REPORT TO THE PRESIDENT

Improving Groundwater Security in the United States

Executive Office of the President
President's Council of Advisors on
Science and Technology

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EXECUTIVE OFFICE OF THE PRESIDENT
PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20502

President Joseph R. Biden, Jr.
The White House
Washington, D.C.

Dear Mr. President,

Your Administration is committed to clean water and healthy communities. The 2021 Bipartisan Infrastructure Law and the 2022 Inflation Reduction Act contain directives and support to improve water quantity, quality, conservation, and use. Together with your Administration's America the Beautiful Initiative and America the Beautiful Challenge, they are focused mainly on surface water in lakes, wetlands, ponds, and other freshwater resources.

Groundwater is an often-overlooked resource across the nation. It resides in aquifers which are underground and accessed mainly through wells, but this subsurface water plays a crucial role in the entire hydrologic cycle, including influencing surface water. Groundwater is vital for agriculture, domestic manufacturing, construction, mining, energy production, and other applications. Moreover, it provides drinking water for half of the U.S. population and nearly all rural residents. Consequently, groundwater is fundamental to the nation's health, food, water, energy security, and economy.

The U.S. is facing a serious and unprecedented groundwater challenge. In many aquifers, groundwater withdrawal has outpaced natural recharge, which is exacerbated by the changing climate and precipitation variability. Much of the water in the major aquifers in the U.S. is fossil water, recharged over 10,000 years ago, and will not be replaced naturally on human timescales. In the western U.S., groundwater resources are being depleted at alarming rates, mostly from agricultural withdrawal. The depletion has caused land subsidence and earth fissures as well as permanent reduction of storage capacity. The depletion has national and global consequences as non-renewable groundwater in the west is embedded in agricultural products transported to the rest of the U. S. and in agricultural commodities exported globally.

Many federal agencies have programs to measure the quality and quantity of groundwater, as well as conservation programs for sustainable use of groundwater. PCAST applauds and endorses their efforts as well as those by state governments, non-governmental organizations, professional organizations, local communities, private citizens, and others, to manage their groundwater resources.

To ensure the sustainability of this indispensable resource and mitigate risks from its depletion, it is imperative that we enhance our understanding and management of groundwater resources. The recommendations that follow seek to enhance the important work so far. This includes investing in research, data collection, modeling and prediction, as well as innovative technologies to understand and protect groundwater reserves. This also includes federal incentives to encourage the planning and sustainable management of groundwater. Equally important is active collaboration with stakeholders and training of the workforce. Only through a comprehensive and informed approach can we secure groundwater for future generations and maintain the health and prosperity of our nation and its citizens.

Sincerely,

Your President's Council of Advisors on Science and Technology

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Executive Summary

Groundwater is an essential resource, critical to our nation's food, energy, health, and economic security. This report seeks to encourage and support efforts that promote sustainable use and long-term security of groundwater.

The U.S. is facing a serious and unprecedented groundwater challenge. Across the U.S., groundwater withdrawal has outpaced natural recharge, while slow natural recharge has been exacerbated by climate change and precipitation variability, including floods, droughts, and early snowmelt. Groundwater is a critical resource for agriculture, domestic manufacturing, construction, mining, energy production, and other uses. The largest use of groundwater, at 70%, is for irrigation. Moreover, groundwater supplies drinking water for half the U.S. population and nearly all the rural population. Sustaining and securing groundwater is thus central to our Nation's health, food, water, and energy security, and economy.

Adding to the challenge, much of the water in the major aquifers in the U.S. is fossil water, meaning it was last recharged over 10,000 years ago and will not be replaced naturally in centuries and millennia. In the western U.S., groundwater resources are being depleted at alarming rates, mostly from agricultural withdrawal. The depletion has caused land subsidence and earth fissures as well as permanent reduction of storage capacity due to inelastic compaction of the subsurface formation. The depletion has national and global consequences as non-renewable groundwater in the west is embedded in agriculture products transported to the rest of the U. S. and in agricultural commodities exported globally.

The Biden-Harris Administration has shown a strong commitment to clean water and healthy communities. The 2021 Bipartisan Infrastructure Law and the 2022 Inflation Reduction Act contain directives and support to improve water quantity, quality, conservation, and use. In addition, the Biden-Harris Administration's America the Beautiful Initiative and America the Beautiful Challenge have supported important conservation efforts relevant to surface water in lakes, wetlands, ponds, and other freshwater resources. The critical issue of groundwater remains insufficiently addressed.

The federal government has limited authority to regulate groundwater. However, there are many ways federal agencies engage with and address groundwater issues. The Department of the Interior (DOI), U.S. Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and other federal agencies, in collaboration with state and local partners, monitor, forecast, and assess groundwater conditions to help inform local management strategies and decisions. These agencies also recognize the urgency of the groundwater depletion problem and have developed conservation programs to promote water security and mitigate risks. In our fact-finding, PCAST learned also of the work of state governments, non-governmental organizations (NGOs), professional organizations, and private citizens to manage their groundwater resources. PCAST applauds and endorses these efforts, and seeks to enhance them.

Groundwater governance in the United States is characterized by a highly decentralized framework, wherein each state is primarily responsible for creating and enforcing its own laws, policies, and regulations. A complex management system is both appropriate and inevitable in the case of groundwater, because of the level of physical (geologic, ecologic, and climatological), economic, and political heterogeneity among aquifers. The federal government does not direct the groundwater practices of states, local communities, and regulators, but it can provide incentives to foster a sustainable groundwater future. Groundwater storage is a crucial engine for the states', and hence the nation's, economy. With capacities that exceed the combined water storage of all surface reservoirs combined, groundwater is a strategic resource in the face of ongoing climate change. It is therefore in the nation's interest to incentivize groundwater conservation and management based on sound science and stakeholder inputs.

Native American and Tribal communities face significant groundwater security risks due to the extraction of nonrenewable resources on Tribal lands, contamination of both surface water and groundwater, and climate change. PCAST recognizes the Biden-Harris administration's dedication to ensuring the health, safety, and prosperity of Indigenous communities. We encourage the federal government to prioritize the unique needs of Tribal communities in its water governance considerations by incorporating robust frameworks that strengthen Tribal sovereignty and self-determination, by recognizing and establishing groundwater rights, by providing incentives for sustainable water use, and by ensuring comprehensive data collection. Engaging Tribal organizations in policy development and implementation is crucial to addressing their specific challenges and fostering collaborative, culturally responsive solutions.

To ensure the sustainability of groundwater and mitigate risks from its depletion, it is imperative that we enhance our understanding and management of this indispensable resource. This includes investing in research, data collection, modeling, and prediction, as well as innovative technologies to understand and protect groundwater reserves. This also includes federal incentives to encourage the planning, recharge, and sustainable management of groundwater. Equally important is active collaboration with stakeholders and workforce training. Only through a comprehensive and informed approach can we secure groundwater for future generations and maintain the health and prosperity of our nation and its citizens.

Summary of Recommendations:

Recommendation 1. Accelerate the development of a comprehensive repository for data and toolkits for groundwater storage, withdrawal, and recharge at spatial and temporal scales useful for water managers and users.

The U. S. needs coordination and collaboration among all federal and state agencies to facilitate comprehensive and reliable information on groundwater quantity and quality, and interoperability across all sectors and across all federal agencies. **PCAST recommends that an Interagency Working Group on Groundwater Security and Sustainability be established to guide, coordinate, and provide oversight of the data, software and toolkits needed to do water**

accounting and prediction by local management, and to mitigate risk of irreversible water depletion.

Recommendation 2. Establish a research program to advance technologies and strategies for safeguarding the future of groundwater supply and quality.

