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The Federal Role in Groundwater Supply

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Summary

Groundwater, the water in aquifers accessible by wells, is a critical component of the U.S. water supply. It is important for both domestic and agricultural water needs, among other uses. Nearly half of the nation's population uses groundwater to meet daily needs; in 2015, about 149 million people (46% of the nation's population) relied on groundwater for their domestic indoor and outdoor water supply. The greatest volume of groundwater used every day is for agriculture, specifically for irrigation. In 2015, irrigation accounted for 69% of the total fresh groundwater withdrawals in the United States. For that year, California pumped the most groundwater for irrigation, followed by Arkansas, Nebraska, Idaho, Texas, and Kansas, in that order. Groundwater also is used as a supply for mining, oil and gas development, industrial processes, livestock, and thermoelectric power, among other uses.

Congress generally has deferred management of U.S. groundwater resources to the states, and there is little indication that this practice will change. Congress, various states, and other stakeholders recently have focused on the potential for using surface water to recharge aquifers and the ability to recover stored groundwater when needed. Some see aquifer recharge, storage, and recovery as a replacement or complement to surface water reservoirs, and there is interest in how federal agencies can support these efforts. In the congressional context, there is interest in the potential for federal policies to facilitate state, local, and private groundwater management efforts (e.g., management of federal reservoir releases to allow for groundwater recharge by local utilities).

The two primary federal water resources agencies are the U.S. Bureau of Reclamation (Reclamation) and the U.S. Army Corps of Engineers (USACE). No significant federal restrictions apply to Reclamation's authorities to deliver water for purposes of aquifer recharge, storage, and recovery. USACE authorities also do not restrict nonfederal entities from using water stored or released from USACE reservoirs for groundwater recharge. Both agencies acknowledge that some state restrictions affect the use of the delivered or stored waters for groundwater activities. Reclamation, the U.S. Department of Agriculture (USDA), and the U.S. Environmental Protection Agency also provide some forms of financial assistance that could be used for enhancing groundwater supplies.

Other federal agencies support activities that inform groundwater management. For example, the U.S. Geological Survey monitors and reports groundwater conditions across the country, develops groundwater models and software tools for characterizing aquifers, and provides long- and short-term forecasts of changing groundwater conditions as part of local and regional groundwater studies. The National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration also make observations and collect data that are relevant to groundwater monitoring and assessment. USDA collects groundwater data related to irrigation.

Long-term changes to the climate affecting the United States, particularly rising temperatures and changes in the patterns, quantities, and type of precipitation (i.e., rain versus snow), could affect the availability of groundwater in the future. Other factors, such as changes to land use, irrigation practices, and patterns of water consumption, also may influence future changes to groundwater supplies.

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Groundwater, the water in aquifers accessible by wells, is a critical component of the U.S. water supply. It serves as a water source for domestic use and as irrigation water for agriculture, and it is used in mining, oil and gas development, industrial processes, livestock production, and thermoelectric power generation, among other uses. Managing groundwater resources largely has been the purview of states rather than the federal government. How each state manages its groundwater resources differs and depends on a mix of common law emerging from the 19th century, state law, court decisions, water settlements, and, to a lesser extent, federal law. The federal role in managing groundwater includes activities under federal trust responsibilities to Indian tribes and reservations.[1] It also includes management responsibilities for certain federal reservations if the purposes of those reservations require water, such as some national monuments, national forests, military bases, and other federal land holdings. In addition, the federal government is involved in groundwater monitoring and assessment and in aspects of groundwater recharge, storage, and recovery. Much of the recent congressional interest in groundwater has been broadly related to policies for increasing water supplies generally, as a response to recent droughts, and in preparation for future droughts.

In recent Congresses, some Members have introduced legislation that could affect how groundwater resources may be managed to better ensure a sufficient and reliable supply, and several such bills (or portions of such bills) have been enacted into law. Drought conditions and constrained supplies of surface water have helped to spur legislative action.[2] These conditions continue to affect many regions in western states, although droughts can occur anywhere in the nation.[3] Congress could continue to explore its authority to shape policy, conduct oversight, and provide appropriations for federal activities that influence groundwater supply management in the United States. This report is intended to provide context and a broad summary of federal authorities and activities affecting the supply and use of groundwater resources.

Whereas the states primarily manage groundwater *supply*, the federal government plays a more direct role in managing the nation's groundwater *quality*. For example, the Comprehensive Environmental Response, Compensation, and Liability Act (42 U.S.C. §§9601 et seq.) authorizes federal cleanup and enforcement actions to respond to releases of hazardous substances to the environment, including groundwater. In addition, the Safe Drinking Water Act (42 U.S.C. §§300f et seq.) authorizes the U.S. Environmental Protection Agency (EPA) to regulate underground injection activities to protect underground sources of drinking water, including injection wells used for aquifer recharge. This report focuses on issues related to groundwater supply, not groundwater quality.[4]

This report is divided into two parts. The first part provides an overview of groundwater supply and management, including selected major issues before Congress. The second part provides a more detailed primer on groundwater resources, including relevant federal activities and authorities.

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[1] Unless otherwise noted, the terms *Indian*, *Indian tribes*, and *tribal reservations* refer to the approximately 1.9 million American Indians and Alaska Natives, the more than 570 federally recognized Indian tribes, and tribal land within reservation boundaries.

[2] Surface water includes streams, rivers, lakes, ponds, and is not groundwater or atmospheric water like rain or snow.

[3] For a general overview of drought in the United States, see CRS Report R43407, *Drought in the United States: Causes and Current Understanding*, by Peter Folger.

[4] Many CRS resources address issues of groundwater quality, including CRS Report R41039, *Comprehensive Environmental Response, Compensation, and Liability Act: A Summary of Superfund Cleanup Authorities and Related Provisions of the Act*, by David M. Bearden; and CRS Report RL31243, *Safe Drinking Water Act (SDWA): A Summary of the Act and Its Major Requirements*, by Mary Tiemann.

Overview

Who Relies on Groundwater?

Nearly half of the U.S. population relies on groundwater to meet their everyday needs. In 2015, groundwater was the primary source of water for domestic indoor and outdoor water uses for about 149 million people (46% of the U.S. population).[5] Most U.S. citizens (approximately 282 million people, or 87%) depended on public water supplies in 2015.[6] The remaining 13% (approximately 42.5 million people) supplied their own water, and nearly all of these citizens (98%, or about 42 million) pumped the water from their private wells. About 38% of public supply water is groundwater, and about 107 million people used groundwater from public water supplies.[7] Combined with the 42 million people pumping groundwater from their private wells, an estimated 149 million people relied on groundwater in 2015.

Groundwater and Irrigation

The greatest *volume* of groundwater used is for agriculture, nearly entirely for irrigation. In 2015, irrigation accounted for over 69% of all fresh groundwater withdrawals in the United States,[8] which corresponded to about 57.2 billion gallons per day (bgpd) in irrigation withdrawals as compared to 18.4 bgpd in withdrawals for domestic use (both public supply and self-supplied groundwater—in total, about 22% of all fresh groundwater withdrawals).[9] Among all states, California uses the most groundwater for irrigation, withdrawing 13.9 bgpd in 2015. Arkansas is second, withdrawing 9.28 bgpd in the same year, followed by Nebraska (5.42 bgpd), Idaho (4.9 bgpd), Texas (4.48 bgpd), and Kansas (2.56 bgpd).[10] Overall, groundwater withdrawals for irrigation in 2015 accounted for 48% of the total water withdrawn for irrigation, an increase of 16% compared to 2010.[11] In comparison, surface water sources supplied 52% of total irrigation withdrawals, a decrease of about 8% from 2010.[12]

Figure 1 illustrates the amount of groundwater withdrawn for irrigation by state. Generally, western states tend to use the most groundwater, due in part to hydrology and other surface water supply constraints.

[5] Cheryl A. Dieter and Molly A. Maupin, *Public Supply and Domestic Water Use in the United States, 2015*, U.S. Geological Survey (USGS), Open-File Report 2017-1131, 2017, at https://doi.org/10.3133/ofr20171131. (Hereinafter, Dieter and Maupin, 2017.)

[6] *Public water supply*, as used in USGS reports and herein, refers to water withdrawn by public and private water suppliers that provide water to at least 25 people or have a minimum of 15 connections. It excludes self-supplied domestic withdrawals.

[7] Dieter and Maupin, 2017.

[8] Cheryl A. Dieter et al., *Estimated Use of Water in the United States in 2015*, USGS, Circular 1441, 2018, at https://pubs.er.usgs.gov/publication/cir1441. (Hereinafter, Dieter et al., 2018.) 2015 is the most recent year for which these data are available. Nearly all groundwater withdrawals in 2015 were freshwater (about 97%); the remainder (3%) were saline water withdrawals.

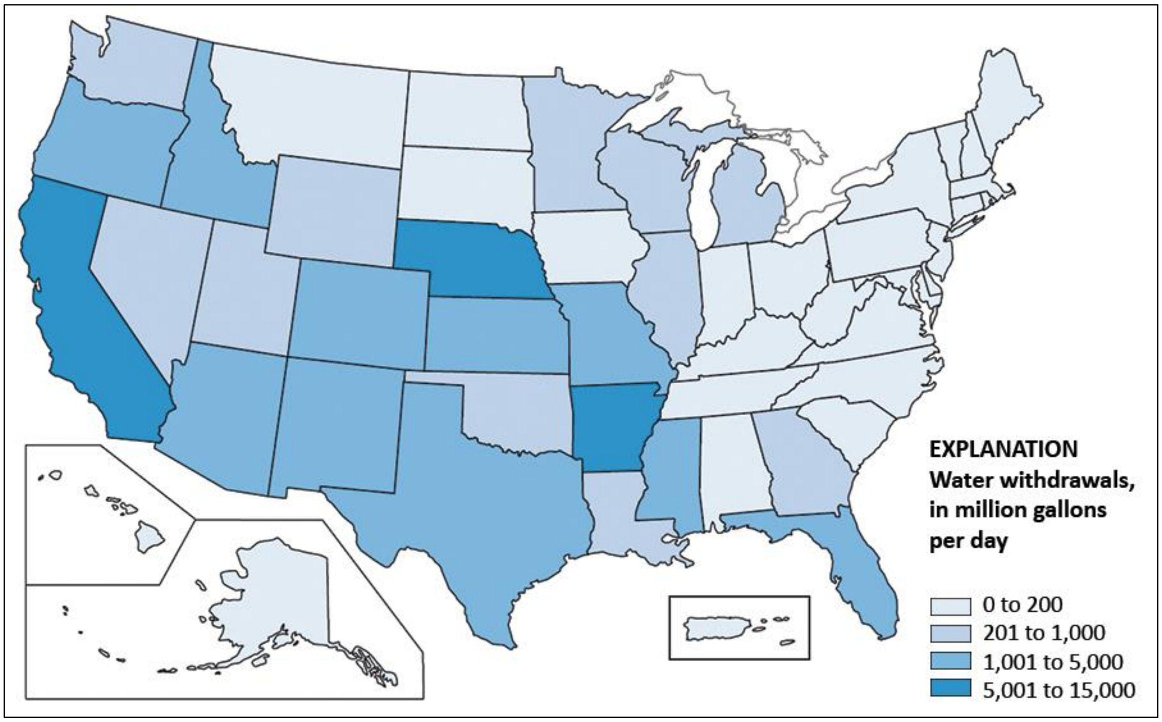
[9] Irrigation, public supply, and self-supplied groundwater withdrawals accounted for about 92% of the total fresh groundwater pumped in 2015. The remaining 8% included uses for livestock, aquaculture, industrial, mining, and thermoelectric power. Dieter et al., 2018, Table 4a.

[10] Dieter et al., 2018, Table 7.

[11] Dieter et al., 2018, p. 28.

[12] Dieter et al., 2018, p. 28.

Figure 1. Groundwater Withdrawals for Irrigation (2015)



Source: Cheryl A. Dieter et al., *Estimated Use of Water in the United States in 2015*, USGS, Circular 1441, 2018, at https://pubs.er.usgs.gov/publication/cir1441, p. 29, figure 7. (Modified by CRS.)

