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Irrigation Organizations:
Groundwater Management

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Abstract

Groundwater resources are vital for U.S. and global irrigated agricultural production. In the United States, groundwater supplies water to approximately 65 percent of all irrigated acreage. The connectivity among irrigators pumping from the same aquifer—paired with growing concerns about groundwater depletion—led to the creation of many of the groundwater organizations currently active in the United States. Groundwater organizations perform a variety of functions to promote groundwater resource stewardship and address groundwater overdraft and quality concerns that impact groundwater irrigators and other nonagricultural users (i.e., residential and municipal groundwater users). The operations of groundwater organizations are shaped by State-level groundwater law, organization governance, and the other irrigation-related activities performed by the organization (such as delivering water directly to farms and ranches). This report leverages data from the USDA's 2019 Survey of Irrigation Organizations to characterize the unique institutions that steward much of the Nation's groundwater resources.

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Summary

The shared nature of many groundwater resources means that pumping by one irrigator affects water availability for nearby irrigators. The connectivity among irrigators pumping from the same aquifer—paired with growing concerns about groundwater depletion—led to the creation of many of the groundwater organizations currently active in the United States. These organizations, established to manage shared groundwater resources, play a critical role in determining the future of groundwater-fed irrigated agriculture. Despite their importance, limited information exists about these institutions stewarding the Nation's aquifers.

This is the third report in a series of economic briefs on key topics related to irrigation organizations using data collected in the U.S. Department of Agriculture's 2019 Survey of Irrigation Organizations (SIO). This report summarizes information from the SIO about organizations that influence on-farm groundwater use. These organizations include groundwater districts, as well as some water delivery organizations that also directly influence on-farm groundwater use. Water delivery organizations include irrigation districts, ditch companies, acequias (communal irrigation ditches), and similar entities that manage the infrastructure required to transport irrigation water. Some of these organizations operate under the auspices of State agencies of natural resources, while others are not associated with State or local governments. This report addresses the knowledge gap about the organizations by asking several questions:

- How much of regional groundwater-fed irrigated agriculture is under the purview of a groundwater organization?
- Where do groundwater organizations exist, and what management functions do these organizations perform?
- What groundwater overdraft and quality concerns influence groundwater organizations' management decisions?
- How are groundwater organizations governed, and what sources of information do the organizations rely on for long-term planning?

Key findings from this report include:

- In some regions, such as the U.S. High Plains, nearly all groundwater-fed irrigated acreage occurs within the service area of a groundwater organization. In other regions, such as the Southeast, a relatively small share of the groundwater-fed irrigated acreage is under the purview of a groundwater organization.
- Groundwater organizations that do not deliver water to farms serve a larger number of irrigation wells and more groundwater-fed acreage than organizations that both influence on-farm groundwater use and deliver water to farms.
- The most common management functions of groundwater organizations are monitoring groundwater conditions, collecting pumping data, charging pumping or water rights fees, and permitting well development.
- Declining well capacity and diminishing water quality are the most commonly cited groundwater overdraft concerns among groundwater organizations. Organizations report that the specific contaminants impairing groundwater quality are nitrates, salinity, other nutrients, and heavy metals.
- The majority of groundwater organizations are governed by an elected board. A smaller proportion of organizations allow their constituents to vote directly on key management decisions.
- Groundwater organizations report that the most important sources of information for long-term planning decisions are groundwater monitoring data, output from groundwater models, long-term weather forecasts, and reservoir storage reports.

Three USDA agencies collaborated in the development and implementation of the 2019 SIO—the Economic Research Service (ERS), Office of the Chief Economist (OCE), and National Agricultural Statistics Service (NASS). The 2019 SIO provides a nationally representative overview of the local water management entities that deliver irrigation water directly to farms or regulate or otherwise influence on-farm groundwater use.

Introduction

Groundwater organizations play a critical role in ensuring the availability of aquifer resources to support current and future irrigated agricultural production. This report focuses on the institutions of groundwater-fed irrigated agriculture in the United States. However, the principles and issues discussed here are global, as international trade in agricultural commodities in some cases involves transfers of virtual water[1]—which has implications for the future of local, regional, national, and international groundwater resources (Dalin et al., 2019).

Water resources are vital for U.S. and global agricultural production. U.S. farms with irrigated acreage accounted for 54 percent of the total market value of crops sold in 2017 (USDA, NASS, 2019a). Groundwater water supplies are an important source of water for the irrigated agricultural sector; in 2018, approximately 65 percent of all irrigated acreage relied on groundwater as a primary or secondary source of water (USDA, NASS, 2019b).[2] [3] Nearly half (49 percent) of all irrigated acreage in the United States in 2018 depended on groundwater as the only source of irrigation water. Much of the groundwater-irrigated agriculture in the Nation is under the purview of groundwater organizations that manage shared groundwater resources and influence on-farm groundwater use (See box, "What Are Groundwater Organizations?").[4] [5] This report leverages data collected in USDA's 2019 Survey of Irrigation Organizations (SIO) to highlight the functions, resource concerns, and operations of the important institutions managing the Nation's groundwater resources (see box, "2019 Survey of Irrigation Organizations" for more information on the survey).

Groundwater-irrigated agriculture occurs throughout the United States, and in some locations, groundwater is the only source of water for supporting irrigated production. Figure 1 details the geography of groundwater irrigation by mapping the spatial distribution of groundwater withdrawals for irrigation purposes using data reported by the U.S. Department of the Interior's U.S. Geological Survey (DOI-USGS) (Dieter, 2018). The most intensive groundwater withdrawals for irrigation occur in the Mississippi Delta, Central Plains, and the Central Valley of California. The geography of agricultural groundwater use aligns with the locations of the Nation's principal aquifers, which include: the High Plains (Ogallala) aquifer of the central United States, the

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[1] 'Virtual water' or 'virtual water trade' refers to transport of water inherent in international trade of water intensive commodities (Oki et al., 2017). For example, the groundwater used to irrigate corn that is then marketed internationally would constitute a trade in virtual water.

[2] Irrigated acreage totals refer to cropland acreage irrigated 'in the open'—i.e., acreage that is not irrigated under the cover or protection of greenhouses, hoop houses, or other structures in which crops are grown. In 2018, acreage irrigated (under the protection of such structures) accounted for approximately 0.09 percent of all irrigated acreage in the United States (USDA, NASS, 2019b). Cropland irrigated acreage that relies on groundwater as a primary source of water refers to acres where other sources of irrigation water (e.g., surface water) do not exist or are not utilized for irrigation. Acres where groundwater is a secondary source of water refers to acreage irrigated using a combination of both surface and groundwater.

[3] The irrigated agricultural sector's reliance on groundwater resources has increased over time. In 1984, only 53 percent of irrigated acreage in the United States relied on groundwater as a primary or secondary source of irrigation water (USDA, NASS, 1984).

[4] Groundwater organizations may also manage how other non-agricultural sectors, such as industrial or municipal, use groundwater resources. However, the focus of this report is the groundwater management activities directed at the irrigated agricultural sector.

[5] The report refers to organizations that influence on-farm groundwater use as groundwater organizations. For this report, influencing on-farm groundwater use is limited to the following activities: monitoring and reporting groundwater conditions, collecting pumping data, charging pumping and/or water rights fees, permitting new well development, managing groundwater recharge, and managing groundwater quality. An organization that reports any of those activities is considered to influence on-farm groundwater use and is classified as a groundwater organization. This is a somewhat narrow definition of 'influencing on-farm groundwater use', as some surface water delivery organizations that do not engage in any of the aforementioned groundwater activities may partially determine on-farm groundwater use as relatively less expensive surface water deliveries may displace on-farm groundwater pumping. Additionally, inter-annual or inter-seasonal variability in surface water deliveries may also determine on-farm groundwater use decisions.

Mississippi River Valley alluvial aquifer of the southeastern United States, the Central Valley aquifer system of California, and the Snake River Plain basaltic-rock aquifers of southern Idaho (Lovelace et al., 2020).[6]

Figure 1 demonstrates that groundwater-fed irrigated agriculture also occurs outside the boundaries of principal aquifers where irrigated producers rely on smaller local sources of groundwater (e.g., Willamette Lowland basin-fill aquifer of Oregon, the Floridian aquifer system of Florida, Georgia, Mississippi, and South Carolina—and the San Luis Valley aquifer of southern Colorado). This report focuses on the institutions of groundwater-fed irrigated agriculture in the United States. However, the principles and issues discussed are global as international trade in agricultural commodities, in some cases, constitutes transfers of virtual water, which have implications for the future of local, regional, national, and international groundwater resources (Dalin et al., 2019).

Groundwater-fed irrigated agriculture has existed in the United States since well before the 20th century, though it was relatively uncommon and was concentrated in areas with shallow aquifers (Webb, 1959). The prevalence of groundwater irrigation began to increase during the mid-twentieth century, following technological advances in groundwater pumps and irrigation technology (i.e., center pivot irrigation systems) that enabled larger-scale irrigation from deeper aquifers (Edwards and Smith, 2018). The increase in groundwater-fed irrigated agriculture altered the path of economic development for many U.S. regions, facilitating high-value agricultural production where it was otherwise impossible due to arid climates and limited surface-water supplies (Hornbeck and Keskin, 2014; 2015).

The increased reliance on groundwater to support irrigated agricultural production has led to a growing concern for the future availability of groundwater resources. Rates of groundwater pumping in excess of recharge have led to groundwater depletion in several of the Nation's most economically important aquifers, including the High Plains and Central Valley aquifers (Scanlon et al., 2012; Haacker et al., 2016; Suárez et al., 2018) (see the "Glossary of Groundwater Terms" text box for more information on groundwater depletion). Persistent rates of groundwater extraction in excess of recharge can, in some cases, lead to the end of an area's economically viable groundwater-fed irrigated agriculture. For example, Haacker et al. (2016) estimated that there will be an end to groundwater-fed irrigation in some southern regions of the High Plains aquifer by 2050 due to limited groundwater recharge.

[6] An alluvial aquifer is a water-bearing deposit of unconsolidated material (i.e. sand and gravel) left behind by a river or other flowing water (Gilliom et al., 1995). Basin-fill aquifers consist of sand and gravel deposits filling depressions formed by faulting or erosion. Basin-fill aquifers are sometimes referred to as valley-fill aquifers, as the aquifers generally occur within basins in topographic valleys (Thiros et al., 2014). Basaltic-rock aquifers are formed by volcanic activity on the earth's surface and generally have a higher degree of permeability and productivity than other aquifers.

What Are Groundwater Organizations?

Groundwater organizations are local institutions formed to manage common groundwater resources (e.g., groundwater management districts, natural resource districts, and groundwater sustainability agencies). Groundwater organizations are generally formed under the auspices of State legislation, which outlines the State's statutory and regulatory authorities of the organizations. For example, Kansas's Groundwater Management District Act of 1972 established a framework for managing the State's groundwater resources through the creation of five Groundwater Management Districts, with the power to tax and draft regulations for water use within their district.

