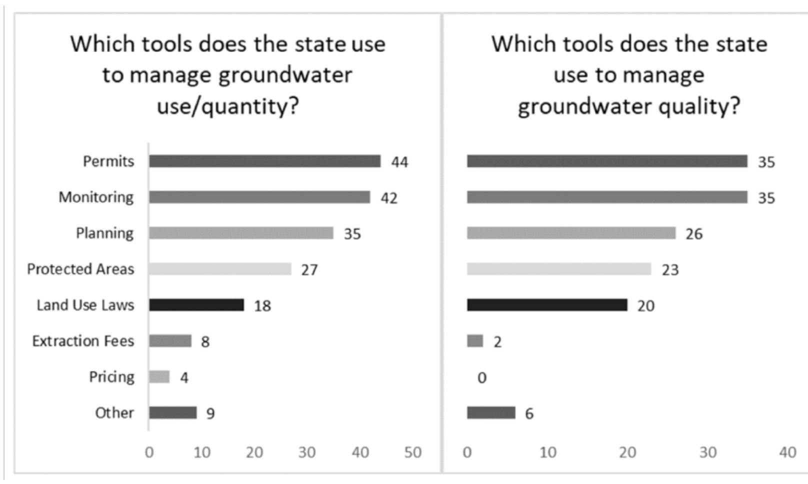

Figure 1. Tools States Use for Managing Groundwater Use, Quantity, and Quality[44]

Less than half of the state respondents (23) reported their state had sufficient regulatory capacity to enforce groundwater priorities.[45] Almost two-thirds

38. *Id.* at 2–3.
39. *See* INITIAL SURVEY, *supra* note 3, at 10.
40. *Id.*
41. *Id.* at 13.
42. *Id.* at 14.
43. *Id.*
44. Figure 1 was adapted using information from *id.* at 12–13, figs.6 & 7.
45. *Id.* at 7.

of states identified declining groundwater levels as a priority.[46] Yet, only fourteen of those states reported there was sufficient regulatory capacity to enforce groundwater priorities.[47]

Nearly all the state respondents reported that water quality was a strong groundwater priority within their states.[48] A second online survey focused on groundwater governance and management questions relating to groundwater quality.[49] This survey of state-level water quality professionals, developed with the assistance of a small advisory committee representing of water quality professionals, was completed in 2017.[50] As with the Initial Survey, respondents reported that impairment of water quality and groundwater quantity were top groundwater concerns in their states.[51] Other concerns included staffing and budget issues, the health and vulnerability of private well users, and aquifer overdraft.[52] State professionals frequently noted their concerns about contamination of groundwater, especially in agricultural sites, but also identified naturally occurring contaminants, underground storage tanks, Superfund/Comprehensive Environmental Response, Compensation, and Liability Act sites, industrial sites, and septic tanks as sources of contamination.[53] Nitrate was the most noted contaminant concern, with chlorinated solvents second.[54] Unconventional oil and gas exploration and production are occurring and regulated in about half of the states.[55] Most respondents indicated that their states had explicit groundwater quality management goals.[56] Although many of the surveyed state water professionals have not observed significant changes to groundwater quality policy in the last ten years, others have.[57] Most states share groundwater quality data with many user groups.[58]

On the funding side, states identified "multiple sources of funding for water quality programs, with 85% . . . receiving some form of federal funds."[59] However, a majority of state respondents reported that groundwater quality program budgets have decreased in the last decade, with a majority of respondents reporting the number of agency staff as too small.[60] This finding is consistent with the Initial Survey's result regarding lack of capacity.[61] When asked about the future, respondents indicated water quality, water level monitoring, and increased groundwater pumping will require additional attention, and about half

46. *Id.* at 10.
47. *Id.* at 7.
48. *Id.* at 10.
49. SECOND SURVEY, *supra* note 32, at 1–2.
50. *Id.* at 2–3.
51. *Id.* at 3.
52. *Id.*
53. *Id.*
54. *Id.* at 12 fig.8.
55. *Id.* at 16.
56. *Id.* at 15.
57. *Id.*
58. *Id.* at 17–18.
59. *Id.* at 24.
60. *Id.* at 25–26.
61. *See* INITIAL SURVEY, *supra* note 3, at 7.

of states anticipate "that changes in groundwater regulation are likely." [62] Responses to some specific questions are reported in the following figures.

In the Second Survey, respondents from nineteen states indicate more than half of human needs for water in their state are met by groundwater.[63] However, this reliance on groundwater can be highly variable within a state, depending on location. More than half of state respondents identified places where groundwater withdrawals significantly exceed recharge.[64] Responses are provided in Table 1.