In the coming decades, the demand for groundwater and safe drinking water is anticipated to increase, while supplies will fluctuate due to competing water use. Concurrently, water quality is deteriorating as both surface and groundwater become increasingly contaminated with nitrates from fertilizers, per- and polyfluoroalkyl substances (PFAS) from wastewater, and other contaminants in managed recharge. Given the critical importance of groundwater to the viability of some of the parts of our country and the economy, it is imperative to develop strategies that optimize the sustainability and economic returns of groundwater withdrawal. **PCAST recommends the establishment of research programs that include: (1) measuring the chemical composition of surface and groundwater; (2) supplementing and enhancing groundwater storage through recharge, recycling, reuse, re-engineering our towns, water pipelines, and new water sources; and (3) identifying opportunities to optimize sustainable use of groundwater to enhance food security and biodiversity.**

Recommendation 3. Establish a federal incentive program and a network of groundwater engagement hubs, including Tribal Nations groundwater engagement hubs, to support and assist in planning sustainable groundwater use.

The federal government has limited authority to regulate groundwater, but can deploy financial incentives, technical assistance, and convening power to promote groundwater sustainability. **PCAST recommends the establishment of a network of groundwater engagement hubs that provide easily accessible platforms for local communities to understand their groundwater resources, access the latest research in groundwater management, and support informed decision-making on sustainable development, agriculture, and business expansion. Personnel in this network would also engage the public in events like town halls to further understanding of local groundwater dynamics and patterns of use.**

Recommendation 4. Create a competitive grants program to incentivize the planning, sustainable management, and restoration of aquifers, along with the surface waters critical to their recharge and cleanliness.

Several portions of the country have already implemented new scientifically-grounded measures to manage and restore their groundwater aquifers, but these efforts are underfunded. Other regions are slow to embark on this transition because of funding constraints, while still others are not yet ready to begin. A grants program would incentivize managers of a groundwater–surface water system to join the early adopters and begin the transition to science-based sustainable management. It would also allow the implementation of promising techniques, such as enhanced recharge, at much larger scales which could dramatically increase sustainable withdrawals for all. The funding should be primarily in the form of federal incentives for the non-federal entities who have the authority to manage an integrated groundwater and surface water system.

Recommendation 5. Incorporate the valuation of groundwater resources into natural capital accounting and ensure these estimates are integrated into all federal cost-benefit analyses and planning.

PCAST fully endorses the whole-of-government National Capital Accounting Strategy and efforts towards the development of methods to account for the value of the Nation's natural assets and to use these valuations when making economic decisions across the federal government. By including the value of groundwater resources in all federal cost-benefit analyses and planning, the federal government will become more effective in its stewardship of the nation's groundwater on federal lands directly and in its support of state and local managers indirectly.

Recommendation 6. Launch a comprehensive campaign to recruit, develop, and retain a skilled workforce in groundwater science, management, and stakeholder engagement.

PCAST recommends that the federal government invest in educational and training programs focused on the latest technologies and best practices in groundwater management and science. By forming partnerships with academic institutions, industry experts, and professional organizations, a pipeline of well-trained multidisciplinary professionals can be created to address current and future challenges. Prioritizing workforce development and stakeholder engagement will ensure a robust and capable team dedicated to maintaining the health and sustainability of the nation's groundwater resources.

Only through a comprehensive and informed approach can we secure groundwater for future generations and maintain the health and prosperity of our nation and its citizens.

Introduction

Groundwater security is one of the most pressing challenges of our time with the U.S. facing serious and unprecedented groundwater risks. Groundwater, though often overlooked, is essential to the entire hydrologic cycle, including its interaction with surface water (Figure 1). Groundwater is vital for agriculture, domestic manufacturing, construction, mining, energy production, and various other water use sectors (Figure 2). The largest withdrawal of groundwater, at 70%, is for irrigation. Moreover, groundwater provides drinking water for half of the U.S. population and nearly all rural residents. Consequently, groundwater is fundamental to the nation's health, food, water, energy security, and economy.

Figure 1: The Water Cycle

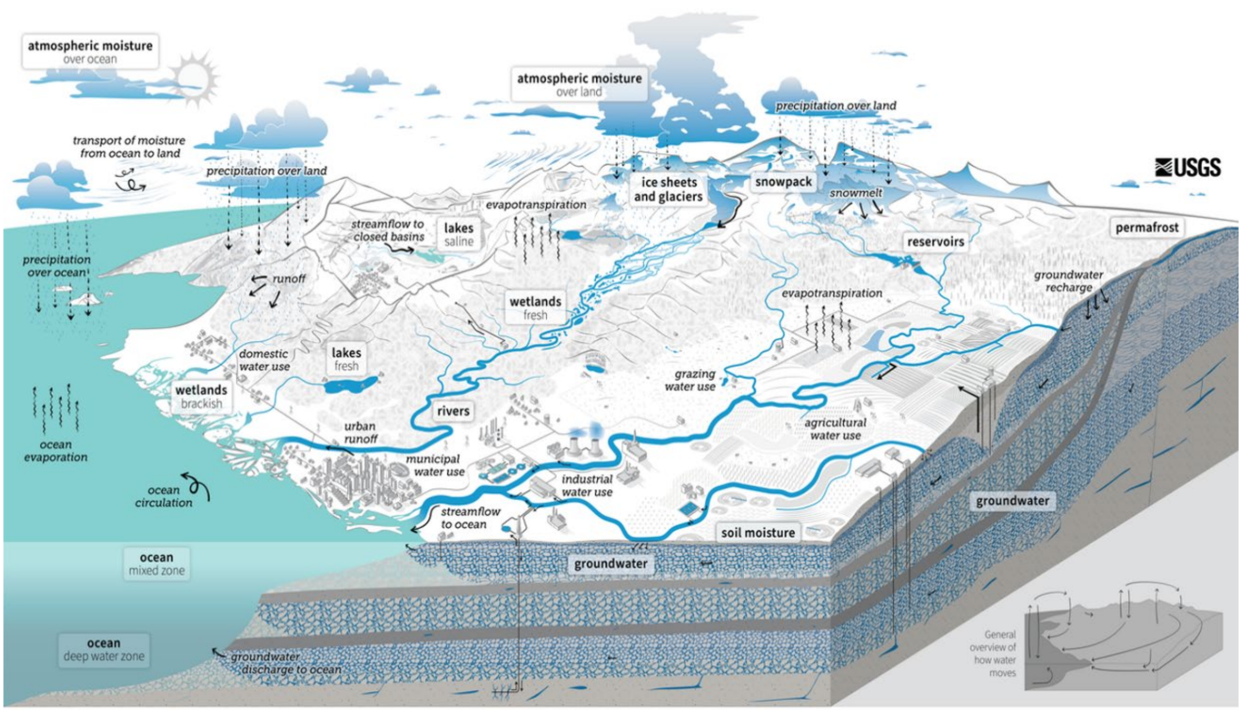

Figure 1. The water cycle describes where water is found on Earth and how it moves. Water can be stored in the atmosphere, on Earth's surface, or below the ground. It can be in a liquid, solid, or gaseous state. Water moves between the places it is stored at large scales and at very small scales. Water moves naturally and because of human interaction, both of which affect where water is stored, how it moves, and how clean it is

Source: U.S. Geological Survey Water Science School. (2022 October 13). The Water Cycle.

The U.S. is facing a serious and unprecedented groundwater challenge. In many aquifers, groundwater withdrawal has outpaced natural recharge, which is exacerbated by a changing climate and variable precipitation (Figure 3). Much of the water in the major aquifers in the U.S. is fossil water, recharged over 10,000 years ago, and will not be replaced naturally in centuries and millennia. In the western U.S. groundwater resources are being depleted at alarming rates, mostly from agricultural withdrawal. The depletion has caused land subsidence and earth fissures as well as permanent reduction of storage capacity. Groundwater depletion has both national and global implications, as non-renewable groundwater in the Western United States is embedded in agriculture products transported throughout the country and agricultural commodities exported worldwide.