The USDA's 2019 Survey of Irrigation Organizations (SIO) collected data representing 735 groundwater organizations throughout the United States. There is no standard definition in the literature describing a groundwater organization; lacking a definition, this report classified groundwater organizations based on the reported primary activities of the organization. Specifically, any organization that undertook any of the following groundwater management activities was classified as a groundwater organization:

- Monitoring and reporting groundwater conditions
- Collecting pumping data
- Charging pumping and/or water rights fees
- Issuing permits for new well development
- Managing groundwater recharge
- Managing groundwater quality

Some organizations that deliver water to irrigated farms and ranches (e.g., irrigation districts, ditch companies, acequias, etc.) also engage in one or more of the previously mentioned groundwater management activities. While these organizations may be structurally different, the organizations are included as groundwater organizations, even though managing groundwater may only constitute a relatively small share of the organization's total activities. Of the 735 groundwater organizations represented by the SIO data, 601 organizations both delivered water to farms and influenced on-farm groundwater use. These organizations are classified as **groundwater and delivery** organizations. The remaining 134 groundwater organizations did not deliver any water to farms and ranches and only engaged in activities influencing on-farm groundwater use. These organizations are classified as **groundwater only** organizations. Among groundwater and delivery organizations, groundwater pumping by wells owned by the organization account for a relatively small percentage (approximately 3 percent) of the total water brought into organization's conveyance and storage system.

USDA 2019 Survey of Irrigation Organizations

The USDA's 2019 Survey of Irrigation Organizations (SIO) collected data on irrigation organizations in 24 States[1] within the Western, Southeastern, and Mississippi Delta regions of the United States, where these organizations are most common. The SIO was a collaboration between the U.S. Department of Agriculture's Economic Research Service, National Agricultural Statistics Service (NASS), and the Office of the Chief Economist. The SIO was funded through a congressional budget initiative aiming to expand research and data on agricultural drought resilience.

The SIO defined an irrigation organization as an entity that either delivers water to farms and ranches or influences on-farm groundwater use. Irrigation organizations are structured differently across the United States according to State water law and regional water resource development history. Examples of irrigation organizations that deliver water include irrigation districts, canal/ditch companies, acequias (communal irrigation ditches, see Hutchins (1928) for more information), and irrigation mutuals. Organizations that can influence on-farm groundwater use include groundwater management districts, natural resource districts, and groundwater sustainability agencies. Some irrigation organizations engage in both on-farm groundwater management and water delivery. The SIO determined that there were 2,677 irrigation organizations in the United States in 2019. Among these organizations, 2,543 delivered water to farms and ranches, 735 influenced on-farm groundwater use, and 601 engaged in both water delivery and groundwater management. The response rate for the SIO was 44 percent.

The 2019 SIO was the first nationally representative Federal data collection effort aimed at irrigation organizations since the U.S. Department of Commerce, Bureau of the Census conducted the 1978 Census of Irrigation Organizations (CIO). The 1978 CIO did not collect information on organizations that solely influence on-farm groundwater use, as these types of organizations largely did not exist in 1978. Additionally, the 1978 CIO collected information on "pass-through" entities, which are organizations that store and deliver water to irrigation organizations but do not deliver water directly to farms and ranches. The 2019 SIO did not collect information on "pass-through" organizations. For a summary of selected survey findings and additional information on survey design, see USDA, NASS Irrigation Organizations publication (USDA, NASS, 2020).

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[1] California, Colorado, Montana, Wyoming, Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, Texas, Idaho, Oregon, Washington, Nevada, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Arizona, New Mexico, and Utah.

Glossary of Groundwater Terms

An **aquifer** is a geologic formation or structure that stores and/or transmits water. Aquifers can be either confined or unconfined. **Confined aquifers** have impermeable layers both above and below the aquifer and often store water under pressure. **Unconfined aquifers** do not have an impermeable layer between the aquifer and the land surface (Baldwin and McGuinness, 1963).

Aquifer recharge refers to the natural or manmade processes that convey water to an aquifer (Hanak et al., 2018). **Natural aquifer recharge** is the recharge that occurs due to seepage from precipitation and infiltration from local bodies of water above the surface. The natural recharge rate of an aquifer may be supplemented using the techniques of **managed aquifer recharge,** which aims to store excess surface water flows in aquifers. Managed aquifer recharge can involve infrastructure, such as recharge basins and injection wells to recharge aquifers, or may simply use existing irrigation systems to apply excess surface water to fallow fields. Natural recharge into confined aquifers generally occurs slowly. In some cases, seepage from the surface can take more than 1,500 years to infiltrate the confined aquifer (Herrera et al., 2021)

Groundwater depletion, or groundwater overdraft, refers to the decreased availability of groundwater resources over time due to over-extraction of aquifer water resources. If the rate at which water is pumped from an aquifer exceeds the recharge rate (both natural and managed), then the amount of groundwater available for irrigation and other purposes will diminish over time. In severe cases, groundwater depletion can result in a loss of access to groundwater resources.

Land subsidence refers to the settling or sinking of the Earth's surface due to the subsurface movement in soils and other geologic materials. The majority of land subsidence in the United States is a result of the pumping of groundwater resources (Galloway et al., 1999).

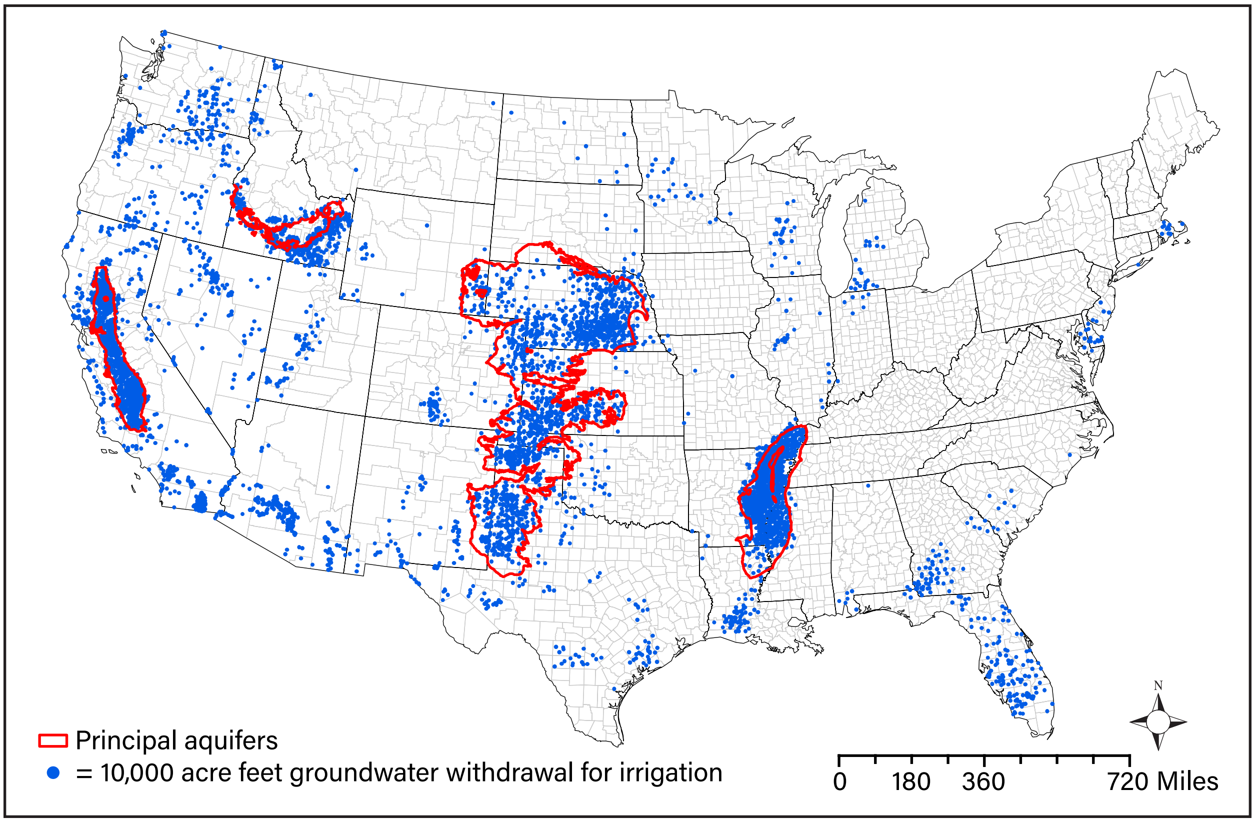
Saturated thickness measures the vertical distance between the confining bottom layer of an aquifer and the water table (McGuire et al., 2012). Declines in the saturated thickness of an aquifer over time generally indicate current rates of extraction exceed recharge, leading to aquifer depletion.

Surface-groundwater interactions refers to connectivity and exchange between aquifers and nearby rivers and streams (Zipper et al., 2022). In these connected aquifer-surface water systems, groundwater depletion can diminish streamflow when an aquifer's water table lies below a nearby river or stream, as some of the streamflow is lost to infiltration into the aquifer (Jasechko et al., 2021).

The **water table** is the top of the zone of saturation for a given aquifer. The zone of saturation refers to regions where geologic materials and structures are saturated with water (Baldwin and McGuinness, 1963).

Well capacity is a well's flow or pumping rate, which is determined by the pump motor and hydrologic conditions. Well capacity, or well yield, places an upper limit on the rate at which water may be pumped out of an aquifer and applied for irrigation purposes (Foster et al., 2014).