Table 1. Areas in States Where Groundwater Withdrawals Exceed Discharge[65]

States where groundwater withdrawals exceed recharge	State water professionals' descriptions of areas where groundwater withdrawals exceed recharge
Arizona	Varies – statewide
Arkansas	Mississippi River Alluvial Aquifer in East Arkansas and Sparta Aquifer in East and South Arkansas
California	Most of the Central Valley as well as many coastal basins
Colorado	High Plains/Ogallala Aquifer
Florida	Floridian aquifer. In most of the Florida Peninsula. Biscayne aquifer. In southeast Florida.
Idaho	Eastern Snake Plain Aquifer
Illinois	St. Peter Sandstone Northeastern Illinois
Iowa	Cambro-Ordovician in east central Iowa
Kansas	High Plains Aquifer
Massachusetts	Ipswich and Ten Mile Basins exceeded their identified basin safe yield. MA does not have specific aquifers defined as exceeding recharge volumes.
Minnesota	Twin Cities Basin, Prairie du Chien/Jordan aquifer
Mississippi	MS River Valley Alluvial Aquifer
Missouri	The Ozark Aquifer is in decline in small scale areas around some cities/towns and where there is high industrial usage in McDonald and Pettis counties.
Nebraska	Southwest, southeast
Nevada	Central Nevada, mining areas
New Mexico	Everywhere
New York	Genessee County
North Dakota	Fox Hills - Western ND
Oklahoma	"Almost all of them...by design"
Oregon	Eastern Oregon; Willamette Valley
South Carolina	Coastal areas

62. SECOND SURVEY, *supra* note 32, at 31, 35.
63. *Id.* at 4 fig.1.
64. *Id.* at 4.
65. Table 1 is reprinted by permission of the authors from *id.* at 5. tbl. 1.

South Dakota	Dakota aquifer in eastern SD. Historical overdraft but stabilized more or less today
Texas	Roughly the western half of the state
Utah	Most of the state except the far north (Cache Valley) continues to see declining water levels, some severe as in the SW part of the state.
Vermont	Individual residential developments, ski resorts
Virginia	Coastal Plain Aquifer System
Washington	Columbia River Basalts, Walla Walla Basin
Wyoming	High Plains aquifer in SE WY

Figure 2 shows the frequency with which state respondents listed particular groundwater concerns in their top three concerns within their states.[66] Only quality and quantity were listed as top three groundwater concerns in over half of the states.[67]

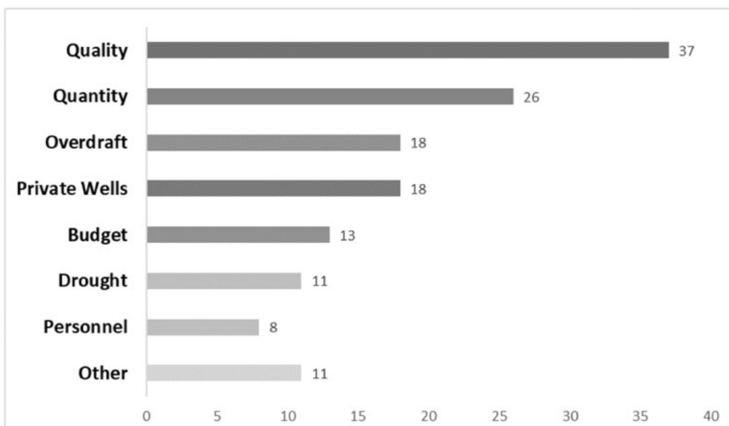

Figure 2. Frequency of Groundwater Concerns Listed in the Top Three by State Respondents[68]

Figure 3 then shows the frequency of groundwater contaminant sources ranked in the top three by state respondents.[69] Agriculture is listed by 30 state respondents in the top three sources of contamination.[70] The agricultural sector,

66. *Id.* at 8.
67. *Id.*
68. Figure 2 was adapted using information from *id.* fig.4.
69. *Id.* at 11.
70. *Id.*

through irrigation and livestock, uses the most groundwater.[71] The industrial/mining sector was also listed by 30 state water professionals.[72] Oil and gas exploration occurs in over half of the states (see discussion below).[73]