The Federal Role in Groundwater Supply

The federal government directly and indirectly influences how groundwater is managed in the United States. Several federal agencies monitor groundwater directly or with partners—through measurements at wells and springs—and remotely, using satellites or other remote sensing devices to provide information on groundwater flow, storage, depletion, and other characteristics that help inform state and local groundwater management. These include the U.S. Geological Survey (USGS), the National Aeronautics and Space Agency (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Department of Agriculture (USDA).[13] Congress has provided other federal agencies with the authority to make available some water delivered from or stored at federal water resource projects available for groundwater recharge, storage, and recovery. These agencies include the two principal federal water resources agencies: the U.S. Army Corps of Engineers (USACE, which operates nationwide) and the U.S. Bureau of Reclamation (Reclamation, which operates in the 17 coterminous states west of the Mississippi River). Additionally, courts have found that when the federal government reserves lands for a particular purpose (such as for a tribal reservation or national monument), it impliedly reserves a right to water necessary to accomplish the purposes for which the reservation was created. Thus, federal land management agencies and the Bureau of Indian Affairs often are involved in water rights issues. Federal reserved water rights doctrine has long been recognized for surface water; more recently, it is also being considered for groundwater.

[13] For more information on the roles of the agencies, see the below section, "Federal Activities and Authorities."

Congressional Interest

In recent years, congressional interest in groundwater has generally been in three major areas:

- aquifer storage, recharge, and recovery;
- groundwater rights (including among other issues, groundwater/surface water interaction and federal reserved water rights); and
- groundwater supply monitoring and assessment.

In some cases, these issues overlap.

Groundwater Recharge, Storage, and Recovery

Background

Historically, the federal government, through USACE and Reclamation, has played a prominent role in constructing infrastructure related to surface water resource management (e.g., storage, control, or delivery). At the same time, the federal government has played a comparatively smaller role in creating infrastructure to develop groundwater storage, which is commonly conducted as aquifer storage, recovery, and/or recharge.[14] The reasons for the differing levels of federal involvement are complex, tied to the long and complicated history of common law water rights, state water law, legal adjudication, federal deference to states on water supply issues, and a historically cruder understanding of how groundwater occurs and moves underground compared to surface water.

Both public and congressional focus on groundwater storage has sharpened in recent years, particularly in reaction to recent major drought events. Congressional interest has increased in the potential for the federal government to assist with state, local, and private groundwater management efforts, including efforts to use surface water to recharge and/or store water in aquifers and to recover (i.e., pump to the surface) the stored groundwater when needed. Some see aquifer recharge, storage, and recovery as potentially complementary to existing surface water storage; some also see these projects as possible alternatives to building new surface water reservoirs that may prove less costly and/or pose fewer environmental issues.[15]

Federal law authorizes Reclamation to provide water for irrigation and USACE to store water for various purposes. These authorities provide some opportunities for the federal government to promote aquifer recharge, storage, and recovery (see below section, "Federal Authority Related to Groundwater Recharge, Storage, and Recovery"). Currently, there are no general federal restrictions on the nonfederal use of water delivered by Reclamation or stored by USACE for aquifer recharge, storage, and recovery purposes; however, some state restrictions and federal environmental protection laws may affect the use of these waters for groundwater recharge.[16]

[14] For more background on this concept, see the below section, "Federal Authority Related to Groundwater Recharge, Storage, and Recovery."

[15] An example of a major aquifer storage project currently operating within a larger water storage framework is the Kern Water Bank, a water storage bank that operates on about 20,000 acres southwest of Bakersfield, California. As of 2018, the bank could store about 1.5 million acre-feet of readily available water underground, with the ability to recover approximately 240,000 acre-feet within a 10-month period. Since its construction in 1996, the bank has formed an important component of California's water storage network. For more information, see http://www.kwb.org/index.cfm/fuseaction/Pages.Page/id/330.

[16] For example, injection wells used for aquifer recharge or aquifer storage and recovery require a permit under the federal Safe Drinking Water Act (42 U.S.C. §300h). For further information, see https://www.epa.gov/uic/aquifer-

Although Congress has authorized aquifer storage, recharge, and/or recovery for some individual projects, general congressional guidance in this area has been limited. Under the Water Infrastructure Improvements for the Nation Act (WIIN Act; P.L. 114-322), Congress provided general authority for Reclamation to support new and enhanced federal and state surface and groundwater storage projects under certain, limited circumstances.[17] Reclamation, USDA, and EPA also provide some forms of financial assistance that could support aquifer recharge, storage, and recovery.

Groundwater Rights

Background

Groundwater and Surface Water Interaction

One reason often cited for the evolution of different legal frameworks for groundwater and surface water in most states is the relative lack of understanding of groundwater occurrence and movement in the 19th and early 20th centuries, when states and courts first established laws and rules allocating groundwater. Surface water was more readily understood, being in plain view, but groundwater was considered different and mysterious, being largely unobservable except at the bottom of a well. One commentator noted that the development of groundwater common law in England and the United States in the 19th century was "steeped in ignorance,"[18] as groundwater hydrology and hydraulics were virtually unknown compared to surface water. Citing a legal case from 1861 referring to groundwater, the commentator said,

> the existence, origin, movement and course of such waters, and the causes which govern and direct their movements, are so secret, occult and concealed, that an attempt to administer any set of legal rules in respect to them would be involved in hopeless uncertainty, and would be, therefore, practically impossible.[19]

Groundwater science has made significant strides in the interim, particularly in establishing the interconnected nature of surface water and groundwater in many instances, especially for shallow aquifers. Some observers argue that groundwater law has not kept pace in some cases, in part because of the courts' reluctance to unsettle a system of common law established under the principle of property rights; observers note that a disruption of this system could result in legal chaos.[20]

The complicated nature of groundwater laws and practices is noteworthy because any new executive branch action or federal legislation authorizing action that affects groundwater resources may perturb long-established state and local groundwater management regimes. The practice of managing groundwater and surface water together, termed *conjunctive management*, better reflects the intertwined nature of groundwater and surface water in many situations and is

recharge-and-aquifer-storage-and-recovery.

[17] For more information, see below section, "Reclamation Authority to Provide Financial Support for Groundwater Storage."

[18] Joseph W. Dellapenna, "A Primer on Groundwater Law," *Idaho Law Review*, vol. 49, no. 265 (2013), p. 267. Hereinafter Dellapenna, 2013.

[19] Dellapenna, 2013, citing Frazier v. Brown, 12 Ohio St. 294, 311 (1861).

[20] Dellapenna, 2013, p. 268.

generally recognized as an effective management approach, especially for shallow aquifers. Yet, groundwater law sometimes does not reflect or address that surface-groundwater interconnection.

Federal Reserved Water Rights

Federal reserved water rights doctrine is an important concept in groundwater law. This doctrine holds that when the federal government reserves lands for a particular purpose (such as for a tribal reservation or national monument), the government impliedly reserves a right to water necessary to accomplish the primary purpose for which the reservation was created.[21] Since 1908, when the Supreme Court established the doctrine in *Winters v. United States*, courts have applied this doctrine to surface waters.[22] A March 2017 decision of the U.S. Court of Appeals for the Ninth Circuit (Ninth Circuit) held, for the first time, that the doctrine can encompass groundwater as well.[23]

Congress has recently been involved in Indian water rights settlements, chiefly regarding tribal rights to surface water supplies and the appropriation of funds for enacted settlement agreements. The importance of groundwater to tribal water supplies is increasingly being discussed, and tribal rights to groundwater are the subject of ongoing litigation.[24]

Groundwater Monitoring

Background

Although the states have assumed primary responsibility for groundwater management, several federal agencies monitor, forecast, and assess groundwater conditions in the United States.[25] One agency, USGS, within the Department of the Interior (DOI), is a science agency with no regulatory or management responsibilities for water resources. For decades, USGS has monitored and reported groundwater conditions across the country; developed groundwater models and software tools for characterizing aquifers; and provided long- and short-term forecasts of changing groundwater conditions as part of local and regional groundwater studies.[26] The information is used to support federal, state, and local decisionmakers, and the research is often conducted in collaboration with federal, state, and local partners. For example, USGS makes data from its distributed water database available to stakeholders. The database is a locally managed network of stations that monitor surface-water flow, groundwater levels, and water quality across

[21] See, for example, the U.S. Department of Justice, "Federal Reserved Water Rights and State Law Claims," at https://www.justice.gov/enrd/federal-reserved-water-rights-and-state-law-claims. The nature of the water right for a specific federal reservation depends on various aspects of the reservation, such as its purpose and the mechanism for the reservation; the discussion herein is intended to introduce the topic of groundwater rights related to federal reservations generally and is not intended to clarify how the specific rights related to a reservation are determined. For example, in some cases, Congress has expressly not reserved water rights.

[22] Winters v. United States, 207 U.S. 564, 575-77 (1908).

[23] Agua Caliente Band of Cahuilla Indians v. Coachella Valley Water District, No. 15-55896 (9th Cir. 2017).

[24] See, for example, CRS Insight IN10857, *Federal Reserved Water Rights and Groundwater: Quantity, Quality, and Pore Space*, by Peter Folger.

[25] For more information on the roles of the agencies, see the below section, "Federal Activities and Authorities."

[26] USGS, "USGS Groundwater Information: USGS Groundwater Science for a Changing World," at https://water.usgs.gov/ogw/about/.

the nation. The database includes long- and short-term records from more than 850,000 groundwater measurement sites.[27]

Other agencies, such as NASA and NOAA, make observations and collect data that also are relevant to groundwater monitoring and assessment. Earth-observing satellites that detect changes in gravity, for example, can help link those changes to losses or gains in the volume of groundwater due to pumping or recharge. NOAA's estimation of drought severity throughout the country, as expressed in the U.S. Drought Monitor,[28] includes the estimation of the effects of drought on groundwater supplies. Also, USDA collects irrigation data, including information on wells, characteristics of aquifers used for irrigation supply, and quantities of water applied from wells.[29]

Primer on Groundwater

Groundwater science has advanced markedly in the last century; this primer presents an introduction to fundamental concepts relevant to groundwater use, management, and recharge.

Groundwater is found in aquifers. An aquifer is composed of (1) solid materials, such as rocks and mineral grains; (2) interconnected spaces or openings (*pore space*); and (3) groundwater, which completely fills the pore space (**Figure 2**). Strictly speaking, an aquifer is sufficiently permeable (i.e., groundwater can move readily through the interconnected pores) to transmit economic quantities of water to wells or springs.[30] In other words, if a farmer drills a well into a water-bearing layer of rock or sediments (sometimes called a *formation*) and can pump sufficient quantities of groundwater to irrigate crops, water livestock, or use for drinking water and washing, then that formation can be considered an aquifer. If the same farmer drilled a well but could not pump enough water to satisfy any needs, then the formation would not be considered an aquifer.

Types of Aquifers

There are two principal types of aquifers: unconfined and confined. An *unconfined aquifer* is one in which the water table moves up and down freely without an overlying confining layer (see **Figure 2**).[31]

[27] See, for example, USGS, "USGS Groundwater Watch," at https://groundwaterwatch.usgs.gov/.

[28] See United States Drought Monitor at http://droughtmonitor.unl.edu/.