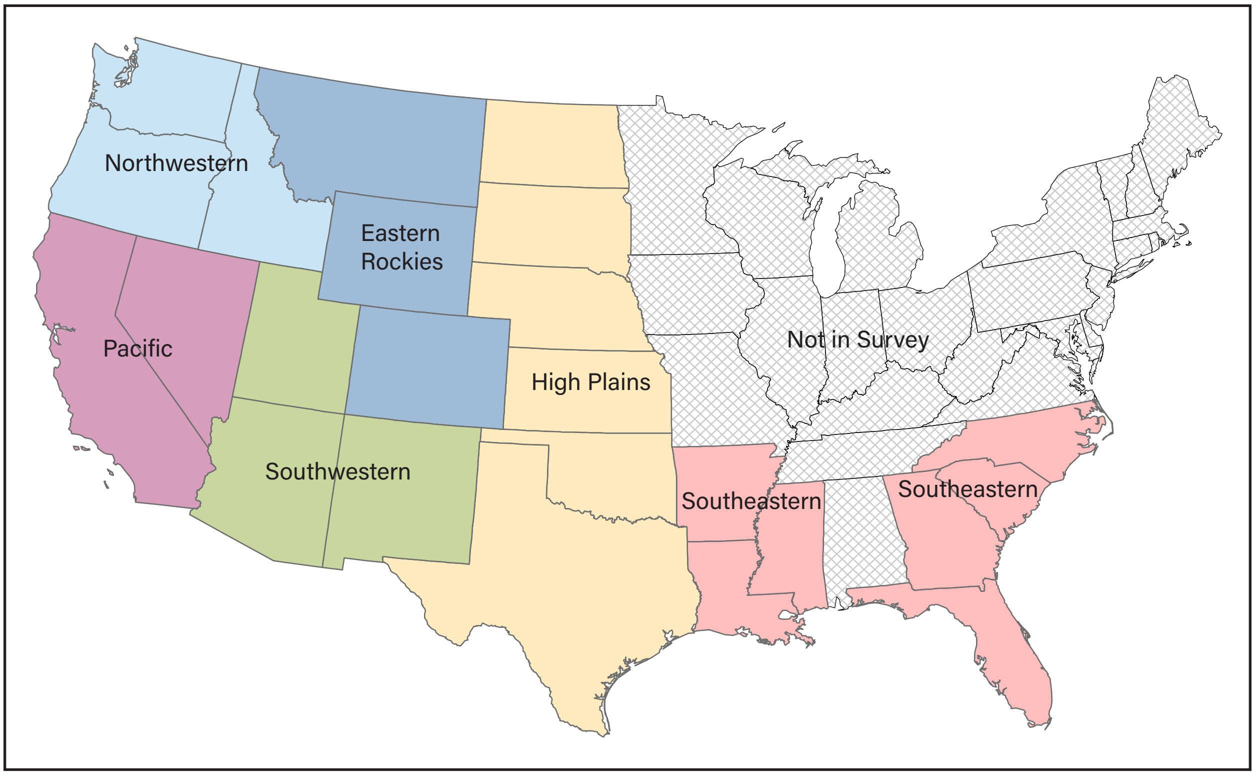
Figure 1
Geography of groundwater-fed irrigated agriculture



Note: The U.S. Geological Survey defines groundwater withdrawals for irrigation as the amount of water removed from a groundwater source and applied as irrigation (Dieter et al., 2018). Each dot corresponds to 10,000 acre-feet of groundwater pumping for irrigation purposes. The location of dots within a county with more than 10,000 acre-feet of pumping for irrigation is randomly placed within the portions of the county used for agricultural purposes. However, the location of a given dot does not necessarily represent groundwater-fed irrigated agriculture within the county, as some parts of a given county may rely on other water sources or use dryland production systems. Red lines present the boundaries for four of the five principal aquifers supporting groundwater-fed irrigated agriculture, as defined by Lovelace et al. (2020). These aquifers, listed in order of their ranking in terms of total groundwater withdrawals for irrigation, include: (1st) the Mississippi River Valley Alluvial Aquifer of the southeastern United States, (2nd) the High Plains (Ogallala) Aquifer of the central United States, (3rd) the Central Valley Aquifer System of California, and (5th) the Snake River Plain Basaltic-rock Aquifers of southern Idaho. Figure 1 does not map the extent of the Basin and Range basin-fill aquifers of the Southwest, which are the fourth-most-important aquifers in the United States, based on withdrawals for irrigation. The disjointed geography of the Basin and Range basin-fill aquifers precludes mapping their extent at a national scale.

Source: USDA, Economic Research Service using county-level water withdrawal data reported by the U.S. Geological Survey in *Estimated Use of Water in the United States in 2015* (Dieter et al., 2018); USDA, Economic Research Service using geospatial data on principal aquifer locations reported by the U.S. Geological Survey in *Estimated Groundwater Withdrawals from Principal Aquifers in the United States, 2015* (Lovelace et al., 2020).

Figure 2
Reporting regions—2019 Survey of Irrigation Organizations



Note: Alaska and Hawaii were not included in the 2019 Survey of Irrigation Organizations (SIO). USDA, NASS' SIO regions are as follows: Eastern Rockies (Colorado, Montana, and Wyoming), High Plains (Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas), Northwestern (Idaho, Oregon, and Washington), Pacific (California and Nevada), Southeastern (Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, and South Carolina), and Southwestern (Arizona, New Mexico, and Utah). All remaining States were not part of the SIO, as organizations that deliver water to farms or influence on-farm groundwater use are rare or nonexistent in these States.

Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service (NASS) Irrigation Organizations publication (USDA, NASS, 2020).

Much of the management of groundwater use falls on groundwater organizations—which are local entities that influence on-farm groundwater use through statutory, regulatory, or other powers generally granted by a State or local government. These organizations also often serve as an interface between local groundwater irrigators and State agencies of natural/water resources, disseminating information to local groundwater stakeholders and communicating local groundwater availability concerns to relevant agencies. Figure 3 demonstrates the regional prevalence of groundwater organizations by comparing the total regional groundwater-fed irrigated acreage (as reported by the USDA's 2018 Irrigation and Water Management Survey (IWMS) with the amount of groundwater-fed acreage located within groundwater organization service areas, as reported in the 2019 SIO (USDA, NASS, 2019b).[7] (See figure 2 for a map of the different regions presented in figure 3). In the Southeastern region, the majority of groundwater-fed acreage occurs outside of groundwater organization service areas, highlighting the relatively sparse groundwater management landscape of the region, where irrigated agriculture remains relatively new (Hrozencik and Aillery, 2021; USDA, NASS, 2020). Meanwhile, in other regions (such as the High Plains, Eastern Rockies, and Pacific), the majority of groundwater-fed acreage occurs under the purview of a groundwater organization.[8]

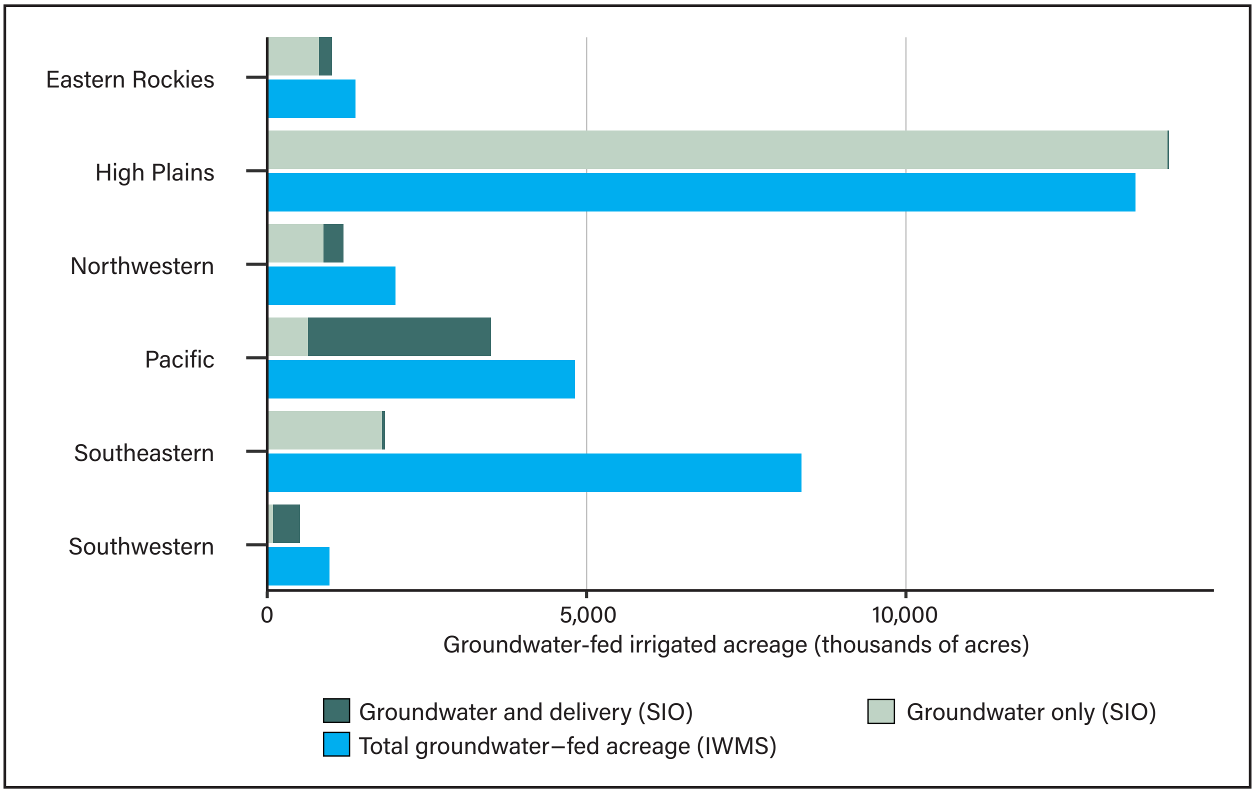
[7] Throughout the report, "service area" is used to refer to the geographic area over which a groundwater organization has jurisdiction and influences on-farm groundwater use.

[8] The total groundwater-fed acreage with organization service areas in the High Plains (reported by the 2019 SIO) exceeds the total groundwater-fed acreage in the High Plains reported in the 2018 IWMS. This discrepancy may be related to differences in growing-season weather conditions influencing irrigation decisions.

Figure 3 differentiates SIO-reported groundwater-fed acreage based on the functions of the groundwater service organization. Specifically, figure 3 differentiates between acreage within "Groundwater only" and "Groundwater and delivery" organization service areas. Groundwater only organizations (those organizations that only influence on-farm groundwater use and do not deliver water to farms) are most prevalent in the High Plains, Eastern Rockies, Northwestern, and Southeastern Regions. Conversely, groundwater and delivery organizations are most common in the Pacific region. Regional differences in groundwater organizations' water delivery functions are attributable to State-level legal institutions and the relative abundance of surface water and irrigation infrastructure (e.g., canals, reservoirs, etc.).

Figure 3

Regional prevalence of groundwater-fed irrigated acreage within groundwater organization service areas



SIO = USDA's 2019 Survey of Irrigation Organizations. IWMS = USDA's 2018 Irrigation and Water Management Survey.