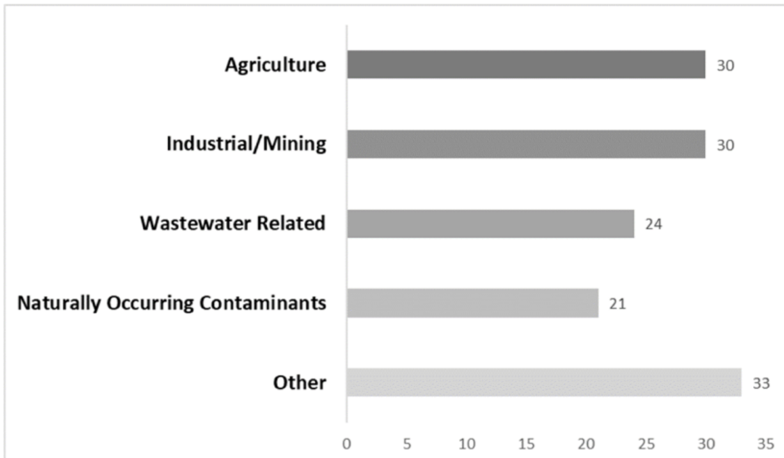

Figure 3. Frequency of Groundwater Contaminant Sources Listed In the Top Three by State Respondents[74]

As discussed, the decentralized nature of U.S. groundwater governance allows for different levels of government exercising groundwater governance authorities. For example, states may delegate groundwater management to substate jurisdictions.[75] Until 2014, California left groundwater quantity largely unregulated.[76] Moreover, at both the state and federal levels, many agencies address the nexus issues of energy, agriculture, food safety, and climate.[77] To address nexus issues, state water agencies, the focus of our surveys, will have to coordinate with other agencies and jurisdictions. Yet, significant barriers may exist in making this occur. The Initial Survey noted that of the state respondents participating, 71 percent "report[ed] that separate agencies deal with water quantity and water quality."[78] In the Second Survey, respondents also reported

71. *See* MOLLY A. MAUPIN ET AL., U.S. GEOLOGICAL SURVEY, ESTIMATED USE OF WATER IN THE UNITED STATES IN 2010, at 14 tbl.4A, 15 tbl.4B (2014), https://pubs.usgs.gov/circ/1405/pdf/circ1405.pdf [https://perma.cc/CVE7-T99A].

72. SECOND SURVEY, *supra* note 32, at 11.

73. *Id.*

74. Figure 3 was adapted using information from *id.* fig.7.

75. Megdal et al., *supra* note 10.

76. Michelle Nijhuis, *Amid Drought, New California Law Will Limit Groundwater Pumping for First Time*, NAT'L GEOGRAPHIC (Sept. 18, 2014), https://news.nationalgeographic.com/news/2014/09/140917-california-groundwater-law-drought-central-valley-environment-science/ [https://perma.cc/5LQG-5JHU].

77. *See, e.g.*, *Climate Impacts on Agriculture and Food Supply*, EPA, https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-agriculture-and-food-supply_.html [https://perma.cc/GFN3-MPVY].

78. INITIAL SURVEY, *supra* note 3, at 7.

that 57 percent of state "groundwater quantity and quality agencies have separate jurisdictions."[79] Another complication is that many issues involving groundwater, food, energy, and the climate transcend state boundaries, requiring coordination among multiple entities.[80] Fifty-seven percent of respondents indicate that there are "programs or settlements addressing international, interstate, or Native American groundwater issues in their states."[81]

Despite barriers to addressing nexus issues, coordination between groundwater quantity and groundwater quality agencies still occurs and "is the norm in most states."[82] However, there are four states where little coordination between quantity and quality agencies occurs.[83]

Nearly all organizations surveyed in the Second Survey (92 percent) "rely on local agencies to implement groundwater quality regulations to some extent," with 46 percent relying sometimes, 42 percent relying rarely, and 11 percent doing this always.[84] Similar findings noted, "92% of state agencies rely on federal agencies to some extent . . . ."[85] County agencies vary in the extent of their participation of groundwater management.[86] Results from the Second Survey indicate water professionals also coordinate through learning about emerging groundwater issues, including through professional meetings and conferences, government reports, and webpages.[87]

These national-scale state reconnaissance-level surveys demonstrates the diversity of groundwater issues related to agriculture and, to some extent, energy production. The surveys provide some indication of the issues the states are addressing—or have to address. They demonstrate how the decentralized nature of groundwater governance creates the need for multi-jurisdictional coordination for addressing nexus issues. However, because resource constraints limited the surveys to a single respondent from each state, it was not possible to ascertain viewpoints related to the effectiveness of state approaches and indications where improvements could be made. Also, the responses collected may reflect the disciplinary background or agency missions of agency officials responding to the survey. Considerable additional work needs to be done before ascertaining the extent to which current groundwater governance frameworks impact food and energy production and how responsive they are to climatic impacts. What can be concluded is that much of the impact will be determined by state, or possibly sub-state, jurisdictions rather than at the federal level.