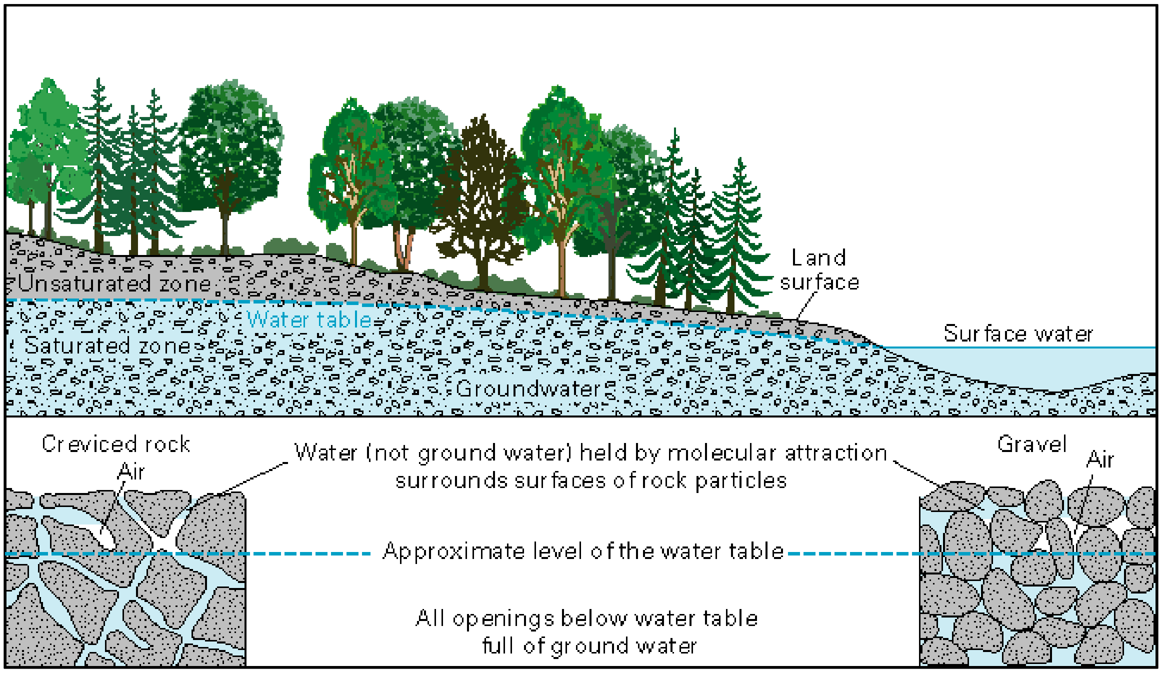
[29] The U.S. Environmental Protection Agency (EPA) plays a significant role in matters related to groundwater quality. Such EPA authorities and activities are beyond the scope of this report.

[30] C. W. Fetter, "Glossary," in *Applied Hydrogeology*, 2nd ed. (Columbus, OH: Merrill Publishing Company, 1988), p. 565.

[31] A *confining layer* is a bed or strata composed of relatively impermeable materials, such as clay, so that groundwater flow through the layer is impeded or significantly restricted. The ability of a bed or strata to conduct groundwater flow is referred to as *hydraulic conductivity*. A confining layer would have a low hydraulic conductivity compared to an aquifer.

Figure 2. Unconfined, or Water Table, Aquifer

(illustrating two types of pore space)

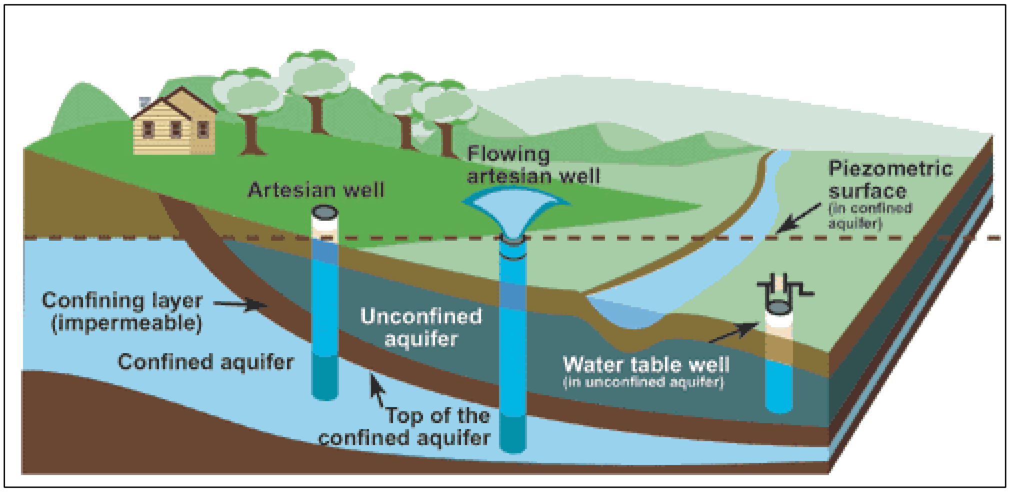


Source: USGS, USGS Water Science School, "Aquifers and Groundwater," at https://water.usgs.gov/edu/earthgwaquifer.html. (Modified by CRS.)

Notes: Above the water table, the pores may contain water but are not completely full. Only the saturated zone below the water table is considered the aquifer.

A *confined aquifer*, in contrast, is an aquifer overlain (and sometimes underlain) by an impermeable or confining layer that the water does not freely move above. The confining beds cause the aquifer to be under pressure. As a result, when a well penetrates a confined aquifer, the water will rise above the top of the aquifer, sometimes all the way to the land surface (the latter case is referred to as an *artesian aquifer*), as shown in **Figure 3**.

Figure 3. Different Types of Aquifers and Wells



Source: Government of Canada, Environment and Natural Resources, "Water Sources: Groundwater," at https://www.canada.ca/en/environment-climate-change/services/water-overview/sources/groundwater.html.

Notes: The piezometric surface in the figure refers to an imaginary line that corresponds to where the water level in the confined aquifer would rise if not for the impermeable confining layer. It also corresponds to the water level in the artesian wells shown in the figure.

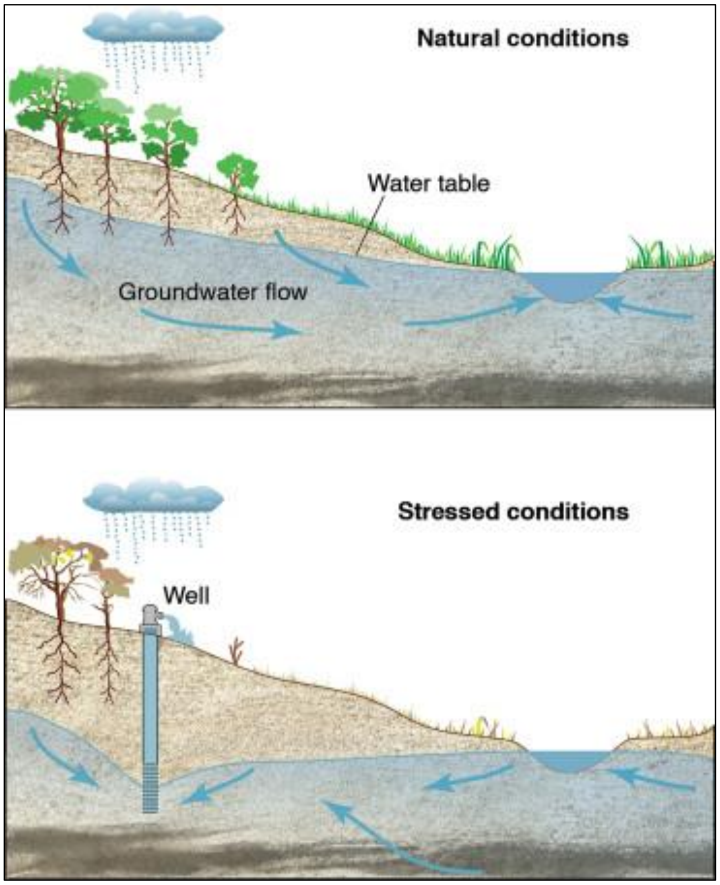
The distinction between unconfined and confined aquifers is important for this discussion, as the technique of groundwater recharge, storage, and recovery differs depending on what kind of aquifer is involved. Because a confining layer or layers separates a confined aquifer from surface water bodies, the degree of connection between surface water and groundwater is not as direct or distinct as it is for unconfined aquifers.[32] Groundwater recharge can occur naturally in confined and unconfined aquifers as water moves downward from the land surface into the aquifer from rain and melting snow, lakes, river, and streams. For unconfined aquifers, other sources of recharge water can include built impoundments, such as reservoirs; unlined irrigation ditches and canals; and applied irrigation water not consumed by crops. In a system of managed *artificial recharge*, water can be added deliberately to a confined or unconfined aquifer by using an injection well; by spreading water across the land surface, where it can trickle down into an unconfined aquifer; or by building an impoundment to temporarily store water and allow it to leak through the bottom down to an unconfined aquifer.

The distinction between an unconfined and a confined aquifer also is important for understanding the connection between surface water and groundwater. In **Figure 3**, the confined aquifer is separated from the river by a confining layer, so that changes in river flow will not directly affect groundwater in the confined aquifer and flow from the artesian wells will not directly affect flow in the river. In **Figure 4**, by contrast, the unconfined aquifer is connected directly to the stream. Under natural conditions, the groundwater will flow toward and feed the stream (top panel) because the slope of the water table is toward the top of the stream level. However, sometimes when aquifers are subject to excessive pumping—during drought conditions, for example, or because of a lack of surface water availability—they are said to be under stress. Under stressed conditions (bottom panel of **Figure 4**), pumping from a well will cause the water table to slope

[32] Decades of groundwater development involving hundreds or thousands of wells in some agricultural regions of the United States, such as California's Central Valley, sometimes have led to interconnections between the unconfined and confined aquifers. Wells penetrating the confining layer above the confined aquifers can serve as conduits for groundwater to flow up or down. See, for example, Claudia C. Faunt et al., *Groundwater Availability of the Central Valley Aquifer, California*, USGS, Professional Paper 1766, 2009, pp. 85-86.

away from the top of the stream. In that case, the water in the stream will leak through the stream bottom and flow into the aquifer, toward the pumping well.

Figure 4. Unconfined Aquifer Without Pumping (top) and With Pumping (bottom)

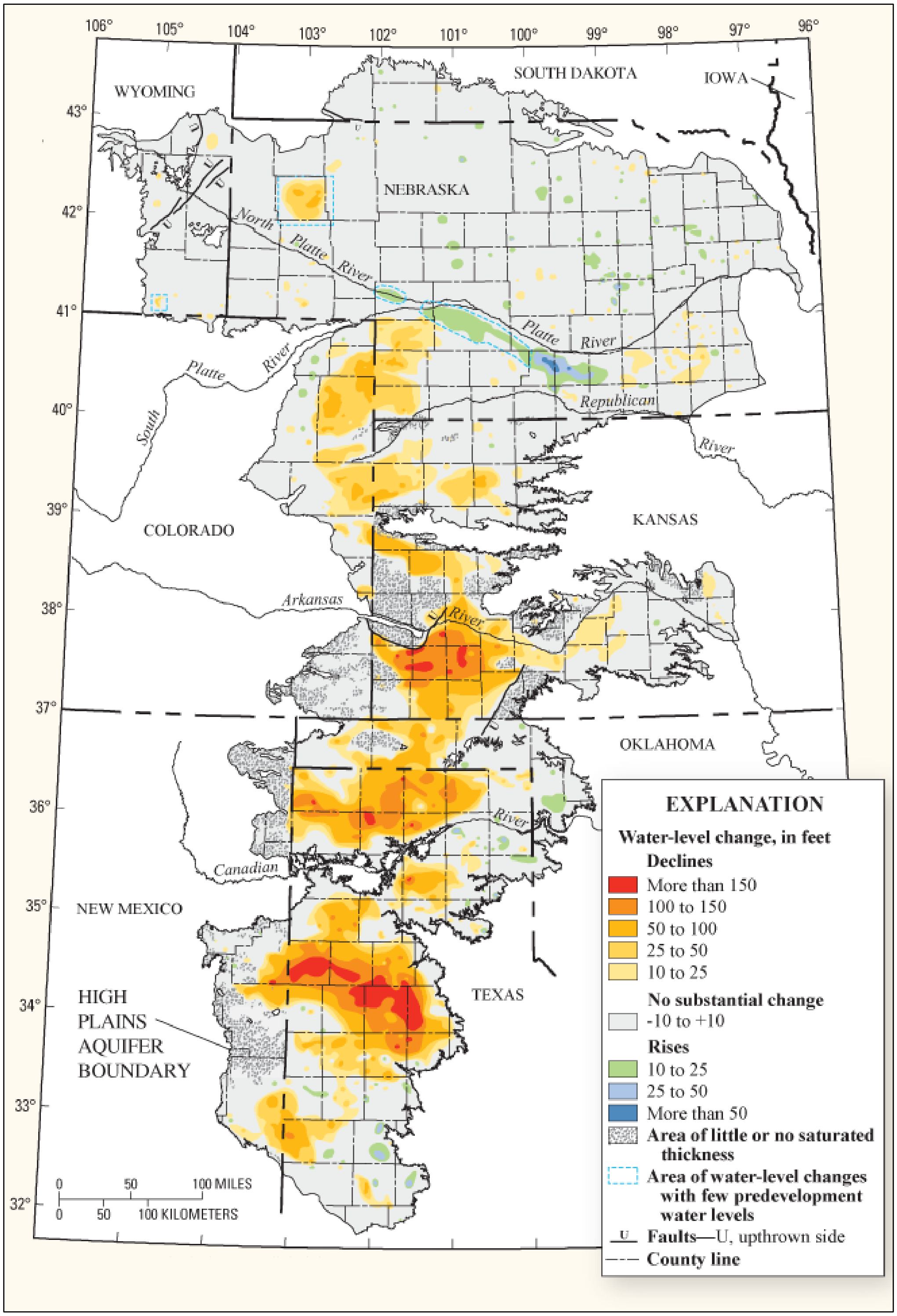


Source: Steven M. Gorelick and Chunmiao Zheng, "Global Change and the Groundwater Management Challenge," Water Resources Research, vol. 51, March 28, 2015 (with permission).