Figure 2: Freshwater Withdrawals in the United States, 2015

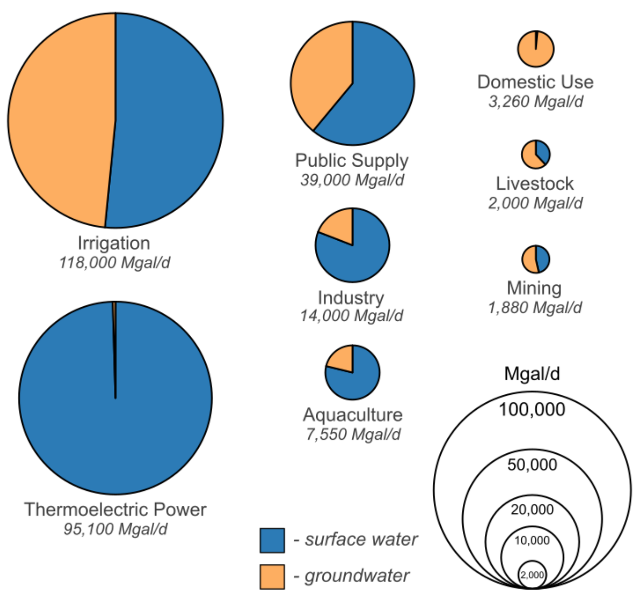

Figure 2. Surface water (blue) and groundwater (orange) usage in the United States in 2015 in millions of gallons per day. The size of the circles represents the average volumes of water withdrawal per day.

Source: Adapted from U.S. Geological Survey Images. (2018 June 20). Source and Use of Freshwater in the U.S. in 2015.

Figure 3: Groundwater Declines Across U.S. South Over Past Decade

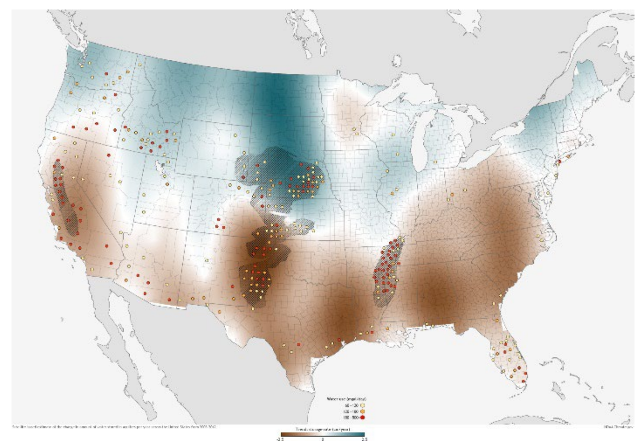

Figure 3. Map of the change in annual water storage per year across the United States from 2003-2012, as estimates from the GRACE satellite. Storage increases are in shades of blue, while storage decreases are in shades of brown. The dots indicate counties where water use exceeded 60 million of gallons per day or more as of 2005, according to data from the U.S. Geological Survey.

Source: Kennedy, C. (2014 October 15). Groundwater Declines Across U.S. South Over Past Decade. National Oceanic and Atmospheric Administration Climate.gov.

The Biden-Harris Administration is committed to clean water and healthy communities. The 2021 Bipartisan Infrastructure Law and the 2022 Inflation Reduction Act contain directives and support to improve water quantity, quality, conservation, and use (Appendix A).[1,2] The Biden-Harris Administration also launched the American the Beautiful Initiative[3] and the American the Beautiful Challenge,[4] which leverage federal conservation and restoration investments to support locally-led efforts to restore and protect our lands and waters. These include surface water in rivers, lakes, wetlands, ponds, and other freshwater resources. At the U.S. Water Summit in November 2023, the Council of Environmental Quality (CEQ) reaffirmed the Biden-Harris Administration's commitment.[5] Despite these efforts, the critical issue of groundwater remains insufficiently addressed.

The federal government has limited authority to regulate groundwater. Groundwater governance in the United States is characterized by a highly decentralized framework, where each state has primary responsibility for creating and enforcing its own laws, policies, and regulations. This has inevitably led to a complex and fragmented network of regulations and incentives. Many states have developed science-based integrated surface and groundwater management programs designed to meet the multifaceted needs of all local stakeholders. In many places groundwater withdrawals are closely regulated and in others they are not. Due to the considerable physical (geologic, ecologic, and climatological), economic, and political heterogeneity among aquifers, a highly complex management system is both crucial and inevitable for managing groundwater resources.

Native American and Tribal communities face significant groundwater security risks due to the extraction of nonrenewable resources on Tribal lands, contamination of both surface water and groundwater, and climate change. PCAST recognizes and supports the Biden-Harris Administration's dedication to ensuring the health, safety, and prosperity of Indigenous communities and notes that more work remains to be done to strengthen Tribal Communities and to support their sovereign resource rights.[6,7,8] We encourage the federal government to prioritize the unique needs of Tribal communities in federal water governance considerations by incorporating robust frameworks that strengthen Tribal sovereignty, by recognizing and establishing groundwater rights, by providing incentives for sustainable water use, and by ensuring comprehensive data collection. Meaningful and effective co-participation with Tribal organizations in policy development and implementation is

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[1] 117th Congress. Public Law 117-58. (2021 November 15). Infrastructure Investment and Jobs Act.

[2] 117th Congress. Public Law 117-169. (2022 August 16). Inflation Reduction Act of 2022.

[3] The White House. (2021 May 6). Biden-Harris Administration Outlines "America the Beautiful" Initiative.

[4] The White House. (2022 April 11). Biden-Harris Administration Launches $1 Billion America the Beautiful. Challenge to Support and Accelerate Locally Led Conservation and Restoration Projects.

[5] The White House. (2023 November 15). CEQ Chair Brenda Mallory Outlines Biden-Harris Administration's Vision for Clean Water Post-Sackett v. EPA.

[6] The White House. (2023 December 6). Executive Order on Reforming Federal Funding and Support for Tribal Nations to Better Embrace Our Trust Responsibilities and Promote the Next Era of Tribal Self-Determination.

[7] The White House. (2021 December 13). Executive Order on Transforming Federal Customer Experience and Service Delivery to Rebuild Trust in Government.

[8] The White House. (2022 November 30). Memorandum on Uniform Standards for Tribal Consultation.

crucial to addressing their specific challenges and fostering collaborative, culturally responsive solutions (Box 1).

Box 1: Groundwater Security in Native and Tribal Communities

Historically, Native American and Tribal communities have confronted significant groundwater issues, including water scarcity, contamination, and lack of access to clean drinking water. Many communities, such as the Navajo Nation, have struggled with aging infrastructure and insufficient resources to maintain safe water systems. Federal and state policies have often prioritized non-Native water users, leading to the diversion of water from Native American lands and exacerbating these challenges.

In recent years, several presidential executive orders have aimed to address these issues and promote Tribal self-determination. Notably, Executive Order 14058 (2021)[9] is focused on transforming federal customer experience and service delivery to rebuild trust in government, while the Presidential Memorandum on Tribal Consultation (2000)[10] and Uniform Standards for Tribal Consultation (2022)[11] emphasize the importance of nation-to-nation relationships and consultation with Tribal nations. Additionally, Executive Order 14112 (2023) reforms federal funding and support for Tribal nations to better embrace trust responsibilities and promote the next era of Tribal self-determination.[12]

Facilitating meaningful partnerships between Tribal nations and federal, state, and local agencies would promote collaborative water management strategies and ensure that Tribal voices are represented and incorporated in decision-making processes.