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79. SECOND SURVEY, *supra* note 32, at 22.
80. *See id.* at 27.
81. INITIAL SURVEY, *supra* note 3, at 6.
82. SECOND SURVEY, *supra* note 32, at 23.
83. *Id.*
84. *Id.* at 27.
85. *Id.*
86. *See id.*
87. *Id.* at 29.

C. Findings from Case Study Analysis

Case studies of groundwater governance and management can provide useful insights. However, generalizations of management and governance practices can sometimes be difficult because the approaches can be highly dependent on the local context. As part of our overall groundwater governance efforts, a small grant funded a three-case-study analysis of illustrative, regional approaches in the U.S. Sun Belt.[88]

The case study looked at three sub-state regions that deployed innovative approaches to groundwater management within the framework of state-level authorizing legislation.[89] The regions were Orange County Water District (OCWD) in southern California, the Prescott Active Management Area (PrAMA) in north-central Arizona, and the Orlando region's Central Florida Water Initiative (CFWI) in central Florida.[90] While these regional collaborations have existed for differing amounts of time, all three have made noticeable progress.[91] All are dealing with growing populations and economies in the face of limited water resources.[92] Each area is approaching the need to meet future water supplies through a regional effort in unique ways. Groundwater comprises an important element of each of their respective overall water portfolios.

The case studies were selected based on the reliance on groundwater and emerging gaps between supply and demand.[93] That two of the three regions are home to Disney parks is coincidental, but perhaps indicative of the pressures on water supplies associated with large tourist destinations. All three regions see water reuse in their long-range portfolios, and all three are or have been home to significant agricultural activities.[94] The study found that innovations were also driven by both long-standing as well as more recent legislation.[95] In addition, litigation—or the threat of litigation—continues to drive regional actions.[96] Stakeholder engagement is likewise important, especially as management options become more expensive and complex.[97]

California is located within the southwestern United States.[98] Southern California's Orange County, situated between San Diego and Los Angeles, has a warm, semi-arid climate.[99] Its rapid population growth over the last seventy-five years has been largely dependent on water resources availability.[100] The OCWD, home to California's famed Disneyland Park, has had a long record of

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88. *See* Megdal et al., *supra* note 13, at 718.
89. *Id.*
90. *Id.*
91. *Id.* at 732.
92. *Id.*
93. *Id.* at 719.
94. *Id.* at 724, 726–27; CENT. FLA. WATER INITIATIVE, REGIONAL WATER SUPPLY PLAN, VOLUME 1, PLANNING DOCUMENT 117 (2015).
95. *See id.* at 730.
96. *Id.* at 730–32.
97. *Id.* at 731–32.
98. *Id.* at 721.
99. *Id.* at 722, 731 tbl.3.
100. *Id.* at 721–22.

success in managing the groundwater within its boundaries.[101] It has successfully implemented indirect potable reuse of effluent through recharge and recovery, thereby diversifying its water portfolio that previously consisted of fresh groundwater and imported surface water.[102] More recently, the District and municipal retailers were involved in the development of the Sustainable Groundwater Management Act (SGMA). California's 2014 SGMA[103] is evidence of the recognition that states can establish the framework for implementation at the sub-state level. The Act requires local or regional agencies to sustainably manage groundwater resources to avoid six undesirable results.[104] Authority is delegated to local or regional agencies to have the flexibility of deciding how to meet those requirements.[105] The agencies are self-organized by local public entities.[106] The state may step in if local efforts fall short; locally developed plans are required to get approval from the state Department of Water Resources.[107] Even with state-level oversight, this allows for the formation for much more locally-tailored institutions and plans, thereby potentially resulting in a wide variety of approaches within the state.

The OCWD's management structure is nearly fully compliant with the Act. Also, the "OCWD has already been designated an 'exclusive local agency' in the Act, and therefore does not have to formally become a [groundwater sustainability agency] or develop a [groundwater sustainability plan]."[108] The OCWD is therefore in a good position to meet the requirements of California's Sustainable Groundwater Management Act.[109]

In semi-arid north-central Arizona's PrAMA, cities and towns have been among the fastest growing communities in the state.[110] Because of previously existing groundwater overdraft in the area, the PrAMA is one of five designated geographic Active Management Areas in the state where groundwater use is regulated.[111] To achieve the PrAMA's goal of achieving safe-yield by 2025, its

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101. *Id.* at 730.

102. GREG WOODSIDE & MARSHA WESTROPP, ORANGE CTY. WATER DIST., GROUNDWATER MANAGEMENT PLAN 2015 UPDATE ES10 (2015), https://www.ocwd.com/media/3622/groundwatermanagementplan2015update_20150624.pdf [https://perma.cc/N4TK-LYT9].