Notes: Under natural conditions in this particular case, groundwater flows toward the stream (arrows indicate direction of groundwater flow) and the water table is high enough to be accessible to trees and plants. During pumping, when the aquifer is stressed, water flows from the stream into the aquifer and toward the well. Also, the water table under stressed conditions drops below the roots of trees and plants depicted in the figure, affecting their growth.

Consistently stressed conditions can have dramatic long-term effects on groundwater. If pumping continues in excess of recharge, increasing stress on the aquifer, the water table may drop tens to hundreds of feet (**Figure 5**). This situation has occurred in many regions of the United States, including the Ogallala aquifer (also called the High Plains aquifer) underlying several Midwest and Great Plains states and in California's Central Valley. In the Central Valley, historical levels of pumping caused the water table to drop so far in some areas that it caused the land surface to drop, or subside, nearly 30 feet (**Figure 6**). Excessive land subsidence can harm surface structures, such as canals and levees.

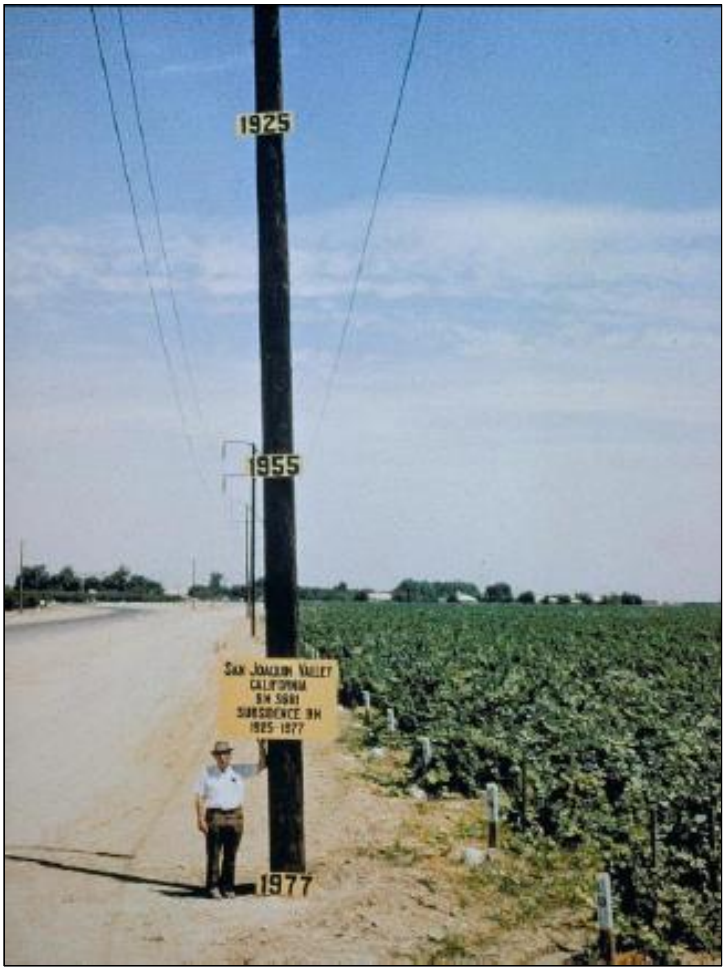
Figure 5. Water Level Changes in the High Plains Aquifer, Predevelopment to 2007



Source: V. L. McGuire, "Changes in Water Levels and Storage in the High Plains Aquifer, Predevelopment to 2007," USGS, Fact Sheet 2009-3005, February 2009. (Modified by CRS.)

Note: *Predevelopment* refers to approximately 1950.

Figure 6. Land Subsidence in the San Joaquin Valley Southwest of Mendota Between 1925 and 1977



Source: Devin Galloway et al., "Land Subsidence in the United States," USGS Circular 1182, 1999, p. 23, at http://pubs.usgs.gov/circ/circ1182/pdf/06SanJoaquinValley.pdf.

Note: Approximate location of the maximum land subsidence in the United States, showing the approximate relative position of the land surface in 1925, 1955, and 1977.

Federal Activities and Authorities

The federal government directly and indirectly influences how groundwater is managed in the United States. Several federal agencies monitor groundwater directly or with partners—through measurements at wells and springs—and remotely, using satellites or other remote sensing devices to provide information on groundwater flow, storage, depletion, and other characteristics that help inform state and local groundwater management. These agencies include the USGS, NASA, the National Oceanic and Atmospheric Administration, and USDA. Congress has provided other federal agencies with the authority to make water delivered from or water stored at federal water resource projects available for groundwater recharge, storage, and recovery. These include the two principal federal water resources agencies: USACE (which operates nationwide) and Reclamation (which operates in the 17 coterminous states west of the Mississippi River). Reclamation, USDA, and EPA also provide some forms of financial assistance that could support groundwater storage, recharge, and recovery.

Additionally, when the federal government reserves lands for a particular purpose (such as for a tribal reservation or national monument), it impliedly reserves a right to water necessary to accomplish the purposes for which the reservation was created. That federal reserved water rights doctrine has long been recognized for surface water; more recently, it is also being considered for groundwater. (See discussion under "Groundwater Rights.")

Groundwater Monitoring and Assessment

Several federal agencies that have no regulatory role in managing groundwater are authorized to collect data, make observations and assessments, and provide information on groundwater supplies that supports decisionmakers at the state and local levels. USGS likely provides the most direct groundwater information and support for groundwater management among the federal agencies, although NASA and NOAA also make pertinent observations and distribute groundwater-relevant information. USDA also collects groundwater data related to irrigation. Selected activities within those four agencies are briefly summarized below.

U.S. Geological Survey

The Groundwater and Streamflow Information Program, within the USGS water resources mission area, funds activities that provide information directly relevant to groundwater management. About 10% ($7.5 million in FY2019) of the approximately $74 million program is directed at groundwater-related activities, including the National Groundwater Monitoring Network (NGWMN).[33] The NGWMN is a compilation of selected groundwater monitoring wells from federal, state, and local monitoring networks across the country. Data from the network are accessible through a portal that contains current and historical data.[34] USGS administers the program through cooperative agreements with state and local water resource agencies; in FY2020, Congress provided $3.9 million to USGS to fund the network, the same as the enacted amounts for the previous four years.[35]

USGS also maintains a distributed groundwater database, the USGS Groundwater Watch. It is locally managed and contains data from more than 850,000 wells compiled over the past 100 years. The long-term and distributed nature of the data is valuable to groundwater managers seeking information about regional groundwater trends over time. **Figure 7** shows an example of one of the products updated daily from groundwater well information within the database.

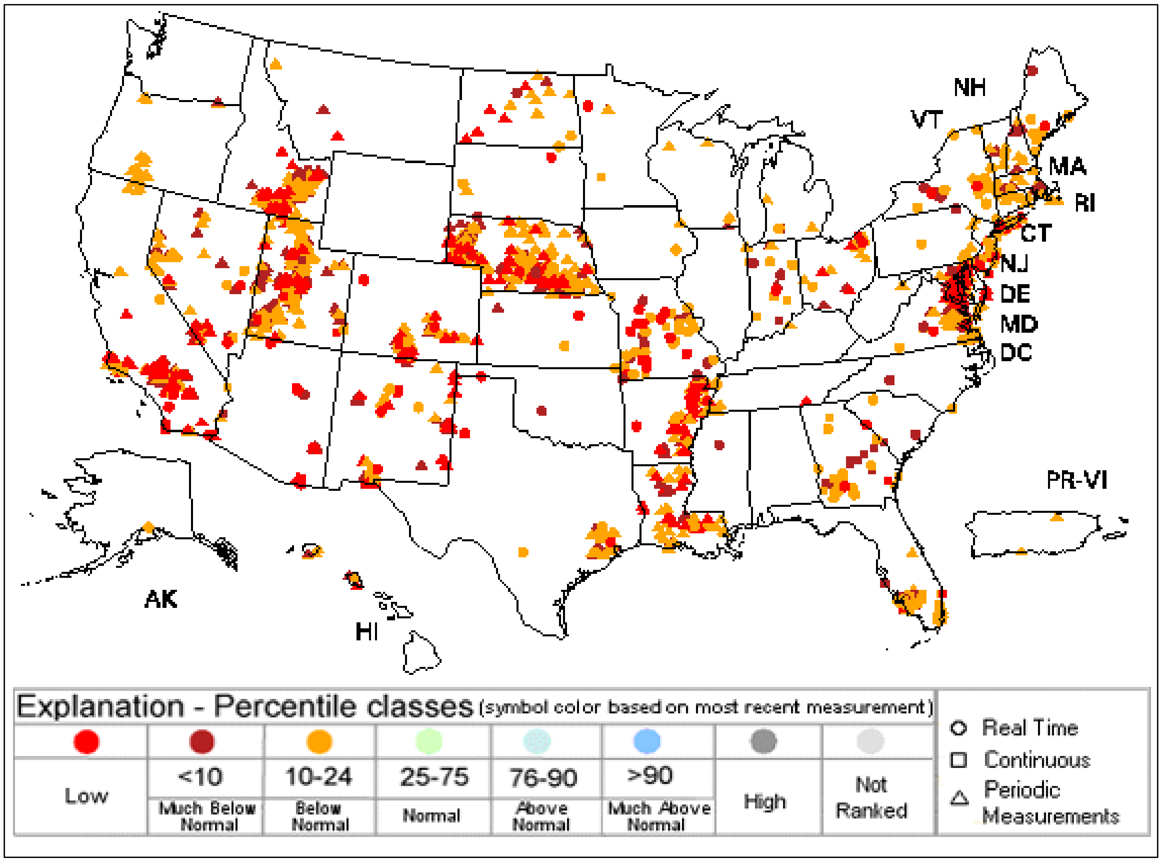
[33] Email from Jeffrey Onizuk, USGS Congressional Affairs, March 19, 2020.

[34] Advisory Committee on Water Information, "National Ground-Water Monitoring Network," at https://cida.usgs.gov/ngwmn/index.jsp.

[35] Email from Jeffrey Onizuk, USGS Congressional Affairs, March 19, 2020.

Figure 7. Below-Normal Groundwater Levels for Actively Monitored Wells

(data from 3,855 wells)



Source: USGS, "Groundwater Watch," at https://groundwaterwatch.usgs.gov/net/ogwnetwork.asp?ncd=lwl. (Modified by CRS.)

Notes: Below-normal means that the wells shown in red or orange had groundwater levels at the 24th percentile or lower for the month the well was measured, compared to the entire period of record for the well. In other words, if the well has been measured for 50 years, it would be shown on this map if the water level was lower than 75% of the measurements taken over the past 50 years. Red dots indicate wells lower than the 10th percentile; orange shows wells at the 10th-24th percentile.