Groundwater storage serves as a vital economic engine for states and, by extension, the national economy, and is a strategic resource in the face of ongoing climate change, with capacities that surpass the combined water storage of all surface reservoirs.[13] Therefore, it is in the nation's interest to incentivize groundwater management based on sound science and stakeholder input.

To ensure the sustainability of this indispensable resource, it is imperative that we enhance our understanding and management of groundwater. This includes investing in research, data collection, and innovative technologies to understand and protect groundwater reserves. This also includes meaningful collaboration with stakeholders and training of the workforce. Only through a

[9] Executive Order 14058. (2011 December 16). Transforming Federal Customer Experience and Service Delivery To Rebuild Trust in Government.
[10] Executive Order 13175. (2000 November 9). Consultation and Coordination With Indian Tribal Governments.
[11] The White House. (2022 November 30). Memorandum on Uniform Standards for Tribal Consultation.
[12] Executive Order 14112. (2023 December 11). Reforming Federal Funding and Support for Tribal Nations To Better Embrace Our Trust Responsibilities and Promote the Next Era of Tribal Self-Determination.
[13] Joint Economic Committee. (2024 May 10). Protecting Groundwater is Essential for our Country and Economy.

comprehensive and informed approach can we secure groundwater for future generations and maintain the health and prosperity of our nation and its citizens.

Groundwater Resource Challenges and Risks

Groundwater resources in the U.S. face numerous challenges and risks that threaten their sustainability, availability, and quality.

Much of the water found in significant aquifers, such as the Ogallala Aquifer, is classified as "fossil water," having been recharged over 10,000 years ago during the last glaciation period. These aquifers experience extremely slow recharge rates, rendering the water they hold a non-renewable resource within the scope of human timescales.[14] The current rate of groundwater pumping exceeds that of natural recharge, leading to significant drops in the water table, increased pumping costs, and negative impacts on surface water bodies and ecosystems.[15] This imbalance can eventually deplete aquifers entirely. In coastal areas, over-extraction can lead to saltwater intrusion, where ocean water seeps into freshwater aquifers, rendering the water saline and unsuitable for most uses. Climate change further exacerbates these risks by altering precipitation patterns and variability, such as floods, droughts, and early snowmelt across the U.S.[16,17,18,19]

In particular, groundwater resources in the Western United States are being depleted at significant rates, primarily from agricultural withdrawal.[20,21] The depletion has caused land subsidence and earth fissures, damaging infrastructure, and reducing land usability.[22,23] As groundwater is embedded in agricultural products, groundwater depletion impacts the livelihood of communities and the economic prosperity of the nation.

In many regions of the U.S., groundwater quality is poor due to the presence of arsenic and uranium from natural geologic sources, as well as pollutants from agricultural, manufacturing, and mining wastewater.[16] Additionally, PFAS levels are an increasing concern in nearly all areas. Groundwater

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[14] GebreEgziabher, M., et al. (2022). Widespread and Increased Drilling of Wells into Fossil Aquifers in the USA. *Nature Communications*.

[15] U.S. Geological Survey Water Science School. (2018 June 6). Groundwater Decline and Depletion.

[16] Taylor, R., et al. (2013 April). Ground Water and Climate Change. *Nature Climate Change*.

[17] Condon, L.E., et al. (2020). Evapotranspiration Depletes Groundwater Under Warming Over the Contiguous United States. *Nature Communications*.

[18] Liu, PW., et al. (2022). Groundwater Depletion in California’s Central Valley Accelerates During Megadrought. *Nature Communications*.

[19] Siirila-Woodburn, E.R., et al. (2021 October 26). A Low-to-No Snow Future and its Impacts on Water Resources in the Western United States. *Nature Reviews Earth & Environment*

[20] Scanlon, B. R. et al. (2012). Groundwater Depletion and Sustainability of Irrigation in the US High Plains and Central Valley. *Proceedings of the National Academy of Sciences of the United States of America* 109, 9320–9325.

[21] Famiglietti, J. S., et al. (2011). Satellites Measure Recent Rates of Groundwater Depletion in California's Central Valley. *Geophysical Research Letters.*

[22] U.S. Geological Survey Water Science School. (2018 June 5). Land Subsidence.

[23] The University of Arizona, Arizona Geological Survey. More on Arizona’s Earth Fissures.

pollution significantly impacts the health of farming and Tribal communities, particularly those lacking access to potable water.

Information about the state of groundwater, as described above, is pieced together from various types of measurements in and reports about individual aquifers or water basins. Measuring groundwater quantity in general is challenging and expensive. It may involve manual reading of water levels recorded by water meters installed in the wells. The measurements from different water districts or different agencies may not use a common metric. Not all wells report their readings to a common database, and much of the historical data have not been digitized. Measurement frequencies also vary; only a small percentage of wells have automated metering and report at hourly or daily intervals. Remote sensing techniques provide repeated observations, but they have mostly remained in the research space, as often the observations have spatial and temporal resolutions that are too coarse to guide individual action. The scant information about groundwater quality comes mainly from concerns about safe drinking water. The Nation lacks the whole-of-country, comprehensive, and timely information essential for guiding actions and strategies to safeguard and manage this vital resource.

The lack of comprehensive data of groundwater quantity and quality makes it difficult to manage and protect this resource effectively. Without accurate information, implementing sustainable and adaptive groundwater management practices is challenging. Addressing these risks requires coordination, improved data collection, and sustainable management practices to ensure the long-term availability and quality of groundwater.

Groundwater Governance

Groundwater governance in the United States is primarily the responsibility of states. As a result, groundwater laws vary from state to state.[24,25] Some states recognize absolute ownership and landowners have unlimited rights to water beneath their land. Others have public trust management and groundwater is viewed as public property with the State administering permits for its use. This decentralized system allows states to address specific challenges and opportunities within their jurisdictions (Box 2), but it can also result in inconsistencies and gaps in groundwater management across the country.

To improve groundwater governance, states often focus on improving data collection and monitoring, updating legal frameworks, and promoting public participation and education. Collaborative efforts among state agencies, local governments, and stakeholders are crucial for developing and implementing effective groundwater management strategies. During its fact-finding, PCAST has learned of, and applauds, the work of the many federal and state agencies, academia, NGOs, organizations of groundwater professionals, Tribal communities, and additional stakeholders that have developed water sustainability plans and legislation for local management of groundwater

[24] Bennett, A., et al. (2020). Groundwater Laws and Regulations: A Preliminary Survey of Thirteen U.S. States. *EENRS Program Reports & Publications.*

[25] Adams, A., et al. (2022). Groundwater Laws and Regulations: Survey of Sixteen U.S. States. *EENRS Program Reports & Publications*.

(Appendix B). The various plans cover recharge, reuse, and recycling of water as well as repurposing of the land. Farmers, landowners, industries, philanthropic and other organizations have worked independently or with the authorities to decide the water management strategies appropriate for the locale. By fostering cooperation and leveraging local knowledge, states can better protect and sustain their groundwater resources for future generations.