103. S.B. 1319, 2013–14 Leg. Reg. Sess. (Cal. 2014).

104. NELL GREEN NYLEN ET AL., TRADING SUSTAINABLY: CRITICAL CONSIDERATIONS FOR LOCAL GROUNDWATER MARKETS UNDER THE SUSTAINABLE GROUNDWATER MANAGEMENT ACT, at ix (2017), https://scholarship.law.berkeley.edu/cgi/viewcontent.cgi?article=1040&context=cleepubs [https://perma.cc/37NJ-BJAD]. The six undesirable results are "(1) depletion of groundwater supply, indicated by chronic lowering of groundwater levels, (2) reduction of groundwater storage, (3) seawater intrusion, (4) degraded water quality, (5) land subsidence, and (6) adverse impacts on beneficial uses of interconnected surface water." *Id.*

105. *Id.*

106. CAL. WATER CODE § 10723(a) (2017) (Westlaw).

107. Kiparsky et al., *supra* note 13, at 3.

108. CHRISTINA BABBITT ET AL., ENVTL. DEF. FUND, THE FUTURE OF GROUNDWATER IN CALIFORNIA: LESSONS IN SUSTAINABLE MANAGEMENT FROM ACROSS THE WEST 53 (2018), https://www.edf.org/sites/default/files/groundwater-case-study.pdf [https://perma.cc/37WK-YS5S].

109. *See* Megdal et al., *supra* note 13, at 724.

110. *Id.* at 725.

111. *Id.* at 724.

management plan "includes water conservation programs for agricultural, municipal, and industrial users, augmentation plans to bolster water supply, and a water management assistance plan."[112] Municipalities expect to meet future water demands through realizing economies of scale by cooperatively building shared water transportation infrastructure.[113] The cities of Prescott and Prescott Valley also entered into a contract in 2004 to transport water from a neighboring sub-basin.[114] A key innovation for one of PrAMA's communities is the auction of recovered effluent to help meet the region's requirements for an assured water supply.[115]

Located in the southeastern United States, Florida, while quite humid, "is highly reliant on groundwater as a water source" for its growing population.[116] Central Florida's Floridian aquifer is divided between three water management districts (WMDs): St. John's River WMD, Southwest Florida WMD, and South Florida WMD.[117] By the mid-2000s, conflicts arose as regulations and permits issued by one district began to have adverse effects on another district's groundwater resources.[118] This, and the conclusion that there would be a significant gap between water supply and demand by 2035, led to "a voluntary effort to voluntarily manage water resources by harmonizing rules for granting water use permits and producing a common scientific and technical foundation."[119] The CFWI was formed to address the growing water needs of the Orlando, Florida region, home to Disneyworld and other destination resorts.[120] At its inception, its membership included local governments, agricultural interests, and commercial interests.[121] Without being statutorily mandated, the regional cooperation in developing the region's future water supply was based in part on the desire to avoid the type of litigation associated with competition across water using sectors and sub-regions of the growing metropolitan area.[122]

III. NEXUS IMPLICATIONS

While the surveys were not designed to focus on food, energy, and climate nexus issues, the surveys, along with the case studies revealed interconnections between groundwater and food, energy, and climate.[123] The interconnections are recognized to differing degrees by states in groundwater governance and management frameworks.[124] The linkages between water, food, energy, and climate

112. *Id.* at 726.
113. *Id.* at 727.
114. *Id.*
115. *Id.*
116. *Id.*
117. *Id.*
118. *Id.* at 727–28.
119. *Id.* at 728.
120. *See id.*
121. *Id.*
122. *Id.* at 731.
123. *See generally* INITIAL SURVEY, *supra* note 3; SECOND SURVEY, *supra* note 32.
124. *Id.*

have also been explored extensively within the literature.[125] This paper explores each issue in turn.

A. Groundwater and Food

Groundwater and food are inextricably linked, as the agricultural sector is easily the largest user of groundwater.[126] This linkage is manifested through water availability and productivity,[127] "virtual water,"[128] improving water efficiencies through reducing residual soil moisture or shifting to "low water consuming crops,"[129] and recharging aquifers for agriculture production.[130] Figure 4, included below, combines information on states where more than 30 percent of human needs are met by groundwater (USGS, 2010) and reported declining aquifer levels (data from the Initial Survey).[131] There is a clear geographic pattern to the thirteen states that could be considered under groundwater stress. Nearly all the states with these characteristics are located in the southern and western United States.[132] Several of these states host large agricultural sectors, including High Plains states using the Ogallala Aquifer.[133]