In addition to collecting and providing data, USGS conducts regional groundwater studies, such as assessing the groundwater availability in the Central Valley aquifer in California,[36] and national overviews, such as the *Ground Water Atlas of the United States*.[37] Several observers have suggested that although groundwater generally is locally managed in the United States, regional studies (such as those conducted by USGS) are important for documenting the status and trends of groundwater availability, as these trends affect local groundwater resources, particularly when changes in an aquifer occur beyond the local or state political boundaries.[38]

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[36] C. C. Faunt et al., *Groundwater Availability of the Central Valley Aquifer, California*, USGS, USGS Professional Paper 1766, 2009, at https://pubs.usgs.gov/pp/1766/.

[37] James A. Miller et al., *Ground Water Atlas of the United States*, USGS, 2000, at https://water.usgs.gov/ogw/aquifer/atlas.html.

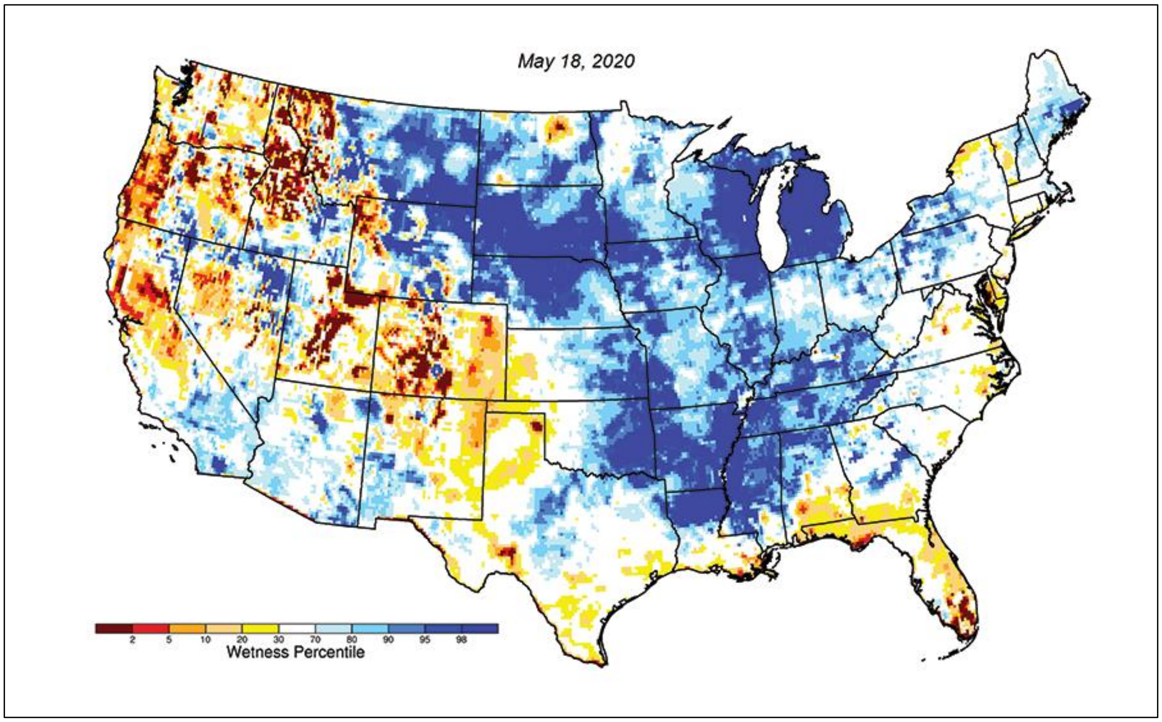
[38] See, for example, K. F. Dennehy, T. E. Reilly, and W. L. Cunningham, "Groundwater Availability in the United States: The Value of Quantitative Regional Assessments," *Hydrogeology Journal*, vol. 23, no. 8 (December 2015), pp.

NASA

Earth-observing satellites can provide information to assess changes in the amount of groundwater stored in large aquifers, variations in the amount of soil moisture, and tiny fluctuations in land elevation that reflect how the water table is moving up and down.

Using data from NASA's GRACE and SMAP satellites,[39] integrated with other observations, scientists can analyze shallow groundwater and soil moisture levels that reflect drought conditions across the United States (**Figure 8**).

Figure 8. Shallow Groundwater and Soil Moisture Comparison from NASA Satellite Data



Source: The National Drought Mitigation Center, "Groundwater and Soil Moisture Conditions from GRACE Data Assimilation," at http://nasagrace.unl.edu/Default.aspx. (Modified by CRS.)

Notes: Map shows wet or dry conditions relative to the probability of occurrence using the baseline period from 1948 to 2012, expressed as a percentile. The lower values in the warmer colors indicate drier-than-normal conditions (30th percentile or less), and the cooler colors indicate wetter-than-normal conditions (70th percentile or more). Areas in white express 31st-69th percentile, spanning the midpoint of 50th percentile (the 50th percentile indicates that half the values are higher and half are lower). The map is available for the contiguous United States from the data source and does not include Alaska and Hawaii.

Data from the GRACE satellite also have been interpreted to show changes in the amount of groundwater held in storage in large, regional aquifers, such as the Central Valley aquifer in California, the High Plains aquifer underlying several states in the Midwest and Great Plains, and

1629-1632; and Roland Barthel, "A Call for More Fundamental Science in Regional Hydrogeology," *Hydrogeology Journal*, vol. 22, no. 3 (May 2014), pp. 507-510.

[39] GRACE stands for Gravity Recovery and Climate Experiment satellite (see https://www.nasa.gov/mission_pages/Grace/index.html); SMAP stands for Soil Moisture Active Passive satellite (see https://smap.jpl.nasa.gov/).

other large aquifers around the world.[40] One study using GRACE data indicated that the volume of groundwater in the Central Valley aquifer pumped out over a 78-month period was equivalent to nearly the capacity of Lake Mead.[41]

Scientists can use a special type of radar data collected by satellites using a technique called synthetic aperture radar interferometry to detect minute changes in the land-surface elevation caused when the water table moves up and down. In one study, NASA scientists and others used the technique to track how the aquifer in the Santa Clara Valley, California, recovered following depletion during a drought when conservation measures were put in place to limit groundwater pumping.[42] In that study, a cluster of Italian satellites provided the radar data. NASA is planning a joint mission with the Indian Space Research Organisation in 2021 that would collect radar imagery of nearly every major aquifer in the world.[43]

NOAA

NOAA coordinates and integrates drought research and forecasting from federal, state, tribal, local, and academic sources through the National Integrated Drought Information System. NOAA uses data from these and other sources to create drought maps, seasonal outlooks, and other drought indicators, including effects of drought on groundwater.[44] A typical U.S. Drought Monitor map, for example, indicates which regions of the country are experiencing short- and long-term impacts from drought. Long-term-impacted regions mean that drought has affected the region's hydrology, including groundwater resources.

NOAA's constellation of both geostationary and polar-orbiting weather satellites provides real-time atmospheric weather data that can be used to better understand the hydrologic cycle in regions across the country. The satellite data contribute to short- and long-term forecasts of precipitation that, for example, can inform groundwater models and other tools about water available for groundwater recharge. NOAA data from satellites and ground-based observing systems also feed into longer-term climate forecasts and climate models, which can be used to help understand the potential effects of climate change on groundwater supplies.

USDA

The Census of Agriculture is required by law and authorizes the Secretary of Agriculture to conduct surveys deemed necessary to furnish annual or other data on the subjects covered by the census.[45] The census is a broad survey that includes questions about irrigation and water use, and is conducted every five years. A more detailed national assessment of irrigated agriculture in the

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[40] See, for example, NASA, Jet Propulsion Laboratory, "GRACE Tellus: Groundwater," at https://grace.jpl.nasa.gov/applications/groundwater/.

[41] About 31 cubic kilometers, or 6.8 trillion gallons. See J. S. Famiglietti et al., (2011), *Satellites Measure Recent Rates of Groundwater Depletion in California's Central Valley*, Geophys. Res. Lett., 38, L03403, at doi:10.1029/2010GL046442.

[42] Estelle Chaussard et al., "Remote Sensing of Ground Deformation for Monitoring Groundwater Management Practices: Application to the Santa Clara Valley During the 2012-2015 California Drought," *Journal of Geophysical Research-Solid Earth*, vol. 122, no. 10 (September 21, 2017), pp. 8566-8582.

[43] See, for example, NASA, Jet Propulsion Laboratory, "Satellites See Silicon Valley's Quick Drought Recovery," October 3, 2017, at https://www.jpl.nasa.gov/news/news.php?feature=6962.

[44] See National Integrated Drought Information System (NIDIS), "What Is NIDIS?," at https://www.drought.gov/drought/what-nidis.

[45] 7 U.S.C. 2204g et seq.

United States is the Irrigation and Water Management Survey (formally the Farm and Ranch Irrigation Survey), also conducted every five years, and usually two or three years after the general census and under the same authority.[46] The most recent Irrigation and Water Management Survey (2018), conducted by the National Agricultural Statistics Service in USDA, supplemented the basic irrigation data collected from all farm and ranch operators in the 2017 census.[47]

Federal Authority Related to Groundwater Recharge, Storage, and Recovery

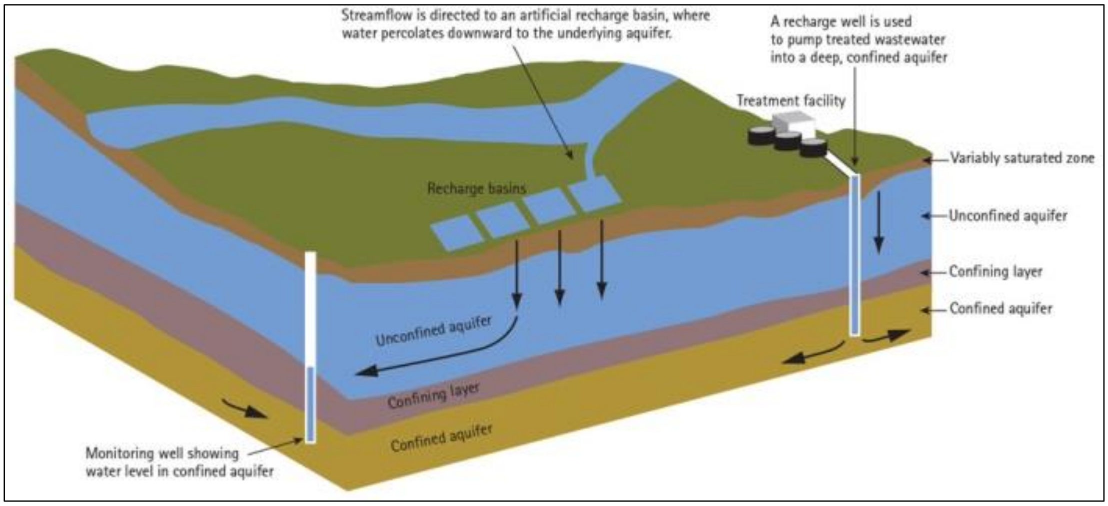
Recharging groundwater artificially with surface water is not a new concept, but interest in the practice is growing at the local, state, and federal levels for several reasons. When surface water supplies are curtailed because of drought, diversion for other uses, regulatory constraints, or other reasons, groundwater is often used to meet the demand. In addition, if demand for water supplies increases and additional surface water is not available, consumers may turn to groundwater. Along the coastline, groundwater extraction and the lowering of the water table sometimes have resulted in saltwater intrusion into the aquifer. Groundwater recharge may be used in those cases to replenish the aquifer and create a freshwater barrier to prevent seawater encroachment. Groundwater recharge, storage, and recovery also may be part of a conjunctive water management strategy in which both surface and groundwater are used, recharging groundwater in times of surface water surplus and extracting groundwater when surface water is in short supply.