Box 2: Examples of Statewide Actions to Address Groundwater Sustainability

- Kansas has successfully established Local Enhanced Management Areas (LEMA's) and a Groundwater Management District (GMD) to implement local measures to conserve water. A LEMA has shown reduction in total groundwater withdrawal and greater efficient use of groundwater per irrigated area.[26]
- Arizona passed the Groundwater Management Act in 1980. Four of the five large urban Active Management Areas have developed "safe-yield" goals by 2025, and the Arizona Water Banking Authority provides credit for storing used portions of the Colorado River entitlement. However, the Groundwater Management Act does not cover rural areas, which make up 80% of the State.
- California passed the Sustainable Groundwater Management Act (SGMA) in 2014 that mandated over 250 water boards to develop and implement sustainable use plans (including land repurposing).[27] Its Groundwater Accounting Platform aims to allow local water managers and users to track water budgets in real-time.[28] The Law is to take effect in 2040, and SGMA pilot implementation projects are underway. Analysis shows that local control of groundwater management and protection of key stakeholders are key to its success.[29,30]
- The Idaho Department of Water Resources, in collaboration with the Bureau of Reclamation, USGS and stakeholders, monitors water level in over 2300 wells, many of which have continuous measurements and can telemeter real-time observations to a database.[31] The critical information including water quality are provided to users and planners.
- In Texas, groundwater management is through individual Groundwater Conservation Districts (GCD)'s, which cooperate with other GCDs that share a Groundwater Management Area or aquifer.
- In New Mexico, the Water Policy and Infrastructure Task Force has formulated recommendations to address water security challenges.[32]

[26] Whittemore, D.O., et al. (2023). 2023 Status of the High Plains Aquifer in Kansas. *Kansas Geologic Survey* Technical Series 25.
[27] California Department of Water Resources. (2024). Sustainable Groundwater Management Act.
[28] California Water Data Consortium. Groundwater Accounting & Data Reporting Project.
[29] Perrone, D., et al. (2023). Stakeholder Integration Predicts Better Outcomes from Groundwater Sustainability Policy. *Nature Communications.*
[30] Chappelle, C., et al. (2023). Achieving Groundwater Access for All: Why Groundwater Sustainability Plans are Failing Many Users. Groundwater Leadership Forum.
[31] Idaho Department of Water Resources. Groundwater Levels. Accessed on 13 December 2024
[32] University of New Mexico, Utton Center. (2022 December). Facing New Mexico's 21st Century Water Challenges: A Report of the New Mexico Water Policy and Infrastructure Task Force.

This decentralized system allows states to address specific challenges and opportunities within their jurisdictions, but it can also result in inconsistencies and gaps in groundwater management across the country. Aquifers traverse county and state lines, withdrawal or recharge in one state may impact water quality and quantity in another.

Federal Role in Groundwater Management

Historically, the federal government management of groundwater has been focused on the quality of groundwater sources of drinking water. Through the Clean Water Act[33], the Safe Drinking Water Act[34], and the Comprehensive Environmental Response, Compensation, and Liability Act[35], the Environmental Protection Agency (EPA) sets clean water standards to ensure that the Nation's water supply is safe. In some areas, groundwater quality is compromised by saltwater intrusion or from contaminants in the recharge. The EPA has developed Ground Water Rules on disease-causing pathogens and other guidelines for the quality of managed aquifer recharge to protect underground sources of drinking water.[36,37]

Other than the EPA, the federal role in groundwater management is primarily supportive, with several federal agencies playing pivotal roles in the management, data collection, science, and modeling of groundwater resources. The U.S. Geological Survey (USGS) coordinates the National Groundwater Monitoring Network, a compilation of water level data at individual wells, and extrapolated across water basins or aquifers.[38] USGS has also developed a National Hydrologic Model Infrastructure that supports hydrologic modeling for forecasting (Box 3).[39] The U.S. Department of Agriculture (USDA) conducts a census to gather data on irrigation and water management practices from farms and ranch operators, although this data may not always be current.[40] Additionally, the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers play roles in managing water resources that can impact groundwater, such as through the operation of reservoirs and the facilitation of aquifer recharge projects. These federal agencies work in collaboration with state and local entities to ensure sustainable groundwater use and to address issues like contamination and over-extraction. Other federal agency activities are listed in Appendix C.

In addition, the National Aeronautics and Space Administration (NASA) deploys remote sensing technologies to monitor changes in soil moisture, evapotranspiration, and water storage in large aquifers.[41,42] NOAA issues drought outlooks for the U.S. and leads the National Integrated Drought

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[33] Environmental Protection Agency. (2024). Laws and Regulations: Summary of the Clean Water Act.
[34] Environmental Protection Agency. (2024). Safe Drinking Water Act (SDWA).
[35] Environmental Protection Agency. (2024). Superfund: CERCLA Overview.
[36] Environmental Protection Agency. (2024). Drinking Water Requirements for States and Public Water Systems: Ground Water Rule.
[37] Environmental Protection Agency. (2024). Underground Injection Control (UIC). Aquifer Recharge and Aquifer Storage and Recovery.
[38] U.S. Geological Survey. National Water Information System: SGS Groundwater Data for the Nation.
[39] U.S. Geological Survey. (2020 March 3). National Hydrologic Model Infrastructure.
[40] U.S. Department of Agriculture. (2024). Surveys: Irrigation and Water Management.
[41] National Aeronautics and Space Administration. (2024). Earth Sciences: NASA-USDA Global Soil Moisture Data.
[42] National Aeronautics and Space Administration, Jet Propulsion Laboratory. (2024). GRACE-FO: Water Storage.

Information System (NIDIS), which is an integrated information system that coordinates drought monitoring, forecasting, planning and information at multiple levels across the country.[43,44]

Box 3: Modeling Infrastructure for Constructing Hydrologic Models

The USGS National Hydrologic Model (NHM) infrastructure supports the construction of local-, regional-, and national-scale hydrologic models. The NHM infrastructure consists of: 1) an underlying geospatial fabric of modeling units with an associated parameter database, 2) a model input data archive, and 3) a repository of the physical model simulation code bases.

The USGS infrastructure was developed to support the efficient construction of local-, regional-, and national-scale hydrologic models for the conterminous United States.[45] The NHM is a modeling infrastructure consisting of three main parts: 1) an underlying geospatial fabric of modeling units (hydrologic response units and stream segments) with an associated parameter database, 2) a model input data archive, and 3) a repository of the physical model simulation code bases. The NHM has been used for a variety of applications since its initial development.

Federal agencies recognize the urgency of the water depletion problem and have programs to foster sustainable water management practices. For example, the USDA supports programs, such as the Conservations Reserve Enhancement Program (CREP), that promote conservation and efficient and sustainable use of water in agriculture.[46] The Western Water and Working Lands Framework for Conservation Action developed by USDA Natural Resource Conservation Service (NRCS) lays out the vision and strategies to help local stakeholders meet the challenge of conserving water, address climate change, and bring drought resilience.[47] In 2020, EPA initiated the National Water Reuse Action Plan (WRAP), a voluntary, non-regulatory, and collaborative program, to advance the reuse of treated water and stormwater to improve resilience and sustainability of the nation's water resources.[48] The Department of Energy's (DOE's) Water Security Grand Challenge and National Alliance for Water Innovation aim to advance technologies and innovations for safe, secure, and affordable water.[49,50]

[43] National Oceanic and Atmospheric Administration, National Integrated Drought Information System. About: What is NIDIS?
[44] National Oceanic and Atmospheric Administration, National Weather Service: Climate Prediction Center. United States Drought Information.
[45] Regan, R.S. et al. (2019). The U. S. Geological Survey National Hydrologic Model Infrastructure: Rationale, Description, and Application of a Watershed-Scale Model for the Conterminous United States. *Environmental Modelling & Software*. Vol. 111.
[46] U.S. Department of Agriculture, Farm Service Agency. Conservation Reserve Enhancement Program.
[47] U.S. Department of Agriculture, Natural Resources Conservation Service. Western Water and Working Lands Framework for Conservation Action.
[48] U.S. Environmental Protection Agency. (2024). Water Reuse Action Plan.
[49] U.S. Department of Energy. Water Security Grand Challenge. Accessed on 13 December 2024.
[50] National Alliance for Water Innovation. Accessed on 13 December 2024.