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125. *See generally, e.g.*, HOLGER HOFF, STOCKHOLM ENV'T INST., UNDERSTANDING THE NEXUS: BACKGROUND PAPER FOR THE BONN2011 NEXUS CONFERENCE (2011), https://www.sei.org/mediamanager/documents/Publications/SEI-Paper-Hoff-UnderstandingTheNexus-2011.pdf [https://perma.cc/M44H-CCYY]; *see also* Robert W. Adler & Michele Straube, *Watersheds and the Integration of U.S. Water Law and Policy: Bridging the Great Divides*, 25 WM. & MARY ENVTL. L. & POL'Y REV. 1 (2000); Morgan Bazilian et al., *Considering the Energy, Water and Food Nexus: Towards an Integrated Modelling Approach*, 39 ENERGY POL'Y 7896 (2011); Eloise M. Biggs et al., *Sustainable Development and the Water-Energy-Food Nexus: A Perspective on Livelihoods*, 54 ENVTL. SCI. & POL'Y 389 (2015); Aiko Endo et al., *A Review of the Current State of Research on the Water, Energy, and Food Nexus*, 11 J. HYDROLOGY: REGIONAL STUD. 20 (2017); Claudia Ringler et al., *The Nexus Across Water, Energy, Land and Food (WELF): Potential for Improved Resource Use Efficiency?*, 5 CURRENT OPINION ENVTL. SUSTAINABILITY 617 (2013); Dennis Wichelns, *The Water-Energy-Food Nexus: Is the Increasing Attention Warranted, From Either a Research or Policy Perspective?*, 69 ENVTL. SCI. & POL'Y 113 (2017).

126. ERIC KEMP-BENEDICT ET AL., ASSESSING WATER-RELATED POVERTY USING THE SUSTAINABLE LIVELIHOODS FRAMEWORK 2 (Stockholm Env't Inst., Working Paper, 2009), http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.319.8847&rep=rep1&type=pdf [https://perma.cc/LYY7-WE2W].

127. *Id.*

128. J.A. (Tony) Allan, *Virtual Water—the Water, Food, and Trade Nexus: Useful Concept or Misleading Metaphor?*, 28 WATER INT'L 4, 6 (2003).

129. M. Dinesh Kumar et al., *The Food Security Challenge of the Food-Land-Water Nexus in India*, 4 FOOD SECURITY 539, 553 (2012).

130. *See Water Capture System in Koraro, Ethiopia*, COLUMBIA WATER CTR., http://water.columbia.edu/research-themes/water-food-energy-nexus/water-capture-system-in-koraro-ethiopia/ [https://perma.cc/S768-NWLA].

131. *See* Megdal et al., *supra* note 10, at 490 fig.24.3.

132. *Id.*

133. *Id.* at 489 fig.24.2, 490 fig.24.3; Brad Plumer, *How Long Before the Great Plains Runs Out of Water?*, WASH. POST (Sept. 12, 2013), https://www.washingtonpost.com/news/wonk/wp/2013/09/12/how-long-before-the-midwest-runs-out-of-water/?noredirect=on&utm_term=.910fa20cf3af [https://perma.cc/4MMW-V4JC].

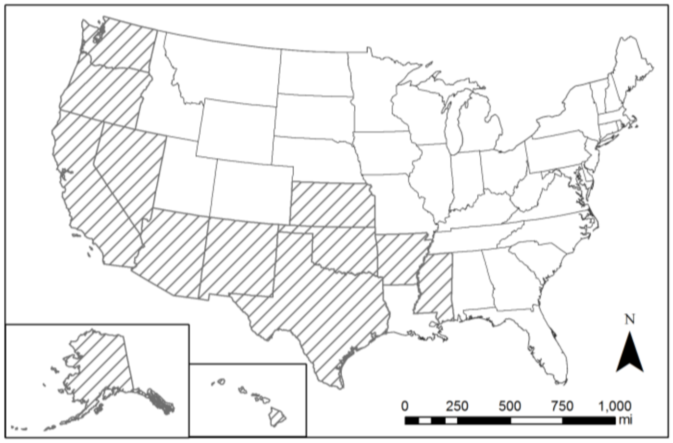

Figure 4. States Where More than 30 percent of Human Needs Are Met by Declining Groundwater and Reported Declining Aquifer Levels, Shaded in Diagonal Lines[134]

Shifts in water uses in some states have driven increased use of groundwater, as reported in the Initial Survey.[135] Agriculture was reported to be a notable contributor to groundwater contamination.[136] According to the Second Survey, almost all states (40) reported nitrates or nutrients, eleven states reported pesticides as a contaminant of concern in their state, and thirty-seven states reported agricultural sites as a source of groundwater contamination.[137] In addition, seventeen states reported concentrated animal feeding operations as a contamination source.[138]