Typically, groundwater recharge, storage, and recovery involves either injecting water into the aquifer through a well or allowing water to recharge from an impoundment (e.g., a pond) or a spreading basin (water is spread on the ground to percolate down to the aquifer). The water is stored in the aquifer until it is recovered by a pumping well for freshwater supply. **Figure 9** illustrates the process.

[46] For more information on the most recent Irrigation and Water Management Survey, see U.S. Department of Agriculture, Census of Agriculture, "2018 Irrigation and Water Management Survey," at https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/index.php.

[47] The USDA Irrigation and Water Management Survey differs from the USGS water use estimates report in methodologies and reporting schedules and should not be compared directly. See footnote 6.

Figure 9. Groundwater Recharge, Storage, and Recovery



Source: National Groundwater Association (NGWA), "Managed Aquifer Recharge: A Water Supply Management Tool," NGWA Information Brief, 2014 (with permission). (Modified by CRS.)

Notes: The figure shows how the aquifer is recharged using a recharge well (on the right) and from recharge basins (middle of the figure). The recharge well is recharging a confined aquifer, and the recharge basins are recharging an unconfined aquifer.

According to several sources, more than 1,000 aquifer recharge wells and aquifer storage and recovery wells, along with many recharge basins, have been constructed across the nation.[48] In addition to technical, economic, and regulatory issues, identifying and providing a source of water for these activities is critical. Increasingly, federal water resource projects, such as those managed by Reclamation and USACE, are being considered as potential sources of recharge water. Reclamation, USDA, and EPA are also potential sources of financial assistance for supporting aquifer recharge, storage, and recovery projects. This section identifies various federal authorities for groundwater storage, recharge, and recovery.

Bureau of Reclamation

Reclamation, a federal agency of the Department of the Interior, owns and operates hundreds of dams and water diversion structures projects in the 17 coterminous U.S. states west of the Mississippi River. Reclamation was created by Congress in the Reclamation Act of 1902,[49] which authorized the Secretary of the Interior to construct irrigation works in western states. In addition to water supply, Reclamation facilities also provide flood control, recreation, and fish and wildlife benefits.[50] Reclamation cites several authorities for groundwater activities, including the authority to deliver project and excess water for aquifer storage and recharge and the authority to provide financial support for these activities. These authorities are discussed below.

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[48] See, for example, U.S. Environmental Protection Agency, Underground Injection Control, "Aquifer Recharge and Aquifer Storage and Recovery," at https://www.epa.gov/uic/aquifer-recharge-and-aquifer-storage-and-recovery#inventory; and National Groundwater Association, "Aquifer Storage and Recovery: Need for Critical Analysis of the Technical, Economic, and Regulatory Issues," at http://www.ngwa.org/Media-Center/issues/Pages/Aquifer-storage-and-recovery.aspx.

[49] Act of June 17, 1902 (ch. 1093, 32 Stat. 388).

[50] For a brief synopsis of Reclamation project authorization and financing, see CRS In Focus IF10806, *Bureau of Reclamation Project Authorization and Financing*, by Charles V. Stern.

Reclamation Authority to Deliver Project or Excess Water for Groundwater Use

Overall, Reclamation reports no federal restrictions on its authority to deliver project or excess water to contractors for groundwater recharge, and contractors using these waters for groundwater recharge are not required to seek any special approvals beyond what is normally required by Reclamation. However, DOI officials also have acknowledged that Reclamation's existing authorities for groundwater use are general in nature, and increased specificity of these authorities may be useful.[51] For example, some aquifers underlie both project and non-project areas, with non-project areas being the preferable delivery location for groundwater uses due to one or more factors (e.g., land use, geology). However, under Reclamation's existing authorities, the delivery of "project waters" (i.e., waters for which Reclamation holds water rights) for groundwater uses may be limited to lands within a Reclamation project's authorized boundaries. As a result, some have urged Congress to clarify Reclamation authorities to deliver project water for groundwater recharge outside of project boundaries.[52] Reclamation also reports that some state restrictions affect the use of these waters for groundwater activities. In general, Reclamation does not track the use of project or excess water for groundwater recharge, although these uses appear to be occurring in at least a few places. The following authorities have been or may be used by Reclamation for groundwater storage:

- Section 9 of the Reclamation Project Act of 1939 (43 U.S.C. §485) is the general authority by which Reclamation is authorized to enter into contracts to furnish water for irrigation, municipal, and miscellaneous water supply purposes. Reclamation interprets the purposes of deliveries under this section to include groundwater recharge.
- Section 1 of the Warren Act of February 21, 1911 (43 U.S.C. §523), authorizes Reclamation to enter into contracts for the conveyance and storage of non-project water through the federal reclamation project, when the water is to be used for irrigation purposes and excess capacity exists. This authority has in some cases been used for groundwater recharge.[53]
- Section 215 of the Reclamation Reform Act of 1982 (P.L. 97-293) is the authority Reclamation uses to enter into temporary water service contracts for un-storable or excess flood flows. Reclamation indicates that it has no restrictions on using these waters for groundwater recharge.
- Section 101(d) of the Reclamation States Emergency Drought Relief Act of 1991 (P.L. 102-250) authorizes Reclamation to participate in state-established *water banks* to respond to drought.[54]

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[51] Statement of Timothy Petty, Assistant Secretary for Water and Science, U.S. Department of the Interior, before the U.S. Congress, Senate Committee on Energy and Natural Resources, *Full Committee Hearing to Examine the 2018 Western Water Supply Outlook and Bills Related to Water Infrastructure and Drought Resiliency*, 115th Cong., 2nd sess., March 22, 2018.

[52] See, for example, U.S. Congress, Senate Committee on Energy and Natural Resources, *Aquifer Recharge Flexibility Act*, Report to Accompany S. 1570, 116th Cong., 1st sess., October 29, 2019, S.Rept. 116-155 (Washington: GPO, 2019). Hereinafter, "S. Rept. 116-155."

[53] In its report accompanying S. 1570, the *Aquifer Recharge Flexibility Act*, the Senate Committee on Energy and Natural Resources noted that the ability to enter into a Warren Act contract for groundwater recharge has been "unevenly" applied by Reclamation. See S.Rept. 116-155.

[54] *Water banking* generally means the temporary storage of water in an aquifer for later extraction and use. See U.S. Bureau of Reclamation, *Groundwater Banking Guidelines for Central Valley Project Water* (under P.L. 102-575 §3408(d)), November 12, 2014, at https://www.usbr.gov/mp/waterbanking/docs/water-banking-guidelines.pdf.

- Section 3408((c), (d), and (e)) of the Central Valley Project (CVP) Improvement Act of 1992 (P.L. 102-575) authorize the *banking* of CVP water, consistent with and subject to state law.

Reclamation Authority to Provide Financial Support for Groundwater Storage

- Title IX, Subtitle F (Secure Water), Section 9504 (Water Management Improvement) of the Omnibus Public Land Management Act of 2009 (P.L. 111-11) authorizes Reclamation to provide financial assistance through the WaterSMART program for groundwater projects.[55]
- Title III, Section 4007(c) of the Water Infrastructure Improvements for the Nation Act (WIIN Act; P.L. 114-322) authorizes Reclamation to participate in state-led storage projects, which are defined to include groundwater storage facilities, among other facility types.
- Title III, Section 4009(a) of the WIIN Act amended the Water Desalination Act of 1996 (P.L. 104-298) to authorize Reclamation to provide financial support for projects that involve the desalination of brackish groundwater.
- Reclamation's Title XVI program (Title XVI of P.L. 102-575) provides Reclamation with the authority to implement water recycling and reuse projects, which may include projects that recycle and reuse impaired groundwater.

U.S. Army Corps of Engineers

USACE, an agency within the Department of Defense, has both military and civil works responsibilities. Congress directs USACE's civil works activities through authorizations, appropriations, and oversight of the agency's study, construction, and ongoing operations of water resource projects. Its civil works responsibilities are to support coastal and inland commercial navigation, reduce riverine flood and coastal storm damage, and protect and restore aquatic ecosystems in U.S. states and territories. In undertaking projects for these purposes, USACE also may pursue additional project benefits related to water supply, hydropower, recreation, fish and wildlife enhancement, and other purposes. That is, USACE projects typically have navigation, flood control, and/or aquatic ecosystem restoration as a primary purpose; other purposes and benefits are generally secondary or incidental. Therefore, USACE projects may support groundwater recharge, but generally recharge is not the primary purpose or justification for the projects. Moreover, USACE activities generally are in support of, rather than a direct performance of, aquifer recharge; that is, how USACE operates its projects may affect how others perform groundwater recharge or may affect the water demand that is met by water stored at USACE reservoirs or by groundwater pumping.[56]

USACE water resource projects typically are for nonconsumptive water uses (e.g., dams that store water to reduce the peak flow of a river during flood conditions), with a few specifically authorized exceptions; thus, the federal government generally has not acquired water rights from states for USACE projects. To access project water for water supply purposes, including groundwater recharge activities, nonfederal entities are responsible for securing any water rights

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[55] For more information on the WaterSMART program, see U.S. Bureau of Reclamation, "WaterSMART (Sustain and Manage America's Resources for Tomorrow)," at https://www.usbr.gov/watersmart/.

[56] The effect that USACE projects may have on altering hydrology in a basin, including natural recharge in the floodplain, is beyond the scope of this report.

pursuant to state law. USACE generally does not deliver water under contract, in contrast to Reclamation. Instead, USACE provides storage at its reservoirs as a nonconsumptive service. USACE has some, albeit constrained, flexibility and authorities to operate its projects to benefit groundwater recharge.[57] That is, for projects with purposes of *water conservation* or *water supply storage*, USACE may be able to operate them in ways that support recharge.[58]

Prior to the WIIN Act in 2016, USACE had no general authority to include storage space in USACE projects for seasonal operations (i.e., short-term retention of water for a few months if storage space is available based on seasonal hydrologic patterns) for water conservation that would benefit municipal and industrial (M&I) water supply.[59] Notwithstanding those projects with specific authorization for water conservation, USACE policy and procedures indicated that seasonal operations for water supply could be conducted insofar as they were consistent with authorized project purposes and law, and subject to hydrologic and hydraulic capability of the project. Nonfederal entities could use the water supply to enhance groundwater replenishment, to increase downstream flow, or to otherwise enhance the general usage of the project for M&I purposes. Also, USACE has two long-standing general authorities related to M&I water supply: a surplus water authority and a water supply authority for permanent reallocations of storage at a reservoir.[60]

Title I of the WIIN Act addressed seasonal operation for water conservation and groundwater recharge in three sections[61]

- **Section 1116**: In a state with a drought emergency between December 2015 and December 2016, the Secretary of the Army is authorized to evaluate and carry out water supply conservation measures, including releases for groundwater replenishment or aquifer storage and recovery.
- **Section 1117**: In a state with a drought emergency between December 2015 and December 2016, upon the request of the governor, the Secretary of the Army is authorized to prioritize the updating of the water control manuals for control structures in the state and incorporate into the manuals seasonal operations for water conservation and water supply for such control structures.
- **Section 1118**: At the request of a nonfederal interest, the Secretary of the Army may review proposals (except those involving a few excluded river basins) to

[57] CRS did not identify any federal restrictions on the use of water released from or water withdrawn from USACE reservoirs for groundwater recharge, as long as that use is consistent with state law (i.e., the entity capturing the water has a right to use the water pursuant to state law) and federal environmental protection laws (e.g., the Safe Drinking Water Act). USACE does not track whether water released from or water withdrawn from USACE reservoirs is used for recharge.

[58] Some USACE aquatic ecosystem restoration projects may have components that relate to groundwater (e.g., aquifers may provide minimum flows into certain streams during low-water conditions). Given this report's focus on the consumptive social uses of groundwater, USACE groundwater-related ecosystem restoration projects and authorities are not discussed further in this report.

[59] USACE Institute for Water Resources, *Comprehensive Water Supply Study*, September 2001, at http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/01-PS-1.pdf;USACE, *Planning Guidance Notebook*, ER 1105-2-100, April 22, 2000, at http://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1105-2-100.pdf.

[60] For more on these authorities and how they are used, see CRS Report RL30478, *Federally Supported Water Supply and Wastewater Treatment Programs*, coordinated by Jonathan L. Ramseur.