Findings and Recommendations

PCAST acknowledges and respects the States' authority for groundwater governance. This PCAST report focuses on the science and technology aspects of groundwater security and sustainability, and does not make recommendations regarding regulations. Our purpose here is to:

- **Facilitate and empower adaptive management of the nation's water system, so that water users and managers have the critical information for their planning, such as assessing Managed Aquifer Recharge and other mitigation efforts.**
- **Safeguard the future of groundwater supply and quality.**
- **Incentivize sustainable management of groundwater.**

I. A Whole-of-Country, Unified, and Comprehensive Picture of the Nation's Groundwater Storage, Withdrawal, and Recharge

One of the fundamental challenges in groundwater management is that it is a hidden resource. We do not have a clear picture of (1) how much groundwater there is, (2) how fast it is being depleted, and (3) if or how quickly groundwater is being replenished. Given changing precipitation patterns and increasing demands, we are even more uncertain with respect to future recharge and depletions, making it difficult to make long term planning and management decisions. There are many groundwater models of individual systems and aquifers that are already used for active management, in places where this is occurring. However, this patchwork of models varies greatly in design and sophistication, and the models do not cover the nation. The resources required to build operational data platforms and modeling tools can be cost- prohibitive for many locations.

Recommendation 1. Accelerate the development of a comprehensive repository for data and toolkits for groundwater storage, withdrawal, and recharge at spatial and temporal scales useful for water managers and users.

It is important to see changes in the nation's water supply in a collective fashion. Pumping groundwater can often deplete surface water supply. The U. S. needs the coordination and collaboration among all federal and state agencies to facilitate comprehensive and reliable groundwater measurements and analyses, and interoperability across all sectors and across all federal agencies. **PCAST recommends that an Interagency Working Group on Groundwater Security and Sustainability be established to guide, coordinate, and provide oversight of the data, software, and toolkits needed to do water accounting and prediction by local management, and to mitigate risk of water depletion.** The Interagency Working Group should have a budget to provide incentives for additional data generation and resources to expand and better maintain current measurement networks. Extensive model development will also be needed to create a modeling program equipped to handle flexible simulations and scenario generation for both current and future management scenarios considering both groundwater and surface water resources.

Recommendation 1.1 Enhance the collection and synthesis of measurements on groundwater inventory and quality across the Nation.

The first step in better understanding and managing groundwater resources is comprehensive data on groundwater inventory at a spatial and temporal scale that is useful to guide planning and decision making. The National Water Information System maintained by the USGS contains groundwater level data from many individual wells across the Nation (Box 4). However, the data reporting is not comprehensive and does not include data from private wells. Groundwater inventories from advances in remote sensing of groundwater inventory are not included. Groundwater quality data are much more sparsely reported. The current groundwater monitoring network provides insufficient observations to characterize existing groundwater resources and rates of decline.

Furthermore, there is often overlap in federal support of groundwater efforts as no single agency is responsible for this resource and it touches on the mission areas of multiple agencies. Coordination is needed to ensure an efficient approach that avoids redundancy across agencies while leveraging existing resources.

Box 4: Groundwater Data for the Nation

There are many sources of information about groundwater status and groundwater risk (Appendix D).

The USGS National Water Information System (NWIS) contains extensive water data for the nation. These water data are collected at over 1.5 million sites around the country and at some border and territorial sites. Many types of data are stored in NWIS, including water flow and levels in streams and lakes, water levels in wells, as well as comprehensive information for site characteristics, well-construction details, precipitation, and physical and chemical properties of water. Additionally, peak flows, chemical analyses for discrete samples of water, sediment, and biological media are accessible within NWIS.

The groundwater database consists of more than 850,000 records of wells, springs, test holes, tunnels, drains, and excavations in the United States (Figure 4). The data are in either approved (quality-assured) or provisional (unverified accuracy) categories. Near real-time information is from 2,000 groundwater wells with automated reported equipment; daily groundwater level data are from approximately 8,500 wells. Water levels in other wells are measured less frequently, e.g. monthly or semi-annually, and so the data may reflect weather events or pumping episodes, and not useful for detecting long-term trends.

In addition to the NWIS, there are many sources of information about groundwater status and groundwater risks (Appendix D). For example, USDA reports that have over 700 irrigation organizations in the U.S., and many of them monitor groundwater conditions and pumping data. The information is dispersed across federal agencies, state water boards, non-governmental, academia, and the private sector. The information is not integrated into a central national inventory.

Figure 4: Groundwater Levels at Stations in the USGS National Water Dashboard

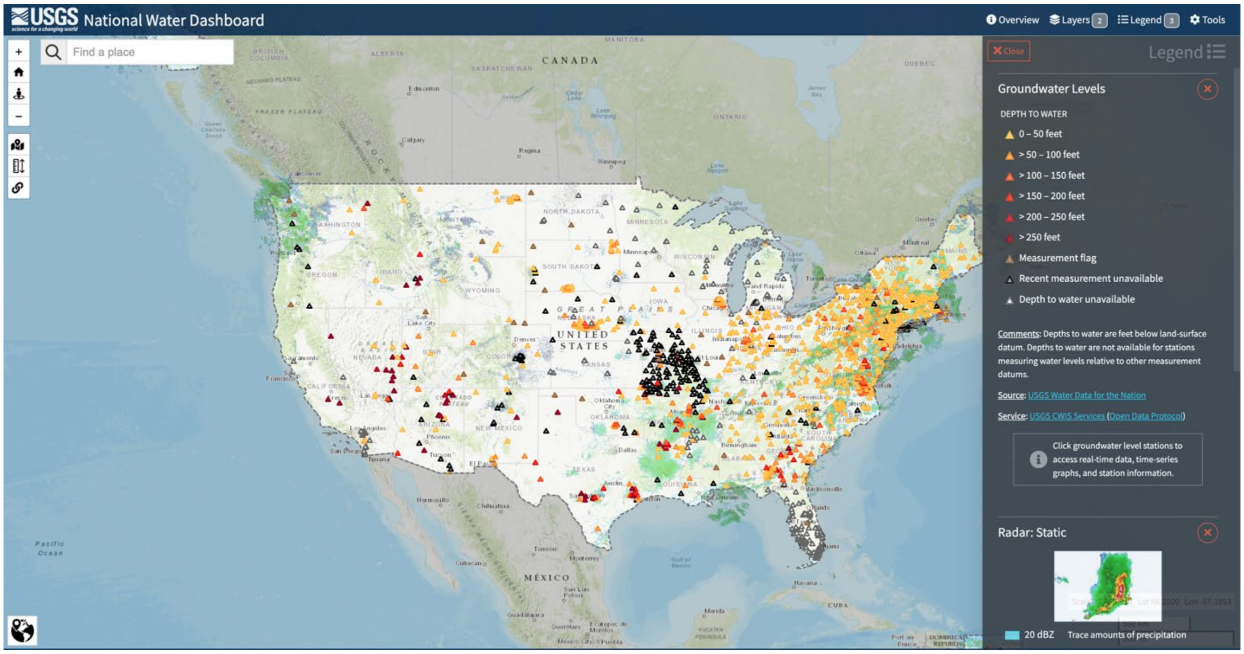

Figure 4. Groundwater levels at stations in the USGS National Water Dashboard. The yellow, orange and red triangles indicate depth from the surface to the water table. The black and grey triangles indicate stations whose measurements are unavailable.

Source: U.S. Geological Survey. [National Water Dashboard.]