As agriculture is the largest consumptive sector of groundwater use, it has directly and indirectly been responsible for regional innovations as revealed by the case study analysis. Agricultural water users, through water consumption, their preservation of their water rights, and participation in water planning efforts, have helped to drive innovations in water conservation and augmentation.[139] In Orange County, California, agricultural users continued to use groundwater that may have eventually reached municipal water supply areas to protect their groundwater right allotments from being curtailed, despite the establishment of the OCWD in 1933 and the introduction of Colorado River water to the supply portfolio in 1949.[140] This led to the OCWD "using advanced wastewater reclamation in 1975 to protect against seawater intrusion into fresh

134. Figure 4 was adapted using information from INITIAL SURVEY, *supra* note 3, at 3 fig.1.

135. *See id.* app. B, https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/pdfs/GroundwaterGovernanceReport-FINALAppendixB.pdf [https://perma.cc/8CUY-PB8P] (App. B posted online separately).

136. SECOND SURVEY, *supra* note 32, at 8.

137. *Id.* at 9 fig.5, 12 fig.8.

138. *Id.* at 9 fig.5.

139. *See* BABBITT ET AL., *supra* note 108, at 7–8.

140. *See* Megdal et al., *supra* note 13, at 724.

groundwater drinking supplies."[141] The OCWD also enacted unique funding mechanisms to purchase supplemental water for the groundwater basin, operate and maintain water production, and purchase water rights and spreading facilities.[142] Agricultural interests were also identified as regulated groundwater users required to participate in the PrAMA and the CFWI.[143] Agricultural users in the PrAMA have participated in water "conservation programs . . . , augmentation plans to bolster water supply, and a water management assistance plan."[144] The Arizona Department of Water Resources has the authority to limit agricultural groundwater pumping in the PrAMA.[145] In the CFWI, agricultural users coordinated with government entities, utilities, and industry to craft a regional water supply plan.[146]

B. Groundwater and Energy

Energy and groundwater are inextricably linked, including through energy needed to pump groundwater,[147] the use of groundwater for extracting natural resources,[148] and biofuel production.[149] The linkages have grown stronger in recent years; particularly as hydraulic fracturing has increased.[150] For instance, increased oil-field industrial use for hydraulic fracturing in North Dakota was reported in the Initial Survey as a driver of increased use and reliance on groundwater.[151] Energy has also been reported by state water professionals as sources of contamination.[152] In the Second Survey, twelve states reported oil/gas exploration and production, nine states reported oil/gas wastewater disposal, eight states reported coal ash impoundments/disposal, and six states reported injection wells (other than Class II) as sources of contamination.[153] Fifteen states also selected contaminants associated with oil and gas as a contaminant of concern.[154] States also predict that the energy sector will require attention with its connections to groundwater.[155] Eighteen states cited oil and gas exploration and production, and fifteen states cited resource development as likely issues requiring

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141. *Id.*
142. WOODSIDE & WESTROPP, *supra* note 102, at 11-1–11-4.
143. *See* Megdal et al., *supra* note 13, at 721.
144. *Id.* at 726.
145. *See id.* at 724–26.
146. *Id.* at 728.
147. Laurent Hardy et al., *Evaluation of Spain's Water-Energy Nexus*, 28 INT'L J. WATER RESOURCES DEV. 151, 152 (2012).
148. R.E. Jackson et al., *Groundwater Protection and Unconventional Gas Extraction: The Critical Need for Field-Based Hydrogeological Research*, 51 GROUNDWATER 488, 489 (2013).
149. J.S. Bergtold et al., *Water Scarcity and Conservation Along the Biofuel Supply Chain in the United States: From Farm to Refinery, in* COMPETITION FOR WATER RESOURCES: EXPERIENCES AND MANAGEMENT APPROACHES IN THE US AND EUROPE 124, 124–25 (Jeffrey M. Peterson & Jadwiga R. Ziolkowska eds., 2017).
150. Jackson et al., *supra* note 148.
151. Megdal et al., *supra* note 6, at 680.
152. *See id.*
153. SECOND SURVEY, *supra* note 32, at 9 fig.5.
154. *Id.* at 12 fig.8.
155. *Id.* at 31.

attention in the next ten years.[156] Along those lines, some state water professionals also predicted that issues involving energy would be likely addressed through groundwater regulations and policies in the next five years.[157] Water professionals in eight states predicted pumping regulations/policies, six predicted injection regulations/policies, and five predicted oil and gas exploration and production regulations/policies.[158]

Figure 5 shows the status of oil and gas exploration in U.S. states. As the figure indicates, oil and gas exploration are occurring in twenty-six states, and the exploration is regulated in every state where it is occurring.