Note: This figure compares total regional groundwater-fed irrigated acreage with the groundwater-fed irrigated acreage located within the service areas of groundwater organizations. Total regional groundwater-fed acreages are based on statistics reported in table 4 of the 2018 Irrigation and Water Management Survey (IWMS) (USDA, NASS, 2019b). The groundwater-fed irrigated acreage located within groundwater organization service areas differentiates between acreage within "Groundwater only" and "Groundwater and delivery" organizations (see, "What Are Groundwater Organizations?"). Groundwater only and groundwater and delivery are mutually exclusive categories. Therefore, the total of the stacked bars represents the regional total groundwater-fed acreage within groundwater organization service areas. Note that the groundwater-fed irrigated acreage regional total from IWMS does not include acreage irrigated under protection (e.g., acreage irrigated in a greenhouse) but does include acreage that relies on both surface and groundwater for irrigation supplies. Groundwater-fed irrigated acreage under protection is relatively small, constituting less than 0.06 percent of the national total groundwater-fed irrigated acreage in 2018 (USDA, NASS, 2019b). The total groundwater-fed irrigated acreage reported by IWMS occurring within SIO regions accounts for 86 percent of the national total of such acreage. SIO regions are as follows: Eastern Rockies (Colorado, Montana, and Wyoming), High Plains (Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas), Pacific (California and Nevada), Southeastern (Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, and South Carolina), and Southwestern (Arizona, New Mexico, and Utah). All remaining States were not part of the SIO. Note that for the High Plains region, the total groundwater-fed acreage within groundwater organization service areas in 2019 exceeds the total groundwater-fed acreage reported in the 2018 IWMS. This difference may be a result of producers adjusting irrigated acreage over time in response to market conditions.

Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service 2019 Survey of Irrigation Organizations and the 2018 Irrigation and Water Management Survey.

The increasing scarcity of groundwater has motivated growing efforts to manage shared aquifer resources and extend the economically viable lifespan of groundwater-fed irrigated agriculture. In response to growing concerns related to future groundwater availability, States are moving forward with legal and institutional efforts to manage local groundwater resources (e.g., California's Sustainable Groundwater Management Act). The Federal Government, in turn, is providing critical data, research, and funding to enhance the resiliency of groundwater-fed irrigated agriculture. For example, the 2018 Farm Bill included language allowing USDA's Natural Resources Conservation Service to implement Environmental Quality Incentive Program (EQIP) contracts with non-farm entities, such as groundwater organizations (Fischer and Willis, 2020). This change in EQIP eligibility provides a means to invest Federal funds in water conservation efforts initiated by groundwater organizations and similar water management entities.

Climate change is already affecting the amount of surface water available for irrigation, particularly in the snowpack-dependent irrigated agricultural production systems of the western United States (Musselman et al., 2021; Fyfe et al., 2017). In regions where both surface and groundwater resources are available for irrigation, groundwater provides an important buffer value in times of surface water scarcity and drought (Tsur and Graham-Tomasi, 1991). This buffer value of groundwater is likely to increase as drought episodes intensify and surface water supplies become increasingly scarce and variable (Gergel et al., 2017; Qin et al., 2020). The growing value of groundwater as a water source during times of surface water scarcity underscores the importance of the groundwater organizations charged with managing aquifer resources. The actions and decisions of groundwater organizations will, in part, determine the quantity of groundwater available in the future to meet the demands of the agricultural sector and other users when surface water supplies are insufficient or unavailable.

The impetus for many groundwater organizations is the shared nature of aquifers, where pumping by one irrigator affects the water availability for nearby irrigators. In these scenarios, pumping by one irrigator imposes an 'external cost' on other nearby irrigators in terms of diminished groundwater availability (Lawell, 2016). In many cases, the management activities and functions of groundwater organizations aim to address the economic damages arising from these external costs through groundwater use regulations or pricing. Groundwater organizations may also function primarily in a monitoring capacity, reporting on groundwater quantity and quality conditions—as well as disseminating information on water management strategies, public policy initiatives, and other topics of interest to constituents. In some cases, the set of management activities available to groundwater organizations is constrained by varied State-level laws defining landowners' property rights for groundwater beneath their land (see box, "Groundwater Law"). For example, in Texas, the "rule of capture" legal doctrine defining a landowner's rights to groundwater precludes many forms of groundwater-use regulation (Opiela, 2002; Hardberger, 2019).

This report does not provide a comprehensive treatment of groundwater governance and management. Instead, the report distills the key features of groundwater organizations for readers seeking an overview of groundwater management in the United States. For a full treatment of groundwater governance, see Megdal et al. (2015), which focuses on the United States, or Varady et al. (2016) or Edwards and Guilfoos (2021), both of which provide a global perspective on groundwater management.

Groundwater Law

The legal institutions governing the right to use groundwater vary across the United States, reflecting regional differences in water abundance, climate, and history. In the relatively water-abundant Eastern United States, rights to use common groundwater sources are less constrained than in the Western United States, where legal precedents have developed to allocate the region's scarce water resources. The following categorization of groundwater law doctrines borrows from the typology presented in Bryner and Purcell (2003). See Jame and Bowling (2020) for information on the dominant groundwater law doctrine by State.

Absolute ownership, or common law doctrine, states that water located underneath land is the property of the landowner, who retains the right to withdraw and use water regardless of the impact on other landowners. Absolute ownership of groundwater is also referred to as the "rule of capture" as landowners have the right to use whatever water they "capture" from beneath their land. The absolute ownership doctrine is still common in the Eastern United States, where the relative abundance of water resources limits competition for groundwater supplies (Bryner and Purcell, 2003).

The **American rule**, or reasonable use doctrine, limits groundwater withdrawals to the amount necessary for a reasonable and beneficial purpose. Wasteful use and transportation to other land is generally not considered a reasonable or beneficial use if that use interferes with an adjacent landowner's ability to exercise beneficial water use.

The **Correlative Rights** doctrine was developed as an alternative to absolute ownership in prominent western States such as California (Bryner and Purcell, 2003). Correlative rights state that landowners situated above a common groundwater stock have equal or correlative rights to use a reasonable amount of shared groundwater for reasonable and beneficial purposes on their land.

The **Prior appropriation** doctrine confers groundwater use rights according to the seniority of when the water was first withdrawn for a beneficial purpose. The first party to put the groundwater source to beneficial use has the senior right to continue that use. Parties that appropriate water afterward have junior rights. Prior appropriation is most common in the Western United States (Smith et al., 1996).

Characteristics of Groundwater Organizations

The characteristics of groundwater organizations vary significantly across the United States and are based upon other irrigation-related functions the organizations perform (e.g., the delivery of irrigation water to farms and ranches). This section summarizes the size and scope of groundwater organizations, focusing on regional variation and whether groundwater organizations also engage in water delivery.

Groundwater resources and the local institutions that govern resource use exhibit heterogeneity across the United States. Table 1 demonstrates this variation in terms of organization functions, acreage served, the number of active wells, and organization employees—using the SIO regions defined in the NASS *Irrigation Organizations* publication (USDA, NASS, 2020). Figure 2 maps the regions discussed in table 1. The amount of acreage irrigated with groundwater within organization service areas is greatest in the High Plains region, which roughly corresponds to the States overlying the High Plains (Ogallala) aquifer. In the High Plains, the average groundwater organization service area contains more than 166,000 acres of groundwater-fed irrigated acreage. The average service-area size of groundwater organizations is significantly less in the other regions, particularly in the Eastern Rockies, where the average organization has less than 6,000 groundwater-fed irrigated acres in its service area.

Table 1 also presents the counts of groundwater organizations that only influence on-farm groundwater use (groundwater only) and organizations that both influence on-farm groundwater use and deliver surface water to farms (groundwater and delivery) (see box, "What Are Groundwater Organizations?"). A sizable majority of organizations also deliver water to farms and ranches, pointing to the importance of combined management of surface and groundwater resources. However, the prevalence of groundwater and delivery organizations varies across regions, according to local surface water availability and other institutional and legal factors. These groundwater organizations are the least common in the High Plains, where relatively scarce surface water supplies offer minimal opportunities for groundwater organizations to provide water delivery services. Variation in the prevalence of groundwater and delivery organizations also highlights regional differences in opportunities to store excess surface water supplies, such as groundwater through managed aquifer recharge (see Wallander et al. (2022) for more information on managed aquifer recharge activities among irrigation organizations).

Table 1 also presents data on the average number of employees working for groundwater organizations. Nationally, the average groundwater organization has slightly more than five employees who are either full- or part-time. These employees may be organization and office staff, field staff, or outside employees (e.g., consultants) who help the organization perform its management functions. Approximately 35 percent of groundwater organizations report having no paid employees, suggesting that these organizations rely on volunteers for their groundwater management activities.

Table 2 provides further details on the differences between "Groundwater only" and "Groundwater and delivery" organizations at a national scale. Overall, the geographical scale of groundwater only organizations is greater than groundwater and delivery organizations. On average, groundwater only organizations have a larger number of irrigation wells, groundwater-fed irrigated acres, and farms that use groundwater for irrigation in their service area.

Table 1
Groundwater organization characteristics by region

Geographic area	Number of organizations	Number of groundwater only organizations	Number of groundwater and delivery organizations	Average acres irrigated with local groundwater per groundwater organization	Average number of active wells per groundwater organization	Average number of employees per groundwater organization
Eastern Rockies	175	15	160	5,805	52	1.94
High Plains	85	(D)	(D)	166,069	2,118	2.98
Northwestern	71	11	60	16,813	113	6.86
Pacific	158	11	147	22,133	483	5.83
Southeastern	12	(D)	(D)	(D)	1,728	3.41
Southwestern	234	11	223	(D)	49	7.82
United States	735	134	634	30,177	416	5.26

SIO = USDA 2019 Survey of Irrigation Organizations.

Note: (D) indicates that a statistic is withheld to avoid disclosing data for individual operations. When calculating the average number of employees, organizations with greater than 1,000 employees were excluded, as these organizations' employees primarily engage in activities not related to agricultural water delivery or management (such as power generation and distribution and municipal water delivery). 'Average number of employees' includes both full- and part-time employees. "Groundwater only" refers to organizations that only manage on-farm groundwater use, while "groundwater and delivery" represents organizations that manage on-farm groundwater use and also deliver water to farms. SIO regions are as follows: Eastern Rockies (Colorado, Montana, and Wyoming), High Plains (Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas), Pacific (California and Nevada), Southeastern (Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, and South Carolina), and Southwestern (Arizona, New Mexico, and Utah). All remaining States were not part of the SIO. The number of active wells refers to privately owned wells supplying water to irrigated farms rather than to wells owned and operated by the groundwater organization.

Source: USDA, Economic Research Service using data from the USDA 2019 Survey of Irrigation Organizations.

Table 2
Groundwater organization characteristics by type

	Average number of active wells	Average groundwater-fed irrigated acreage	Average number of farms
Groundwater only organizations	1,673	136,772	663
Groundwater and delivery organizations	136	6,410	68

Note: "Groundwater only" refers to organizations that only manage on-farm groundwater use, while "groundwater and delivery" represents organizations that manage on-farm groundwater use and deliver water to farms. The number of active wells refers to privately owned wells supplying water to irrigated farms rather than to wells owned and operated by the groundwater organization. The average number of farms refers only to farms that use groundwater resources to irrigate. Farms that only rely on surface water for irrigation are included in these groundwater organization type averages.