[61] USACE has published implementation guidance for each of the WIIN Act provisions discussed below; they are available at http://www.usace.army.mil/Missions/Civil-Works/Project-Planning/Legislative-Links/wrda2016/wrda2016_impguide/.

> increase the quantity of available water supplies at a federal water resources development project by modifying the project, modifying how the project is managed, or accessing water released from the project. Among other things, proposals may include diversion of water released or withdrawn from the project to recharge groundwater or for aquifer storage and recovery.

As with other aspects of USACE reservoir operations, the storage or release of water to support nonfederal recharge activities pursuant to these authorities is to be consistent with the USACE project's congressionally authorized project purposes and subject to the project's capability.

In September 2019, EPA released a draft national action plan for water reuse that included the following recommended action on incorporating water reuse into USACE projects:

> Civil Works projects are developed, implemented, and operated with non-federal sponsors for flood risk management, commercial navigation, ecosystem restoration, recreation, and environmental stewardship. Clarification on how the civil works project development process can directly include water reuse considerations could enable better incorporation of such reuse features in projects authorized by Congress.[62]

In particular, interest has been growing regarding how to capture and use floodwaters to enhance groundwater recharge on agricultural lands and in urban areas. One method is to reestablish more natural floodways rather than confined channels transporting flood flows. Congress has authorized USACE to evaluate more nature-based approaches in legislation.[63] Among the challenges for reestablishing wider floodplains are real estate-related property rights and maintaining flood risk reduction in developed areas.[64]

USDA

USDA does not have a federal mandate to control groundwater use, recharge, storage, or recovery on private agricultural lands. The disproportionate percentage of groundwater usage by agriculture relative to other industries, however, has led USDA to take an active role in research, conservation, and education related to groundwater and its agriculturally connected uses.

Conservation of Groundwater

USDA provides agricultural producers with financial and technical assistance, as well as research to conserve on-farm water use. A number of USDA agencies provide support through education, outreach, and research in addition to providing direct federal assistance for adoption of on-farm irrigation best management practices. For more information on irrigation in the United States and related best management technologies, see CRS Report R44158, *Irrigation in U.S. Agriculture: On-Farm Technologies and Best Management Practices*.

Financial assistance for irrigation conservation practice adoption is primarily authorized through omnibus farm bills. Most recently, the 2018 Agriculture Improvement Act (2018 farm bill; P.L. 115-334) authorized a number of programs that provide cost-share assistance to private farm and

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[62] U.S. Environmental Protection Agency, *National Water Reuse Action Plan Draft*, September 2019, p. 21, at https://www.epa.gov/sites/production/files/2019-09/documents/water-reuse-action-plan-draft-2019.pdf.

[63] For example, see Section 1184 of WIIN Act, as amended (33 U.S.C. §2289a), and Sections 1176 and 1183 of WIIN Act.

[64] Thomas Jacobson, "Too Much Water, Not Enough Water: Planning and Property Rights Considerations for Linking Flood Management and Groundwater Recharge," *Water International*, vol. 4, no. 5 (September 2019).

ranch land owners to adopt water conserving practices.[65] Technical assistance, which includes planning and design of on-farm water conservation measures, can be provided either in connection with financial assistance or through a separate irrigation water management plan.[66] The primary USDA agency administering both financial and technical assistance is the Natural Resources Conservation Service.

USDA also conducts research into groundwater-related areas, such as irrigation technologies, plant water use efficiency, hydrologic connectivity, and source water protection, to name a few. Primary research activities are conducted either through the Agricultural Research Service, USDA's intramural research agency, or the National Institute of Food and Agriculture, which administers extramural funding to support agriculture-related science and research, primarily at state universities.

U.S. Environmental Protection Agency[67]

To promote development of and private investment in water infrastructure projects, the 113th Congress authorized the Water Infrastructure Finance and Innovation Act (WIFIA) in the Water Resources Reform and Development Act of 2014 (P.L. 113-121, Title V; 33 U.S.C. §§3901-3914). WIFIA authorizes EPA and USACE to provide credit assistance—secured or direct loans—for a range of water infrastructure projects. EPA is implementing a WIFIA program.

Categories of projects eligible for assistance from EPA's WIFIA program include aquifer recharge or development of alternative water supplies to reduce aquifer depletion, among others. Activities eligible for WIFIA assistance include project development and planning, construction, acquisition of real property, and carrying costs during construction. WIFIA credit assistance is available to a number of entities, including private entities, some of which may be interested in aquifer recharge, storage, and recovery projects.[68]

Projects carried out by private entities are required to have a public sponsor to be eligible for WIFIA assistance. WIFIA requires private entities to demonstrate to EPA that the affected state, local, or tribal government supports the project. The maximum amount of a loan is 49% of eligible project costs, but the act authorizes EPA to make available up to 25% of available funds each year for credit assistance in excess of 49% of project costs. Except for certain projects, the total amount of federal assistance (i.e., WIFIA and other sources combined) may not exceed 80% of a project's cost.[69]

[65] For example, the Environmental Quality Incentives Program (EQIP) provides financial assistance to address natural resource concerns, including water conservation, under the general authorities established in §§1240-1240G of the Food Security Act of 1985 (P.L. 99-198), as amended (16 U.S.C. 3839aa et seq.).

[66] Most conservation technical assistance is provided by USDA under the general authorities of the Soil Conservation and Domestic Allotment Act (P.L. 74-46), as amended (16 U.S.C. §590a et seq.).

[67] This section was contributed by Elena H. Humphries, Analyst in Environmental Policy.

[68] The eligible entities include state infrastructure financing authorities; a corporation; a partnership; a joint venture; a trust; or a federal, state, local, or tribal government, or consortium of tribal governments.

[69] For more information on WIFIA, see CRS Report R43315, *Water Infrastructure Financing: The Water Infrastructure Finance and Innovation Act (WIFIA) Program*, by Jonathan L. Ramseur, Mary Tiemann, and Elena H. Humphreys. For an example of a groundwater project funded in part under WIFIA, see the Pure Water Monterey Groundwater Replenishment Project, at https://www.epa.gov/wifia/pure-water-monterey-groundwater-replenishment-project.

Federal Reserved Rights to Groundwater

The federal government typically defers to states to allocate water resources within the state.[70] An exception has been the right to regulate water supplies on federal reservations, stemming from the U.S. Supreme Court decision in *Winters v. United States*.[71] Under the *Winters* doctrine, when Congress reserves land (e.g., for an Indian reservation), Congress also reserves water sufficient to fulfill the purpose of the reservation.[72] The *Winters* case specifically addressed the priority and extent of Indian reserved water rights, but the Supreme Court also recognized these rights in non-Indian contexts. In 1976, the Court noted that it "has long held that when the Federal Government withdraws its land from the public domain and reserves it for a federal purpose, the Government, by implication, reserves appurtenant water then unappropriated to the extent needed to accomplish the purpose of the reservation."[73]

Although the *Winters* doctrine has been applied to federal reserved water rights generally, the federal reserved rights for groundwater are more ambiguous than the rights for surface water. Tribal rights to groundwater, for example, have not been legally established to the same extent as rights to surface water (and other natural resources, such as timber, oil and gas, and minerals).[74] However, an ongoing legal case involving a Southern California Indian tribe's rights to groundwater under the *Winters* doctrine may establish those rights more specifically.[75]

Climate Change and Other Long-Term Influences on Groundwater Supply

Long-term changes to the climate affecting the United States, particularly rising temperatures and changes in the patterns, quantities, and type of precipitation (i.e., rain versus snow), could affect the availability of groundwater in the future. Changes in temperature and precipitation could affect the amount of water that recharges aquifers and therefore could shape how much groundwater is available for irrigation, domestic water supply, and other uses. However, the amount of natural recharge is just one variable (albeit an important one) influencing groundwater supply (i.e., its amount and availability). In some important aquifers, such as the Central Valley aquifer in California, the largest portion of recharge comes from irrigation return flow—excess water applied to the crops that is not lost to evapotranspiration or runoff.[76] Changes in irrigation

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[70] Some legal scholars observe that the federal government has authority to regulate water resources, based on the Commerce Clause and the Property Clause of the U.S. Constitution. For further discussion, see, for example, John D. Leshy, "The Federal Role in Managing the Nation's Groundwater," *Hastings West-Northwest Journal of Environmental Law and Policy*, vol. 11, no. 1 (Fall 2004), p. 2.

[71] Winters v. United States, 207 U.S. 564, 575-77 (1908). Also, in United States v. New Mexico, the Supreme Court noted that "the 'reserved rights doctrine' is a doctrine built on implication and is an exception to Congress's explicit deference to state water law in other areas." United States v. New Mexico, 438 U.S. 696 (1978).

[72] For more information on rights stemming from Winters v. United States, see CRS Report RL32198, *Indian Reserved Water Rights Under the Winters Doctrine: An Overview*, by Cynthia Brown (available to congressional clients upon request).

[73] See Cappaert v. United States, 426 U.S. 128, 138 (1976).

[74] For more information on Indian water rights and water settlements, see CRS Report R44148, *Indian Water Rights Settlements*, by Charles V. Stern.

[75] See CRS Insight IN10857, *Federal Reserved Water Rights and Groundwater: Quantity, Quality, and Pore Space*, by Peter Folger.

[76] Thomas Meixner et al., "Implications of Projected Climate Change for Groundwater Recharge in the Western United States," *Journal of Hydrology*, vol. 534 (January 4, 2016), p. 127. Evapotranspiration is the combination of evaporation

practices and technology could significantly alter irrigation return flow in the Central Valley. For example, more efficient irrigation would use less water for the same yield yet conversely would contribute less return flow as recharge to the aquifer.

Policies that would enable greater artificial recharge, such as current authorities at Reclamation and USACE or new authorities that Congress may introduce, also may create long-term changes to groundwater supply and availability. In addition, broad changes in water demand, such as a transition to less irrigation and more municipal use, could influence how groundwater is used. All of these factors complicate any precise projection of changes to U.S. groundwater supply. Data collected and distributed by the USGS, NASA, NOAA, and the USDA will likely improve the understanding of long-term trends in groundwater storage and use. The long-term trends can be assessed against the effects of climate change in the future.

Climate Change and Groundwater Recharge

Intense global interest in greenhouse gas-influenced climate change prompted a number of studies investigating how a changing climate could affect groundwater, particularly affecting groundwater depletion and the amount of water available for recharging aquifers.[77] These studies have helped identify the many complexities involved in forecasting long-term consequences of climate change on groundwater supplies. Two broad review studies published in 2016 and 2017 are summarized below.

One study (by Meixner et al., 2016) synthesized the results of several other studies in an attempt to gauge the impacts of future climate change on the western United States (states west of the 100th meridian).[78] The study focused at the scale of major aquifers (specifically, eight aquifers),[79] because the study authors considered that global-scale studies are too broad to inform policymaking and that local-scale studies do little to illuminate potential changes across larger regions, such as states, which are important for setting water policy. The authors selected the western United States because of the importance of groundwater in that area relative to the more humid east, with its more abundant supplies of surface water.[80]

A conclusion from the study is that a "wet gets wetter, dry gets drier" scenario may prevail in the West, meaning generally that the already arid southwest is predicted to become drier, reducing the availability of precipitation for recharge, and the northern portion of the western United States may get wetter, increasing the availability of water for recharge. However, even for regions experiencing wetter conditions, higher average temperatures in the future could cancel out some of the gains, because of higher evaporation and other effects. Mountain systems, in which snowpack plays an important role in water supply and recharge, are likely to provide less water because of lower precipitation (in the south, particularly) and because of a transition to less snow and more rain in the northern ranges. However, the study notes that the impacts of expected

and respiration by plants. Hereinafter, Meixner et al., 2016.

[77] See USGCRP, Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II, 2018, U.S. Global Change Research Program, Chapter 3: Water, *Key Message 1*, https://nca2018.globalchange.gov/chapter/3/. See, also, the 2014 National Climate Assessment, U.S. Global Change Research Program, *Key Message 4: Groundwater Availability*, at https://nca2014.globalchange.gov/report/sectors/water.