PCAST recommends that the Interagency Working Group on Groundwater Security and Sustainability designate USGS as the lead agency to host all federal and non-federal data on groundwater inventory and use, to ensure common protocols and standards for groundwater monitoring and accounting, and to provide actionable information to facilitate planning and decision making. The protocols should include data format, quality (calibration), frequency, and transparency. Submission of data and metadata adhering to the protocol should be required from all federally funded efforts, and should also be incentivized for the private and non-governmental sectors. The data repository could be built upon USGS's National Water Information System and National Water Census to prioritize efforts in three focus areas.

The first focus should be increasing the number of observations of well water levels available through national databases, and incorporating remote sensing data into the national inventory. This can be done by through the following efforts:

(1) Long-term support to expand and continue to maintain the existing USGS groundwater monitoring network. This is already widely used and respected and should be leveraged for all efforts going forward.

(2) Invest in efforts to expand the national database by gathering additional observations that are publicly available but currently distributed across state and local agencies. Where possible these efforts should include efforts to develop automatic data ingestion that can be continuously updated moving forward.

(3) Provide incentives to enhance the timely collection and automated reporting of well data that is not currently being publicly reported. This should include groundwater levels, withdrawals, and water quality from private wells.

(4) Expand the types of data sources that are included in the national groundwater database to include spatially distributed remote sensing observations (Box 5). Hydrogeodesy is an emerging field wherein observations of subtle changes in the Earth's shape and its gravity field are used to yield information about changes in water loading. In particular, GPS data from the Global Navigation Satellite System and satellite observations from InSAR provide local-scale information about surface deformation.[51] They complement the coarse-resolution gravimetric observations of water loading from space.[52]

The second focus area is investment in data protocols and data interfaces to improve the usability of existing datasets. This would entail the following:

(1) Develop a national groundwater data and metadata protocol for groundwater monitoring and accounting. This should include data on groundwater level, use, reuse, recharge, and recycling.

(2) Expand the system for ingesting and automating data collection from non-federal sources including transparent QA/QC standards and processes.

(3) Build a unified data portal for managing and sharing all groundwater observations from every source. This should build off the existing USGS NWIS system but include expanded options for working with and downloading data based on operational user needs.

The third area of focus encompasses the datasets required to comprehensively characterize aquifers and groundwater-surface interaction. At a minimum, this should include the following:

(1) Support research to better study and quantify long-term recharge rates and primary recharge drivers, which may evolve over time (e.g., shifts in episodic recharge or induced recharge);

(2) Develop high-resolution national hydrogeologic maps that include porosity, permeability, and other primary drivers of groundwater flow and quality; and

(3) High-resolution mapping of the depth to bedrock and confining units that define aquifer boundaries.

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[51] Martens, H. R., et al. (2024 July 02). GNSS Geodesy Quantifies Water-Storage Gains and Drought Improvements in California Spurred by Atmospheric Rivers. *Geophysical Research Letters*.
[52] G. Carlson, et al. (2024 September 01). A Novel Hybrid GNSS, GRACE, and InSAR Joint Inversion Approach to Constrain Water Loss During a Record-Setting Drought in California. *Remote Sensing of Environment*.

Box 5: High Resolution Groundwater Data Collection

Advances in remote sensing, especially in the field of hydrogeodesy, have provided independent sources of information about the status of groundwater in the Nation.[53,54] Satellite observations GRACE and GRACE-FO satellites provide monthly water loading around the globe, albeit at 250 km resolution.[55,56,57,58] A source of near-real-time high-resolution information is GPS data from the Global Navigation Satellite System (GNSS) and satellite observations from InSAR, typically used for seismological studies; these provide local-scale information about surface deformation due to poroelastic response to water loading e.g. land subsidence associated with droughts and water withdrawals.[59,60,61,62] On a regional scale, Airborne Electromagnetic (AEM) surveys have been deployed to map the extent, depth, geometry, and subsurface geology of the upper 500m of aquifers, to identify recharge zones, among other things.[63,64] These have not been integrated into groundwater inventory or planning.

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[53] Adams, K. H., et al. (2022). Remote Sensing of Groundwater: Current Capabilities and Future Directions. *Water Resources Research*.
[54] White, A.M., et al. (2022 June 30). A review of GNSS/GPS in Hydrogeodesy: Hydrologic Loading Applications and their Implications for Water Resource Research. *Water Resources Research*.
[55] Rodell, M., et al. (2023 January 19). Water Cycle Science Enabled by the GRACE and GRACE-FO Satellite Missions. *Nat Water*.
[56] Scanlon, B.R., et al (2012 April 18), Ground referencing GRACE satellite estimates of groundwater storage changes in the California Central Valley, USA. *Water Resources Research.*
[57] Long, D., et al. (2013 June 14). GRACE Satellites Monitor Large Depletion in Water Storage in Response to the 2011 Drought in Texas. *Geophysical Research Letters.*
[58] Famiglietti, J.S., et al. (2011 February 05). Satellites Measure Recent Rates of Groundwater Depletion in California's Central Valley. *Geophysical Research Letters*.
[59] Kang, S., et al. (2023 April 28). Isolating the Poroelastic Response of the Groundwater System in InSAR Data from the Central Valley of California. *Geophysical Research Letters*.
[60] California Department of Water Resources. California's Groundwater Live: Land Subsidence. Accessed on 13 December 2024.
[61] Carlson, G., et al. (2024 September 1). A Novel Hybrid GNSS, GRACE, and InSAR Joint Inversion Approach to Constrain Water Loss During a Record-Setting Drought in California. *Remote Sensing of Environment.*
[62] Knight, R., et al. (2022 December 02). Airborne Geophysical Method Images Fast Paths for Managed Recharge of California's Groundwater. *Environmental Research Letters.*
[63] Knight, R., et al. (2018 March 09). Mapping Aquifer Systems with Airborne Electromagnetics in the Central Valley of California. *Groundwater*.
[64] Knight, R., et al. (2022 December 02). Airborne Geophysical Method Images Fast Paths for Managed Recharge of California's Groundwater. *Environmental Research Letters.*

Recommendation 1.2 Develop tools to enhance the Nation's capacity to manage groundwater sustainably, to support water management planning decisions, and to mitigate risk of groundwater depletion.

Modeling tools and evaluation frameworks are critically important for synthesizing the diverse sources of groundwater observations and for decision making and planning. While there already exist many groundwater models with varying degrees of sophistication, they are generally isolated to specific heavily managed systems.[65] Model coverage across the country is inconsistent, and it can be cost prohibitive for local groups to develop their own models from scratch. Modeling efforts must also reflect the fact that groundwater is an integral part of the entire hydrologic cycle. It cannot be separated from water in rivers and lakes or from precipitation and evapotranspiration.

PCAST recommends that the Interagency Working Group on Groundwater Security and Sustainability establish a national framework to coordinate hydrologic modeling with consistent approaches to incorporate surface water and groundwater. The national framework should expand the scope of the Presidential Memorandum of October 10, 2018 (The "Water in the West" memo) to include the entire nation and to explicitly include groundwater.[66]

The national modeling framework should be run operationally to provide consistent national watershed conditions and outlooks similar to how weather models are operated. In addition to standard forecasting outputs, the models should be able to run flexibly to explore the impact of different water management and policy scenarios. Dashboards and tools for planning, cost-benefit analysis by users and managers should be developed along with the modeling platform. Tools and resources from the national modeling platform could be adapted directly by regional groundwater managers to locally relevant decision support tools for exploring the effectiveness and sustainability of different water use, groundwater withdrawal and recharge strategies in the face of future change.