Source: USDA, Economic Research Service using data from the USDA 2019 Survey of Irrigation Organizations.

Functions of Groundwater Organizations

The management functions of groundwater organizations vary significantly by organization, according to resource issues and the requirements imposed by the legal and institutional context within which the organization operates. This section outlines the primary functions that groundwater organizations engage in to manage groundwater resources within their service area. These data are then supplemented with additional information on the rules and regulations groundwater organizations implement to promote resource stewardship and how those rules vary regionally. See Edwards and Guilfoos (2021) for a useful review that places U.S. groundwater organizations within the global context of groundwater governance and institutions.

The functions of groundwater organizations range from active functions (such as charging pumping or water rights fees) to more passive activities (such as monitoring and reporting on groundwater conditions). An organization's ability to engage in a given management function is directly linked to the legal authorities granted to the organization. For example, according to SIO data, the majority of groundwater and delivery organizations charge pumping or water rights fees. However, these organizations are only able to do so with appropriate regulatory authority to assess taxes. While charging pumping or water rights fees is relatively common among groundwater and delivery organizations, charging fees per unit of water pumped (e.g., dollars per acre-foot) is relatively uncommon.[9] Less than 15 percent of the organizations that charge pumping or water rights fees report charging these fees on a per acre foot-of-use basis, suggesting that in some cases, the fees may be used to generate revenue rather than alter on-farm groundwater use.[10]

Organizations without the power to assess taxes may instead use more passive management activities like monitoring groundwater conditions or collecting groundwater pumping data. These activities are among the most common conducted by groundwater organizations. According to SIO data, approximately 45 and 42 percent of groundwater organizations monitor groundwater conditions and collect groundwater pumping data, respectively. Organizations without authority to levy taxes may also affect groundwater use through less direct means such as well-permitting. Organizations with authority to issue permits for wells can implement de facto well-drilling moratoria by not granting new permits for additional groundwater wells.[11]

The management functions available to groundwater organizations depend crucially on State-level legal institutions defining groundwater pumping property rights, which often vary according to the use of the groundwater resources. For example, many States regulate groundwater extraction for irrigation and domestic use differently. In some States (such as Texas), groundwater-pumping property rights preclude most regulations or legal restrictions on an individual's access to groundwater resources (Opiela, 2002; Hardberger, 2019). In other cases, legal restrictions or regulations on groundwater access may exist but fall outside the domain of the groundwater organization. For example, in Colorado, the State engineer issues permits for groundwater well drilling but leaves most additional groundwater management functions to the local groundwater organizations (Sperling and Brown, 1997). In other States, groundwater organizations have not yet fully begun regulating groundwater access. For example, in 2014, California's legislature passed the Sustainable Groundwater Management Act (SGMA), which mandated the creation of local groundwater organizations to

[9] 1 acre-foot = 325,851 gallons.

[10] In lieu of charging pumping fees on a per acre foot-of-use basis, groundwater organizations may charge annual fees based on the number of acres irrigated or the number of wells used for irrigation.

[11] In theory, limiting irrigation well-drilling may not lead to less groundwater extraction if irrigators are allowed to transfer pumped water to other fields and farms. However, in practice, well-drilling moratoria limits are often implemented concurrently with irrigated acreage limits, which diminish the incentive to transfer pumped water to nearby fields lacking groundwater access (Schoengold and Brozovic, 2018). Additionally, physical constraints limit the extent to which pumped groundwater can be transferred to other fields and farms, as the cost of moving water can become prohibitive as the transfer distance increases.

implement regulations to reach groundwater sustainability (Aladjem and Sunding, 2015). However, many of the groundwater organizations formed under the auspices of SGMA are still relatively nascent and have not yet implemented any groundwater use rules or regulations. Thus, existing groundwater organizations' rules and management activities are dependent on State-level groundwater property rights and the timing of legislation clarifying or limiting those rights.

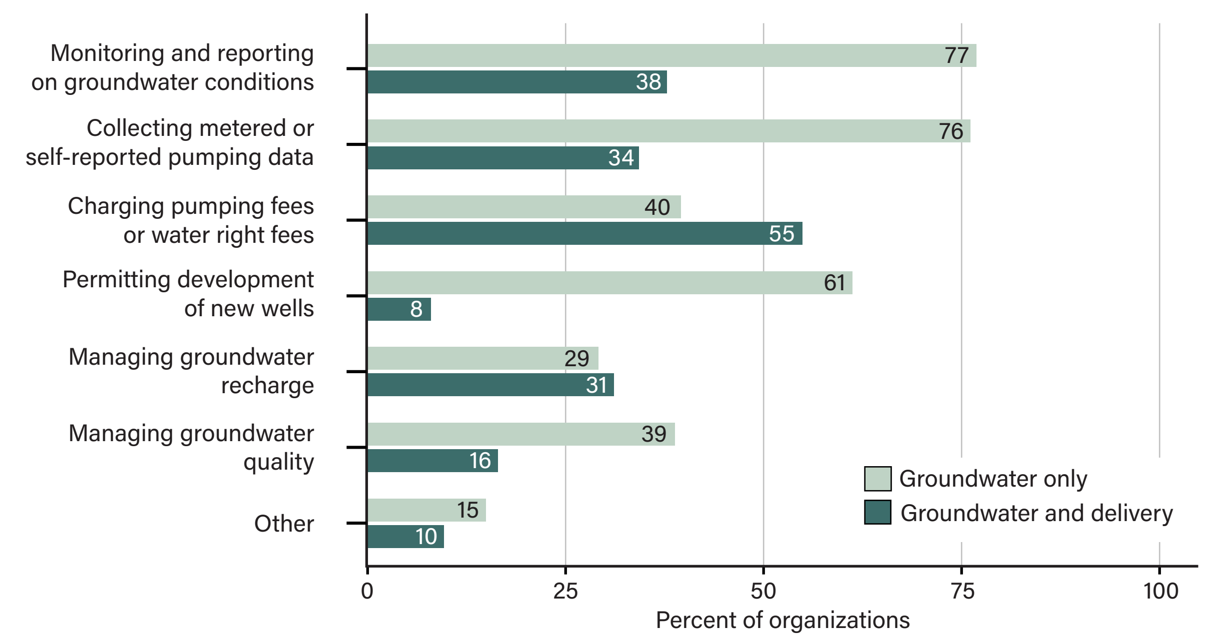
In some regions, where access to groundwater is legally restricted or regulated by groundwater organizations, irrigators are allowed to transfer rights to withdraw groundwater across years (Maliva, 2014). These interannual transfers are sometimes referred to as "soft-cap" groundwater regulations and generally take the form of a regulation that allows irrigators to use a certain quantity of water over a prespecified time horizon (Young et al., 2021).[12] Soft-cap groundwater regulations increase the flexibility of groundwater-use policies by allowing irrigators to save water during relatively wet growing seasons for use in drier growing seasons. In some regions where the combined use of surface and groundwater (conjunctive surface-groundwater use) for irrigation is common, groundwater organizations may facilitate groundwater banking through managed aquifer recharge from excess surface water supplies. For example, groundwater irrigators in the South Platte River Basin of Colorado use excess surface water supplies to augment groundwater stocks in the South Platte River's alluvial aquifer, banking water in the aquifer for use later in the growing season (McMahon, 1976; Howe, 2008; Jones, 2018).

[12] A groundwater use regulation that allows for interannual pumping rights transfers refers to a policy that limits groundwater pumping to a certain volume of water over a specified time period. For example, an irrigator may be regulated to use a maximum of 500 acre-feet (1 acre foot = 325,851 gallons) over 5 years. In this scenario, the irrigator may pump more water in a dry year (e.g., 150 acre-feet) and less water in a wet year (e.g., 50 acre feet). This approach to groundwater use regulations offers more flexibility than hard cap regulations while achieving similar water conservation objectives. For example, the water conservation outcomes of regulating an irrigator to pump no more than 100 acre feet in a given year (hard-cap policy) versus regulating an irrigator to pump no more than 500 acre feet over 5 years (soft-cap policy) are likely similar. The soft-cap regulation affords flexibility to the irrigator to use more water in times of drought, reducing the economic costs imposed by groundwater regulation (Young et al., 2021).

Groundwater organizations report performing a variety of functions to support their constituents and encourage resource stewardship

- Monitoring groundwater conditions and collecting pumping data are among the most common management functions performed by groundwater organizations. More than 75 percent of groundwater only organizations engage in these functions. A relatively smaller percentage of groundwater and delivery organizations (less than 38 percent) monitor groundwater conditions or collect pumping data (figure 4).
- Charging pumping or water rights fees is a relatively common function among groundwater organizations. A larger share of groundwater and delivery organizations (55 percent) charge fees compared to groundwater only organizations (40 percent).
- Issuing permits for the development of new wells is also a common management function, particularly among groundwater only organizations. Approximately 61 percent of groundwater only organizations engage in permitting, while only 8 percent of groundwater and delivery organizations do.

Figure 4
Functions of groundwater organizations



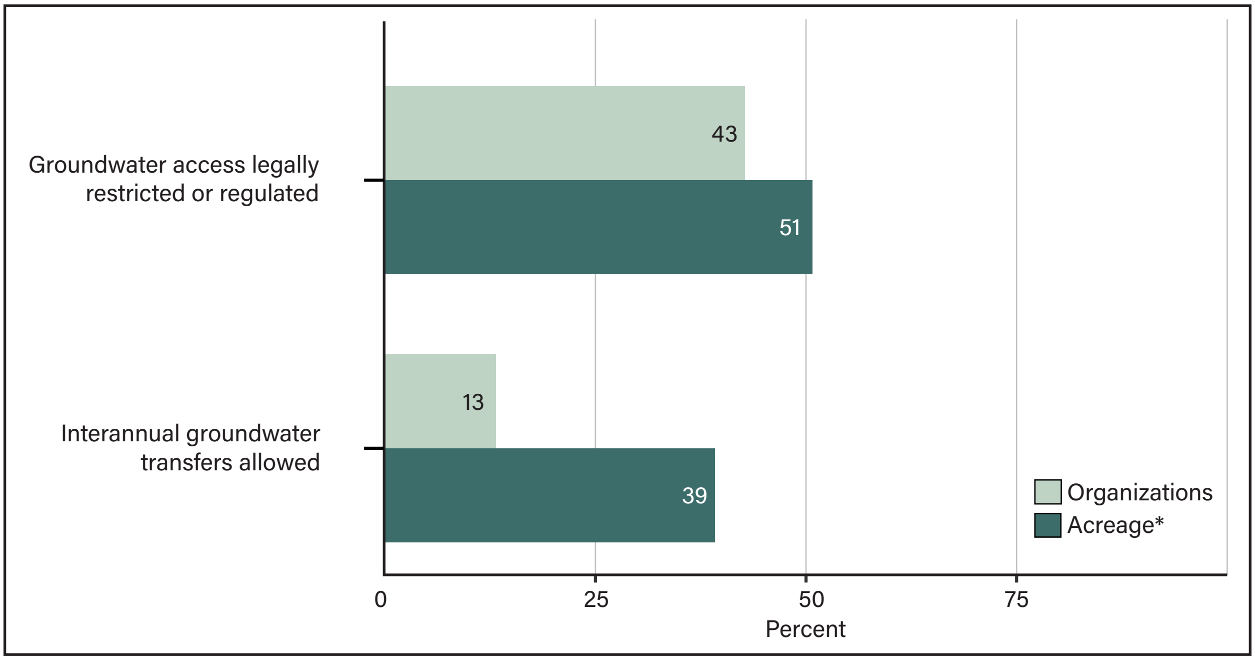
Note: The bars show the percent of groundwater organizations engaging in differing functions of groundwater management and corresponding acreage shares. “Groundwater only” represents the 134 organizations that only manage on-farm groundwater, while “Groundwater and delivery” refers to the 601 organizations that manage on-farm groundwater use and deliver water to farms. Groundwater organizations can engage in multiple activities to influence on-farm groundwater use. As a result, adding percentages of groundwater organizations engaged in differing functions will not sum to 100.