Figure 5. Status of Oil and Gas Exploration in the United States. Diagonal lines indicate where exploration is occurring and regulated, dark gray indicates where it is not occurring because there is no potential, and light gray indicates where it is not occurring for other reasons.[159]

Energy is also undoubtedly significant in transporting groundwater, particularly through pumping. As groundwater levels decline, energy costs increase to pump water from greater depths and treat water that is often of lower quality.[160]

C. Groundwater and Climate

Groundwater is often turned to as a source of water when surface water is not readily available or scarce, such as in the cases of drought, or when hydrologic conditions become more variable.[161] Groundwater use is projected to increase in the context of rising temperatures and variable, decreasing precipita-

156. *Id.* at 31 fig.22.
157. *Id.* at 36 fig.26.
158. *Id.*
159. Figure 5 was adapted using information from *id.* at 17 fig.13.
160. *Groundwater Depletion*, USGS, https://water.usgs.gov/edu/gwdepletion.html [https://perma.cc/MT57-PK2D].
161. Megdal et al., *supra* note 6, at 678.

tion in certain locations.[162] In the Initial Survey, for example, "[t]he respondent from Colorado noted that 'changing hydrologic conditions, changes to river call conditions, and other factors have led to tighter administration and inclusion of other nontraditional uses in administration [of groundwater].'"[163]

The connections between surface water and groundwater can also affect ecosystems.[164] However, only 51 percent of state respondents indicate that their states have laws explicitly recognizing or addressing "the connection between surface water and groundwater."[165] In the Initial Survey, half of respondents (25 of 51) reported that laws in their state consider the needs of groundwater-dependent ecosystems, with respondents from Montana and Nebraska reporting "indirect environmental protection through in-stream flow provisions."[166] Oftentimes environmental needs are neglected in state groundwater laws.

The survey and case study represent illustrative investigations into groundwater governance and management in the United States, yet much remains to be uncovered. The surveys reveal that many states have similar priorities and tools for managing and governing groundwater, yet have varying challenges, policies, and resources available to them.[167] The case studies reveal local complexities related to groundwater governance and demonstrate how stakeholder engagement and litigation (or the threat thereof) can act as drivers of innovation and policy-making.[168] Limited study scopes, due in part to funding availability, meant that the research team could not get into the depth of analysis necessary to assess the efficacy of alternative governance regimes. Such assessment would require large-scale and longer-term investigations.

The results show the decentralized nature of U.S. groundwater governance. This decentralization and division of state responsibilities by water quantity and water quality result in piecemeal consideration of water-food-energy-climate nexus issues.

Based on this analysis, we can offer some insights for approaches that can address issues spanning the water-food-energy-climate nexus. Cross-jurisdictional collaboration is one such approach. The findings highlight the need for states to collaborate with sub-state, federal, and neighboring jurisdictions on groundwater challenges relating to food, energy and climate, particularly in areas where these groundwater problems are more regional or transboundary in nature.

Another approach states may wish to consider is the consideration of conjunctive water linkages in future policies. Though groundwater is very often

162. Christopher A. Scott, *The Water-Energy-Climate Nexus: Resources and Policy Outlook for Aquifers in Mexico*, 47 WATER RESOURCES RES., Dec. 10, 2011, at 1, 16.
163. Megdal et al., *supra* note 6, at 680.
164. *Id.* at 682.
165. INITIAL SURVEY, *supra* note 3, at 7.
166. Megdal et al., *supra* note 6, at 679–80.
167. *See generally* INITIAL SURVEY, *supra* note 3; *see also* SECOND SURVEY, *supra* note 32.
168. Megdal et al., *supra* note 13, at 732.

linked with surface water, many states do not manage or govern groundwater in a conjunctive manner.[169] This may lead to future unintended environmental consequences for riparian ecosystems, particularly as the climate continues to increase in variability, as groundwater may be used more intensely to mitigate for deficits in surface water supplies. Addressing such issues such as groundwater-surface water connectivity, enforcement of regulations, and monitoring, they will be better positioned to address nexus challenges. Examining these challenges within the framework of the water-food-energy-climate nexus is simply a newer way of addressing issues that have been previously recognized.

Future work could investigate linkages between food, energy, and climate governance and their linkages with groundwater in more depth, thereby decreasing the invisibility of groundwater's links to food, energy, and climate.

169. Megdal et al., *supra* note 10.