[78] Meixner et al., 2016.

[79] These included the Ogallala (or High Plains aquifer; NE, CO, KA, TX, NM, AZ), San Pedro (AZ), Death Valley (NV, CA), Wasatch Front (UT), Central Valley (CA), Columbia Plateau (WA, OR, ID), Spokane Valley-Rathdrum Prairie (WA), and Williston Basin (ND, MT) aquifers.

[80] Meixner et al., 2016, p. 125.

snow-to-rain shifts on groundwater are uncertain due to a lack of robust knowledge about mountain system aquifers.[81]

A finding in the Meixner, et al. study was that knowledge gaps in forecasting changes in the frequency and intensity of future precipitation events will translate into uncertainty in predicting changes to recharge. **Figure 10** captures possible broad changes indicated in the study between current conditions and potential future climate conditions for the western United States under a greenhouse gas-induced global warming scenario.[82]

Another study (Smerdon, 2017) provides a broad synopsis of the published science. It summarized six review articles published between 2011 and 2016 on groundwater and climate change, noting common conclusions on aspects related to predicting changes in groundwater recharge.[83] The study noted that varying predictions of future recharge result from uncertainty inherent in the distribution and trend of future precipitation as predicted in climate change models (also called *general circulation models*, or GCMs). The study reported additional uncertainty in groundwater recharge forecasts because of uncertainties in downscaling GCM results from the global to the regional scale, similar to the findings in the paper discussed above.

One of the articles reviewed suggests "the role of vegetation is shown to be paramount for the recharge process, where change in precipitation could be accommodated by natural adjustment in evapotranspiration in some cases."[84] The finding implies that making predictions of recharge could be difficult because the water consumed by vegetation would not be available to recharge an aquifer. Other articles reviewed in the Smerdon study pointed out that GCMs do not directly incorporate changes in groundwater; in other words, groundwater recharge was not directly modeled in the GCM approach, so changes to groundwater can only be inferred from other model results.

One conclusion from the study is that forecasting future groundwater supplies requires better long-term groundwater observations to match the long-term changes in climate to investigate their relationship. The Smerdon study notes that given all the uncertainties, several of the articles reviewed indicate that even the direction and magnitude of change to groundwater recharge is difficult to predict; some GCM modeling results suggest recharge could decrease, whereas other GCM results suggest the opposite for similar regions. Mountainous regions likely will be the most sensitive to changes in climate, according to the review.[85]

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[81] Meixner et al., 2016, p. 136.

[82] Meixner et al., 2016, figure 1, p. 126.

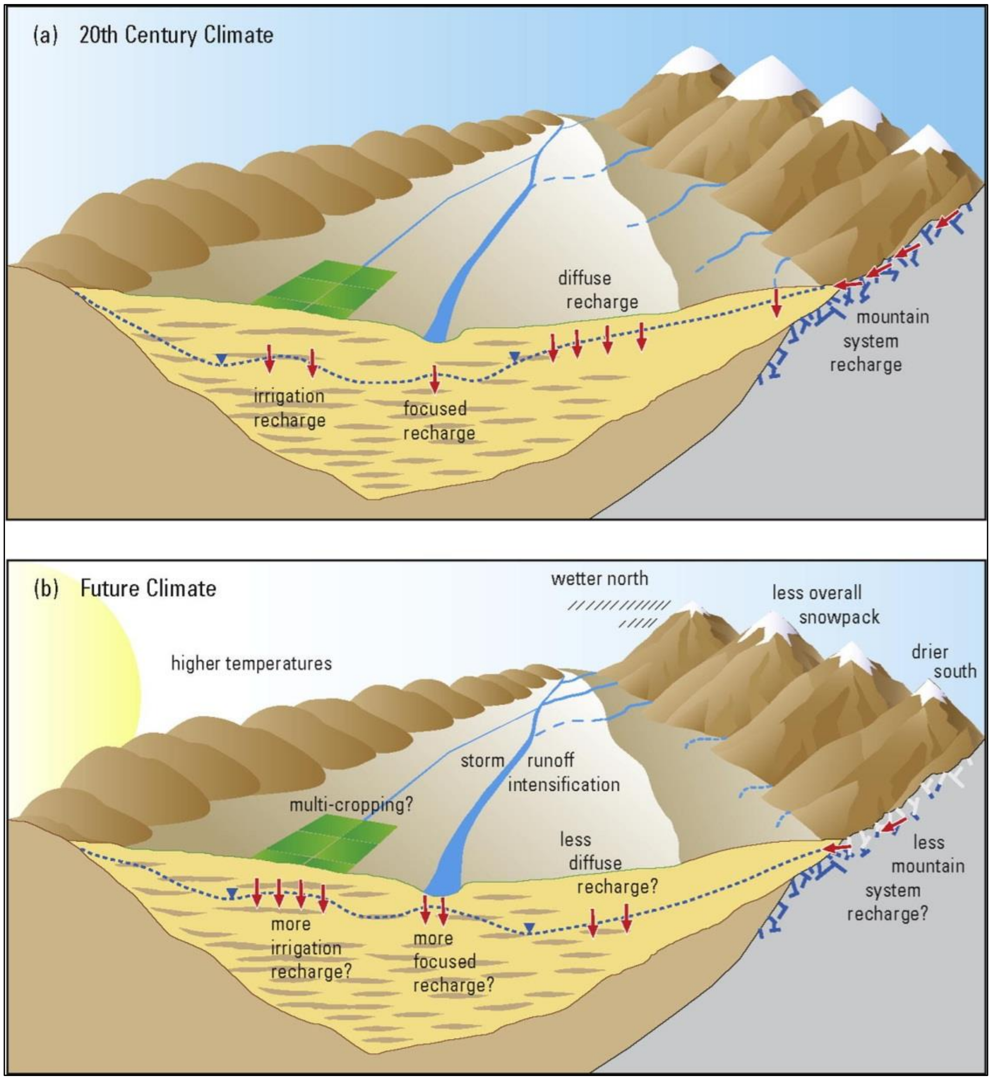
[83] Brian D. Smerdon, "A Synopsis of Climate Change Effects on Groundwater Recharge," *Journal of Hydrology*, vol. 555 (September 28, 2017). Hereinafter, Smerdon, 2017. (One of the six reviewed articles in the Smerdon synopsis is the Meixner et al., 2016, study discussed in this section.)

[84] Smerdon, 2017, p. 126.

[85] Smerdon, 2017, p. 127.

Figure 10. Conceptual Illustration of Recharge Mechanisms Under Two Different Climate Scenarios

(for the western United States)



Source: Thomas Meixner et al., "Implications of Projected Climate Change for Groundwater Recharge in the Western United States," *Journal of Hydrology*, vol. 534 (January 4, 2016), p. 126, figure 1, (with permission).

Notes: Four different recharge mechanisms are illustrated: *diffuse recharge*—resulting from infiltration of precipitation and direct recharge of the aquifer; *focused recharge* from rivers, streams, and lakes; *mountain system recharge* from where snow melts and infiltrates at the mountain front; and *irrigation recharge* from excess irrigation water that infiltrates the ground and reaches the water table. Under a greenhouse gas-induced warming climate (b), some of the recharge mechanisms may be diminished (such as mountain system recharge) and some may be enhanced (such as focused recharge) compared to 20th century conditions (a).

Other Factors

Other factors may also have profound influence on groundwater recharge and groundwater supply. For example, the Intergovernmental Panel on Climate Change Fifth Assessment noted that changing land use is expected to affect freshwater systems globally, including groundwater.[86] The report noted that increasing urbanization, for example, may decrease groundwater recharge.[87] How irrigation practices evolve likely will influence the use and availability of groundwater, particularly for regions of the country where surface water supplies may decrease due to increasing aridity over the long term and where groundwater would substitute for surface water supplies during short-term droughts, much as it does today. Alternatively, regions experiencing wetter conditions could see reduced demand for groundwater if surface water supplies become more abundant. Because most groundwater in the United States is used for irrigation, more efficient irrigation practices may reduce overall water demand, which could place less stress on groundwater resources. A possible exception would be for aquifers that depend on excess irrigation flows for aquifer recharge (e.g., the Central Valley aquifer).

Summary and Conclusions

Congress generally has deferred management of U.S. groundwater resources to the states, and that practice appears likely to continue. Severe and widespread droughts over the last 10 years in California, the Midwest, and Texas and a longer period of drier-than-normal conditions in the Southwest have contributed to increasing congressional attention to the effects of drought on increased groundwater pumping and the depletion of groundwater supplies. These events have led to congressional interest in policies that would support augmentation of water supplies by enhanced aquifer recharge and the ability to store groundwater in an aquifer for later recovery when surface water supplies are curtailed by drought. Existing authorities for Reclamation and USACE allow federal projects to be involved in aquifer recharge, storage, and recovery in some way. Reclamation, USDA, and EPA also provide some forms of financial assistance that could support aquifer recharge, storage, and recovery.

A connection between federal water projects and groundwater enhancement already exists in Arizona, as part of the Central Arizona Project, and activities are being implemented via state law. More recently, California enacted three groundwater laws known collectively as the Sustainable Groundwater Management Act (SGMA), which directed the California Department of Water Resources to identify water available for replenishing groundwater in the state. Because the water provided by the Central Valley Project is integral to the water supply and delivery infrastructure of the state,[88] it is also recognized as part of the surface water resources potentially available for recharging aquifers as the SGMA is implemented.[89] Other western states with significant Reclamation water infrastructure also may look to enhance their sources of water for aquifer recharge by tapping the federal projects.

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[86] Jimenez Cisneros et al., "Freshwater Resources," Intergovernmental Panel on Climate Change, in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*, contribution of Working Group II to the *Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 2014, p. 240.

[87] Increasing urbanization may include more covered surfaces, such as roads, parking lots, and other types of materials that are less permeable to precipitation than natural surfaces and could decrease the amount of water that infiltrates the ground and reaches the water table.

[88] For more information, see CRS Report R44456, *Central Valley Project Operations: Background and Legislation*, by Charles V. Stern and Pervaze A. Sheikh.

[89] See California Department of Water Resources, Sustainable Groundwater Management Program, *Water Available for Replenishment*, April 2018, at https://water.ca.gov/News/News-Releases/2018/April-18/Innovation-Investment-and-Infrastructure-Needed-to-Replenish-Groundwater-Basins.

Further technological developments in desalinating brackish or saline groundwater could help make those water supplies available for domestic, agricultural, or other uses.[90] Congress authorized an assessment of brackish groundwater in Section 9507(c) of P.L. 111-11 in 2009, and USGS released its assessment report in 2017.[91] In general, the assessment found that deeper wells had more brackish groundwater than shallower wells. Seventy percent of wells between 1,500 feet and 3,000 feet below the surface were brackish or highly saline, whereas less than 20% of wells 50 feet deep or shallower were brackish.

USGS reports that many water providers are turning to brackish groundwater to augment or replace freshwater for drinking and other uses, such as power generation, irrigation, aquaculture, and uses in the oil and gas industry (e.g., hydraulic fracturing).[92] For greater use of this potential resource, more detailed evaluations of specific aquifers likely are required. Technological and economic analyses would be needed to determine if brackish groundwater, especially from the deeper wells, could be used economically on a greater scale in the future.

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[90] Brackish water generally is more saline than fresh groundwater but less saline than seawater, containing total dissolved solids in concentrations ranging between 1,000 and 10,000 milligrams per liter (mg/l). Water with less than 1,000 mg/l is considered fresh; water with more than 10,000 mg/l is considered highly saline. Seawater is about 35,000 mg/l on average.

[91] Jennifer S. Stanton et al., *Brackish Groundwater in the United States*, USGS, Professional Paper 1833, 2017, at https://pubs.er.usgs.gov/publication/pp1833.

[92] Jennifer S. Stanton and Kevin F. Dennehy, "Brackish Groundwater and Its Potential to Augment Freshwater Supplies," USGS, Fact Sheet 2017-3054, July 2017, at https://pubs.er.usgs.gov/publication/fs20173054.

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