Source: USDA, Economic Research Service using data from the USDA 2019 Survey of Irrigation Organizations.

For many organizations, access to groundwater is not legally restricted or regulated within their service area

- Approximately 43 percent of all groundwater organizations report that access to groundwater is legally restricted or regulated in their service area (figure 5).
- Organization rules allowing for interannual groundwater transfers remain relatively uncommon in terms of the share of all organizations. Around 13 percent of all groundwater organizations allow constituents to transfer groundwater withdrawal rights across years.
- Organizations comprising 39 percent of all groundwater-fed acreage within organization service areas permitted irrigators to transfer pumping rights across years.

Figure 5
Groundwater regulations



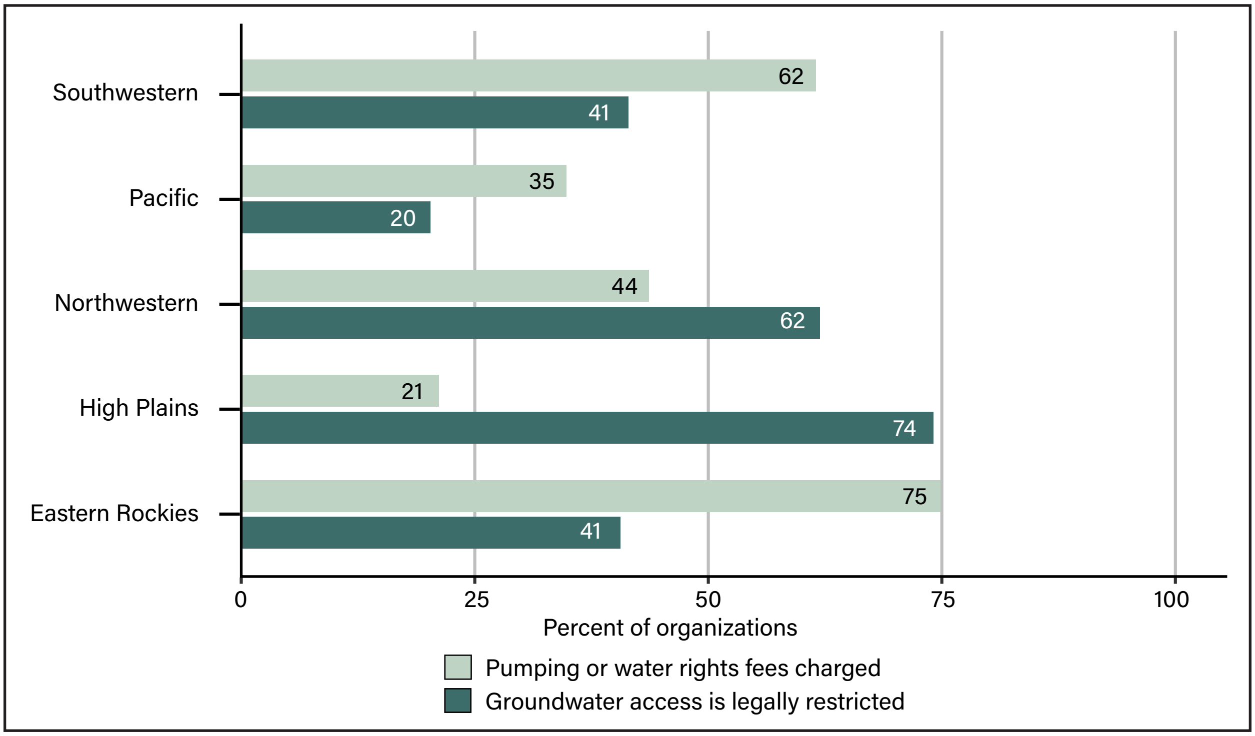
Note: This figure shows the percentage of groundwater organizations that regulate groundwater use and permit interannual transfers of groundwater withdrawal rights, as well as the corresponding share of acreage. *Acreage refers to the groundwater-fed irrigated land located within the service areas of groundwater organizations, where the organization by some means influences groundwater use. Approximately 60 percent of all groundwater-fed irrigated acreage in the United States is located within the service area of a groundwater organization. "Percent of organizations" refers to the percentage of the 735 groundwater organizations (both "groundwater only" and "groundwater and delivery"). "Groundwater access legally restricted or regulated" refers to any legal or regulatory restrictions on an individual's groundwater use, which may include limits on groundwater use, on the number of groundwater pumping permits issued, or on the number of acres irrigated by a given well, or restrictions on the distance between new groundwater wells and existing groundwater wells. "Interannual transfers of groundwater withdrawal rights" refers to the case where a given individual/entity with a right to pump groundwater each year is entitled to transfer that right to another year for use by the same individual/entity (interannual transfers of groundwater withdrawal rights do not refer to the case where groundwater withdrawal rights may be temporally transferred between users. See footnote 12 for more information on intra-user interannual groundwater withdrawal rights). See the box "Groundwater Law" for more information on the legal institutions defining groundwater pumping property rights.

Source: USDA, Economic Research Service using data from the USDA 2019 Survey of Irrigation Organizations.

Legal restrictions on groundwater access and organization's use of groundwater pumping fees vary regionally

- Groundwater organizations that charge pumping or water rights fees are most common in the Southwestern and Eastern Rockies regions, where 75 and 62 percent of organizations (respectively) utilize fees to influence on-farm groundwater use or raise revenue to support other management activities (figure 6).
- The majority of groundwater organizations in the High Plains and Northwestern regions report that access to groundwater is legally restricted or regulated within their service areas. Approximately 74 and 62 percent of groundwater organizations, respectively, in these regions report that access to groundwater is legally restricted.
- Legal restrictions and regulations of groundwater access are relatively less common in the Pacific region, where approximately 20 percent of organizations report that groundwater access is legally constrained in their service area.

Figure 6
Prevalence of groundwater access restrictions and pumping fees by region



Note: The figure shows the percentage of groundwater organizations where access to groundwater is legally restricted and that charge pumping or water rights fees by USDA, National Agricultural Statistics Service's SIO regions. "Groundwater access legally restricted" refers to any legal or regulatory restrictions on an individual's groundwater use, which may include limits on an individual's groundwater use, on the number of groundwater pumping permits issued, and on the number of acres irrigated by a given well, or restrictions on distance between new groundwater wells and existing groundwater wells. Results from the Southeastern region are suppressed due to disclosure concerns. USDA, NASS' SIO regions are as follows: Eastern Rockies (Colorado, Montana, and Wyoming), High Plains (Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas), Pacific (California and Nevada), and Southwestern (Arizona, New Mexico, and Utah). All remaining States were not part of the SIO.

Source: USDA, Economic Research Service using data from the USDA 2019 Survey of Irrigation Organizations.

Groundwater Overdraft and Quality Concerns

The recognition of the exhaustible nature of many important aquifers motivated the creation of many groundwater organizations in the United States (Kemper, 2004; Peck, 1980). Concerns related to the quantity and quality of aquifer resources—and resulting impacts on the economy and natural environment—continue to prompt the management actions of groundwater organizations.

Some groundwater overdraft concerns directly affect the irrigated agricultural sector, while others only directly affect other sectors or the environment. For example, diminished well capacity (which SIO data indicate are the most commonly cited groundwater overdraft concern in terms of acreage affected) directly impact the irrigated agricultural sector and limit the amount of water that can be applied to a crop within a given time, which can reduce irrigated crop yields and farm profits (Foster, 2014; Hrozencik et al., 2017). In some cases, declining well capacity is a precursor to other concerns, such as well abandonment, where irrigators cease pumping from a well due to diminished groundwater availability. Other groundwater resource concerns, such as stream interactions and land subsidence (caving-in or sinking), generally do not directly impact the groundwater-fed irrigated agricultural sector in the short run.[13] Instead, these issues primarily impose costs on other parties. For example, land subsidence can damage nonagricultural infrastructure, and depleted aquifers can reduce streamflow and harm riparian ecosystems (those related to a river or stream) (Jasechko et al., 2021; Bagheri-Gavkosh et al., 2021). However, these groundwater resource concerns can affect the agricultural sector indirectly if the concerns lead to policy interventions impacting irrigated agriculture.

Degraded water quality, which SIO data indicate is the most common groundwater overdraft concern in terms of the percentage of organizations who cite it, directly impacts the agricultural sector as contaminated groundwater can harm crops or preclude groundwater irrigation entirely (Petersen-Perlman et al., 2018). Organizations cite a range of different contaminants that impair groundwater quality. Some of these contaminants (such as nitrates, which affect the largest share of organizations and acreage, according to SIO data) are related to agricultural input use (Burri et al., 2019; Gleeson et al., 2020). In other cases, groundwater overdraft contributes to degraded water quality. For example, saltwater intrusion caused by groundwater depletion is a major concern for many coastal and inland aquifers, as high salinity levels in aquifers can preclude groundwater irrigation of the most common crops (Barlow and Reichard, 2010).

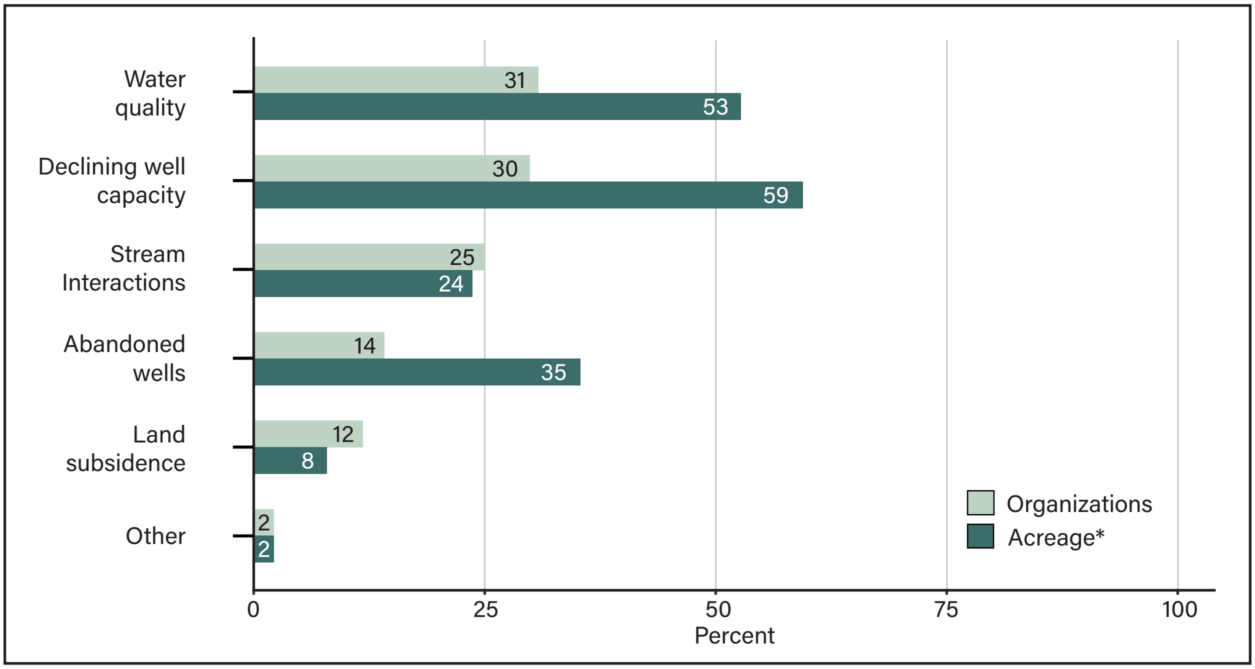
In other cases, groundwater depletion leads to extraction from increasingly deeper aquifers, which are more prone to water quality issues (Jurgens et al., 2010; Levy et al., 2021). The prevalence of many groundwater overdrafts and quality concerns exhibits significant variation based on differences in regional surface water and aquifer characteristics.

[13] Land subsidence can potentially impose a direct long-term cost on the irrigated agricultural sector if the sinkage permanently diminishes the groundwater storage capacity of the aquifer (Smith and Majumdar, 2020). Land subsidence can also damage irrigation infrastructure such as canals, ditches, and aqueducts (Sneedet al., 2018). Additionally, changes in streamflow related to groundwater depletion can diminish the amount of surface water available for downstream agricultural users (Bartolino and Cunningham, 2003).

Water quality and declining well capacity are the most common groundwater overdraft concerns affecting groundwater organizations

- Groundwater organizations most commonly cite water quality and declining well capacity as groundwater depletion concerns in their service area. Water quality and declining well capacity affects approximately 31 and 30 percent of groundwater organizations, respectively (figure 7).
- Water quality and declining well capacity issues affect approximately 53 and 59 percent of acreage within organization service areas, respectively.
- Stream interactions and abandoned wells are also commonly cited groundwater depletion issues. About 25 and 14 percent of organizations report stream interactions and abandoned wells as groundwater depletion issues affecting their constituents.

Figure 7
Groundwater overdraft concerns



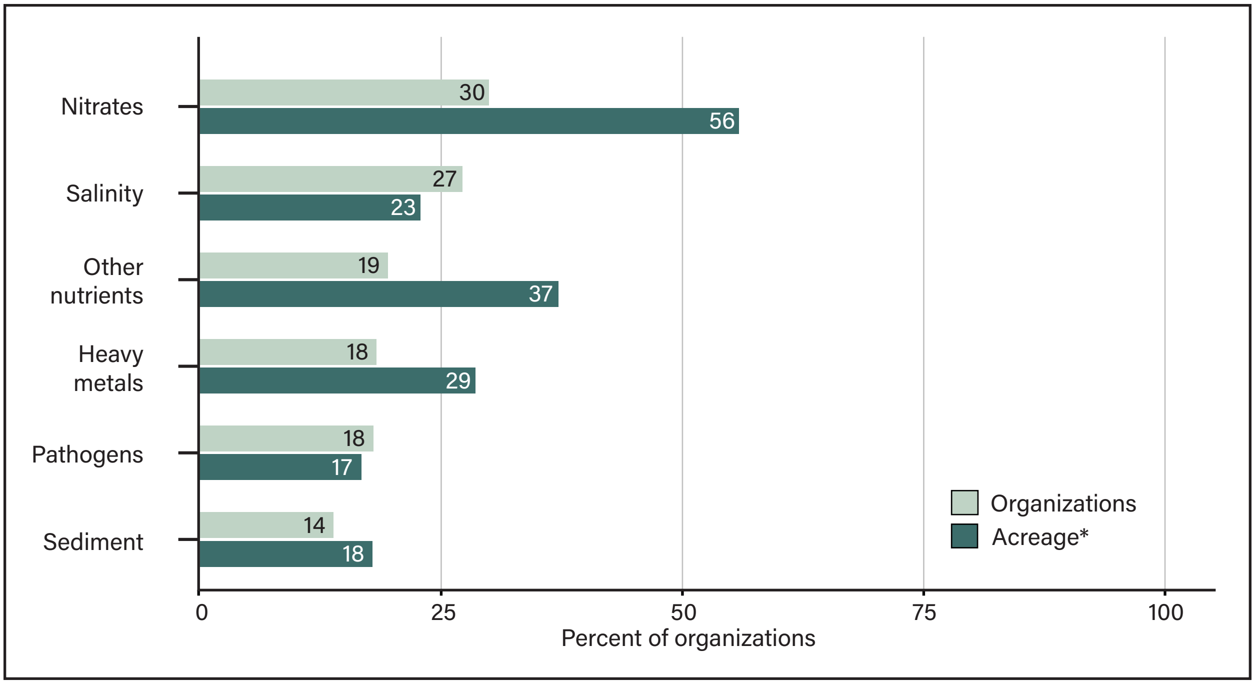
Note: This figure shows the percentage of groundwater organizations and acreage affected by differing groundwater overdraft concerns. *Acreage refers to the groundwater-fed irrigated acreage located within the service areas of groundwater organizations where the organization, by some means, influences groundwater use. Approximately 60 percent of all groundwater-fed irrigated acreage in the United States is located within the service area of a groundwater organization. 'Percent of organizations' refers to the percentage of the 735 groundwater organizations within a given category. Groundwater organizations can be concerned with multiple groundwater overdraft issues. Similarly, there may be multiple groundwater overdraft concerns for the same groundwater-fed acreage. As a result, adding percentages of groundwater organizations or acreage across all groundwater overdraft concerns may sum to more than 100.

Source: USDA, Economic Research Service using data from the USDA 2019 Survey of Irrigation Organizations.

A variety of contaminants raise groundwater quality concerns among groundwater organizations

- Nitrates are the most commonly cited groundwater contaminant, causing concern among approximately 30 percent of groundwater organizations (figure 8).
- Nitrate contamination is a concern for about 56 percent of the total groundwater-fed irrigated acreage within groundwater organization service areas.
- Salinity, other nutrients, and heavy metals are three other major concerns, and they constitute about 27, 19, and 18 percent of groundwater organizations' concerns, respectively.

Figure 8
Groundwater quality concerns



Note: This figure shows the percentage of groundwater organizations and acreage affected by differing groundwater quality concerns. *Acreage refers to the groundwater-fed irrigated acreage located within the service areas of groundwater organizations where the organization, by some means, influences groundwater use. Approximately 60 percent of all groundwater-fed irrigated acreage in the United States is located within the service area of a groundwater organization. 'Percent of organizations' refers to the percentage of the 735 groundwater organizations within a given category. Groundwater organizations can be concerned about multiple groundwater quality measures and/or contaminants. Similarly, there may be multiple water quality concerns for the same groundwater-fed acreage. As a result, adding percentages of groundwater organizations or acreage across all contaminants may sum to more than 100. Heavy metals are commonly used in producing herbicides and pesticides, and some heavy metal contamination may derive from the seepage of pesticides and herbicides into groundwater (Defarge, 2018).

Source: USDA, Economic Research Service using data from the USDA 2019 Survey of Irrigation Organizations.

Groundwater Organization Governance and Operations

The functions performed by groundwater organizations to enhance resource stewardship and address groundwater overdraft and quality concerns depend on the governance and accountability structure of the organization and the sources of information the organization relies on for decision making.[14]

Many groundwater organizations give their constituents opportunities to provide input on organization management decisions. In some cases, organizations solicit water-user input through direct voting on policy options. In other cases, water users elect representatives to a board that makes organization management decisions. Organization management decisions may also be made by an appointed board. Organizations may use some hybrid of these differing governance structures, wherein major decisions are voted on directly by water users while an elected or appointed board handles day-to-day operations. Elected and appointed representatives are generally groundwater organization constituents (i.e., groundwater irrigators); boards may also include other community members concerned with local and regional groundwater resources. These differing governance structures aim to promote accountability in organization management, balancing the best interests of the organization's constituents with potentially competing resource stewardship objectives (Beecher, 2013).

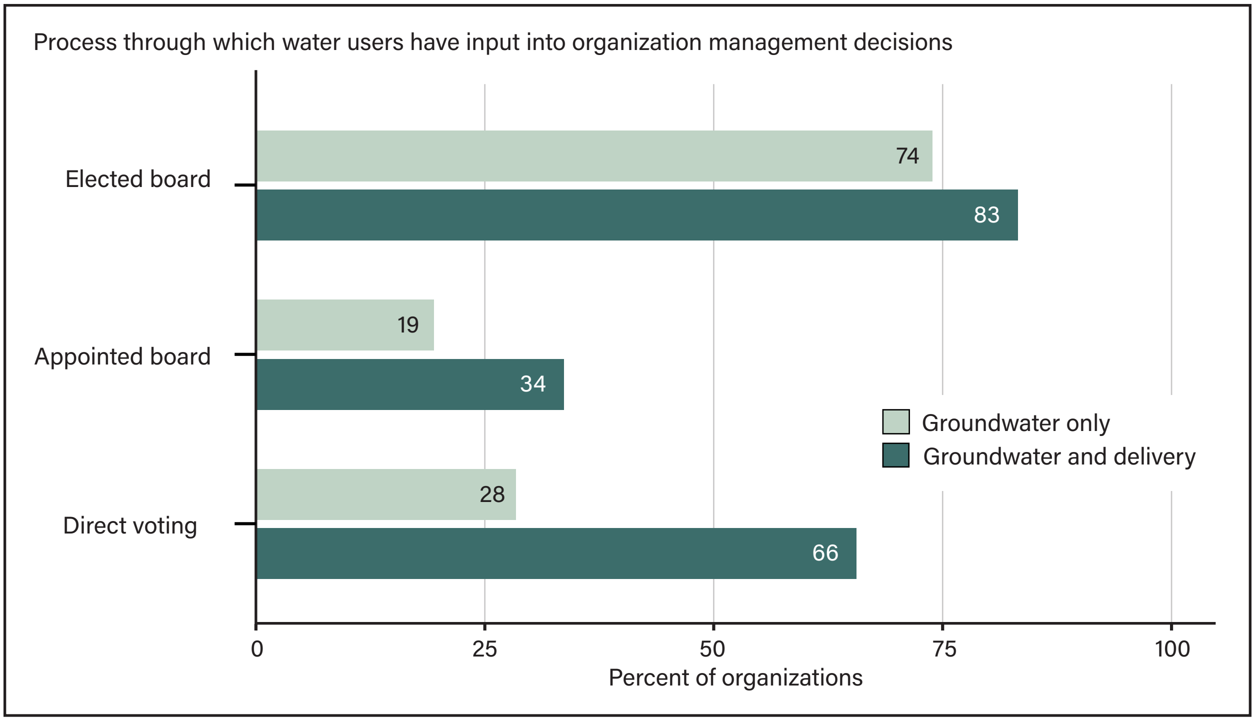
Groundwater organizations rely on a variety of information sources for long-run decision-making. These sources include groundwater monitoring networks, groundwater models, long-term weather forecasts, climate simulation models, and reservoir storage reports. The information helps organizations anticipate future changes in groundwater use and availability. Although projected future trends in climate (and changes in groundwater recharge and use) are subject to a high degree of uncertainty, understanding likely future trends allows organizations to tailor management plans to facilitate long-run groundwater stewardship (Kundzewicz et al., 2018).

[14] "Long-run decisions" refers to those decisions taken by a groundwater organization that have implications beyond the year in which the Survey of Irrigation Organizations data were collected.

Groundwater organizations receive input from constituents through a variety of channels

- Elected boards are the most common means by which groundwater users have input into organization management decisions. Elected boards govern about 74 percent of groundwater only organizations and 83 percent of groundwater and delivery organizations (figure 9).
- Appointed boards are relatively less common among groundwater organizations, governing about 19 percent of groundwater only organizations and 34 percent of groundwater and delivery organizations.
- Direct voting is more common among groundwater and delivery organizations compared to groundwater only organizations. Approximately 66 percent of groundwater and delivery organizations allow water users to vote directly on key management decisions. Conversely, direct voting by constituents governs about 28 percent of groundwater only organizations.

Figure 9
Groundwater organization governance



Note: This figure shows the percentage of groundwater organizations using differing forms of governance. "Groundwater only'" represents the 134 organizations that only manage on-farm groundwater, while "Groundwater and delivery" refers to the 601 organizations that manage on-farm groundwater use and also deliver water to farms. Groundwater organizations may have hybrid governance structures. For example, a given groundwater organization may have both elected and appointed members of their governing board. This same organization may also allow water users to vote on key issues at times. Thus, adding percentages across differing means by which water users have input into organization management decisions may sum to greater than 100 percent. Additionally, some groundwater organizations that operate under the auspices of a State agency (e.g., department of natural resources or environmental quality) may not be governed by an appointed or elected board or offer direct voting to water users.

Source: USDA, Economic Research Service using data from the USDA 2019 Survey of Irrigation Organizations.

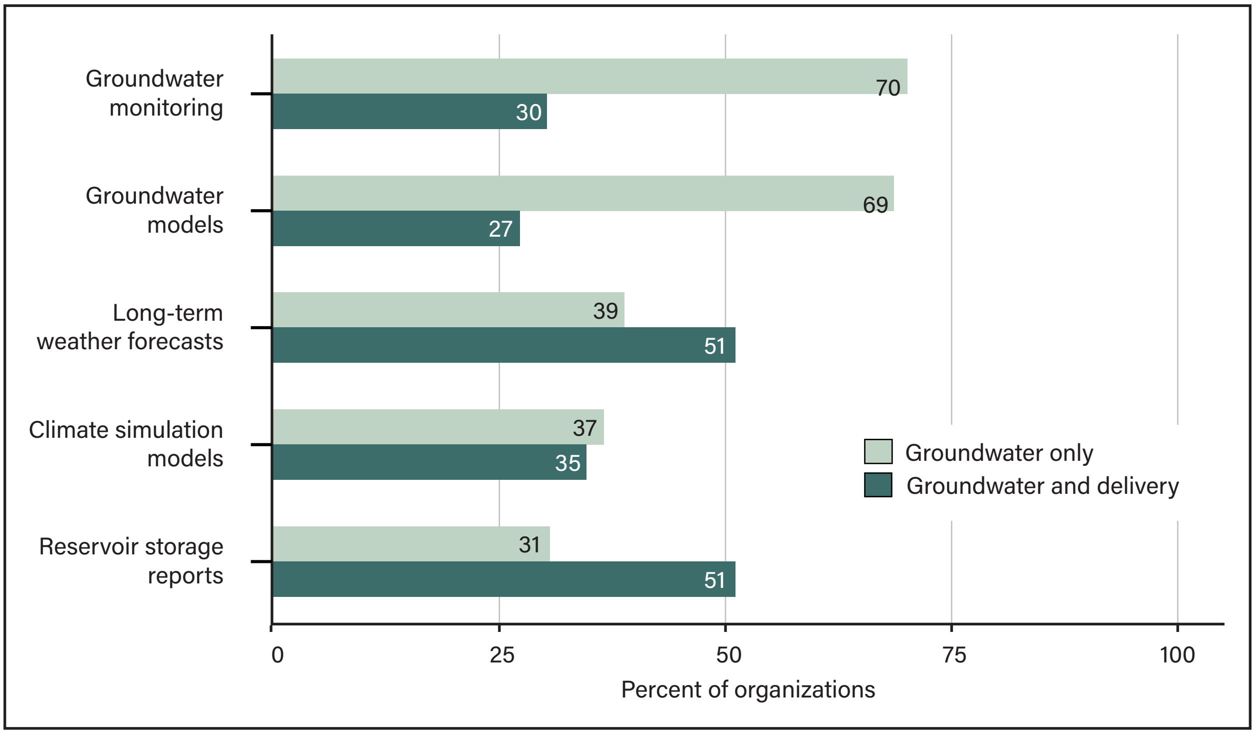
Groundwater organizations rely on various sources of information for their management decisions

- Groundwater monitoring and groundwater modeling are the two most commonly used sources of information for groundwater only organizations, supporting the long-run decisions of approximately 70 and 69 percent of groundwater only organizations, respectively (figure 10).[15]

- Fewer groundwater and delivery organizations rely on groundwater monitoring and groundwater modeling for their long-run decision-making. Approximately 30 and 27 percent of groundwater and delivery organizations use groundwater monitoring and groundwater modeling, respectively, to inform long-run planning.

- Groundwater and delivery organizations more commonly use long-run weather forecasts and reservoir storage reports to inform long-run decision-making. Information from these sources informs the decision-making of about 51 percent of groundwater and delivery organizations.

Figure 10
Information sources for long-run organization decision-making by organization type



Note: Figure 10 presents the percentage of groundwater organizations that indicate differing sources of data as "critical" or "somewhat useful" for their long-run decision-making. "Groundwater only" represents the 134 organizations that only manage on-farm groundwater, while "Groundwater and delivery" refers to the 601 organizations that manage on-farm groundwater use and also deliver water to farms. "Groundwater monitoring" can also refer to groundwater level and use trend analysis. "Groundwater models" include models developed by the U.S. Geological Survey, as well as other governmental agencies and academic institutions. Long-term weather forecasts refer to projections of 3 months or longer. Climate simulation models also include regional climate reports.

Source: USDA, Economic Research Service using data from the USDA 2019 Survey of Irrigation Organizations.

[15] The integrated use of both groundwater monitoring and modeling for long-run planning is relatively common among groundwater organizations. Among all the organizations that cite using these sources for long-run planning, a majority (63 percent) rely on both. The joint use of these sources of information is common, given that groundwater monitoring data are often used as inputs for groundwater modeling exercises (Condon et al., 2021).

Conclusion

Groundwater is a vital resource supporting U.S. irrigated agricultural production. Approximately 60 percent of the groundwater-fed irrigated acreage in the United States falls under the purview of groundwater organizations. These organizations perform a variety of management functions to promote groundwater resource stewardship and address the groundwater overdraft and quality concerns of their constituents. Groundwater organization management functions range from monitoring and reporting on groundwater conditions to charging groundwater pumping fees or irrigated acreage assessments. The management functions available to organizations depend on the local legal institutions governing groundwater-pumping property rights. In some cases, organizations allow groundwater irrigators to transfer withdrawal rights across years, which means that an irrigator can transfer an unused right from a given year to a later year. These inter-temporal transfers offer enhanced flexibility when groundwater use regulations are in place.

Groundwater quantity and quality concerns motivate many of the management functions performed by groundwater organizations. Among these concerns, diminished water quality and reduced well capacity affect the largest number of organizations and groundwater-fed irrigated acreage. Groundwater overdraft or depletion (caused by rates of pumping in excess of recharge) generates many of the concerns affecting groundwater organization constituents. Nitrates and salinity are among the most commonly cited contaminants impairing groundwater quality.

Governance structures promote accountability within the management of groundwater organizations, providing a means by which water users can communicate the groundwater overdraft and quality concerns affecting their operations and discuss potential mitigation strategies. The majority of organizations are governed by elected boards, while a smaller proportion of organizations allow for direct voting by water users on key issues facing the organization.

The importance of groundwater resources for U.S. irrigated agriculture, faced with current and projected future changes in surface water availability due to climate change, underscores the importance of promoting stewardship of groundwater resources (Fyfe et al., 2017; Qin et al., 2020; Musselman et al., 2021). Federal and State policy initiatives increasingly recognize the importance of the institutions monitoring, regulating, and managing the Nation's groundwater resources. For example, recent changes in the USDA, NRCS EQIP extending eligibility to non-farm entities like groundwater organizations allow Federal funds to support capacity building among groundwater organizations. These public investments enhance the ability of groundwater organizations to address current and future groundwater depletion and quality issues.

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This Economic Brief is the third in a series of briefs based on the USDA 2019 Survey of Irrigation Organizations:

Irrigation Organizations: **Infrastructure**

Irrigation Organizations: **Drought Planning and Response**

Irrigation Organizations: **Groundwater Management**

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