Currently there are multiple hydrologic modeling platforms that are developed and used by federal agencies such as the USGS, EPA, USDA, and DOE. However, existing models are built for different purposes (e.g., water availability, groundwater flows, water quality) and they are not readily interoperable or consistently configured. PCAST recommends that the Interagency Working Group on Groundwater Security and Sustainability tasks USGS with coordinating across agencies to determine the best way to develop shared and interoperable modeling platforms and datasets and to prioritize development of a centralized hydrologic modeling platform.

In addition, there is great need for additional research and development of next generation models and different modeling applications. For example, the models should incorporate high-resolution observations from hydrogeodesy in their development and testing. Research is needed to better understand physical systems such as shallow crustal water environments. Work should also focus

[65] Condon, L. E., et al. (2021 December 03). Global Groundwater Modeling and Monitoring: Opportunities and Challenges. *Water Resources Research*.
[66] The White House Archives. (2018 October 19). Presidential Memorandum on Promoting the Reliable Supply and Delivery of Water in the West.

on the economic value of water, recognizing that groundwater is embedded in food, manufactured products, energy production, among other things. Research should assess the market value of water contributions to the different sectors of the economy, and contributing to the ongoing Natural Capital Accounting (Recommendation 5 below).

The national modeling platform should facilitate a better understanding of programs that can inform future management strategies. A groundwater review task force should use historical data and simulations to analyze the historical impacts of past strategies (both failed and successful). This information can inform the prioritization of federal incentives for adaptive management strategies that are based on lessons learned.

II. Safeguarding the Future of Groundwater Supply and Quality

Over the next few decades, the demand for groundwater and safe drinking water is expected to rise significantly and exacerbated by the unpredictable occurrence of droughts and floods across various regions. Natural replenishment of groundwater from precipitation and snowmelt will in many cases not keep up with groundwater withdrawals.[67] At the same time, water quality is deteriorating, as surface and groundwater accumulate nitrates in fertilizers and PFAS in wastewater, as well as contaminants in managed recharge. As groundwater is a critical resource for agriculture, strategies for sustainable groundwater use need to be developed to enhance food security and ecological systems.

Recommendation 2. Establish research programs to advance technologies and strategies for safeguarding the future of groundwater supply and quality.

PCAST recommends the establishment of research programs that should include (1) measuring the chemical composition of surface and groundwater, (2) supplementing/ enhancing groundwater storage via recharge, recycling and reuse as well as new water sources, and (3) identifying opportunities to sustainable groundwater use to enhance food security and biodiversity.

Recommendation 2.1 Develop a research program for comprehensive analysis of the chemical composition of groundwater.

The chemical composition of groundwater changes with the withdrawal of older, compositionally distinct and fossil groundwater and with the addition of recharge waters that contain pollutants from modern agricultural, industrial, and waste runoff, including PFAS. Measuring both the concentrations of key pollutants and identifying the increasingly complex chemical composition of our Nation's aquifers will help assure the quality of water that the U.S. population requires.

[67] Payton, E.A., et al. (2023). 4. Water. *Fifth National Climate Assessment*.

PCAST recommends a coordinated measurement program that deploys state-of-the-art techniques for molecular-level identification of hundreds of thousands of chemicals in water. The program should be built on the programs at EPA and DOE that analyze the chemical composition of water, and should be partnered with the National Science Foundation (NSF), academia, and the private sector.

EPA carries out extensive analysis of groundwater recharge and withdrawal that may impact the safety of drinking water. DOE's National Energy Technology Laboratory (NETL) has advanced technologies for treatment and reuse of produced water from power generation. USDA's National Institute of Food and Agriculture (NIFA) water programs support research, extension and education programs to protect and improve agricultural water quantity and quality. These agencies have different missions and there is little coordination among their efforts on water quality.

Many of the pollutants in surface and groundwater are not detectable by standard analysis techniques. State-of-the art high-resolution mass-spectrometry techniques, such as at the NSF's National High Magnetic Field Laboratory, can examine hundreds of thousands of individual organic tracers at the molecular level which is key to understanding not only the inherent chemical complexity of groundwaters, but also examination of chemically diverse pollutants such as PFAS. In recent years, such molecular-level techniques have derived unique signatures of distinct human impacts into different aquatic settings. Such an approach has not yet been deployed to measure groundwater quality, but can be used to map and assess the chemical composition of groundwater across our aquifers, by making use of isotopic analysis.[68, 69, 70, 71]

The chemical composition of groundwater varies widely not only from aquifer to aquifer, but also with depth in a water basin. Research is needed to devise sampling strategies that yield statistically meaningful descriptions of the water composition of a basin, as well as information about how and why the composition is changing. To protect the privacy of landowners, the sampling strategies should include ways to anonymize the sampling locations, as is done for the U.S. Census and the USDA's Forest Inventory and Analysis program.

A program examining the chemical composition of our groundwaters not only positions our Nation at the vanguard of groundwater management, but also links the best technologies currently available as a nation to examine the impacts on our groundwaters to readily available analyses in water quality laboratories across the country. Ultimately, such an approach will greatly enhance our knowledge of the chemical complexities of our groundwater and thus both the challenges facing our groundwater.

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[68] Young, R.B., et al. (2022). PFAS Analysis with Ultrahigh Resolution 21T FT-ICR MS: Suspect and Nontargeted Screening with Unrivaled Mass Resolving Power and Accuracy. *Environmental Science & Technology*.
[69] McDonough, L.K., et al. (2022 April 20). A New Conceptual Framework for the Transformation of Groundwater Dissolved Organic Matter. *Nature Communications*.
[70] Young, R.B., et al. (2022 January 31). PFAS Analysis with Ultrahigh Resolution 21T FT-ICR MS: Suspect and Nontargeted Screening with Unrivaled Mass Resolving Power and Accuracy. *Environmental Science & Technology*.
[71] Vaughn, D.R., et al. (2023). Anthropogenic Landcover Impacts Fluvial Dissolved Organic Matter Composition in the Upper Mississippi River Basin. *Biogeochemistry.*

Such a program is also a precursor to figuring out the locale-specific methods for efficient purification of groundwater prior to utilization.

Recommendation 2.2 Establish a national research program to advance technologies for groundwater monitoring, recharge, conservation, and reuse, as well as new water sources to reduce pressure on groundwater resources in different groundwater basins or aquifers.

With rapid depletion of and increasing demand for groundwater, it is imperative that the Nation find new ways to use water sustainably, and replenish the supply where possible. Recycling and reuse are the centerpieces of any conservation program. **PCAST recommends expansion of these conservation programs at USGS, USDA, DOI, and DOE.** Research should expand strategies to minimize wastage, for example, by redirecting storm runoff into collection ponds for reuse or recharge.

Water availability for water sector use is a function of not only the quantity but also the quality of the water. PCAST applauds USGS's Next Generation Water Observing System (NGWOS) to advance cutting-edge technologies and computational capabilities to provide real-time data on water quantity and quality.[72] **PCAST recommends that NGWOS should include an emphasis on groundwater quantity and quality. PCAST also recommends that the Environmental Quality Incentives Program (EQIP) of USDA's Natural Resources Conservation Service should be enhanced to include groundwater in the conservation portfolios.** The program should incentivize local water managers to embrace integrated groundwater and surface water management programs based on measurements and state-of-the art models, like those implemented by early adopters across the nation. The program should also focus existing federal funding on those groups that are ready to make this change.

In many areas with lowering water tables, Managed Aquifer Recharge (MAR), a water management technique that involves intentionally recharging aquifers with water for later use, is deployed to purposefully slow the decline in water storage in aquifers.[73,74] This is done by augmenting natural drainage with recharge basin, or by drilling deep wells and injecting water directly into the aquifer. In rainy areas, ponds and catchment systems are constructed to collect rainwater or stormwater. In dry areas, the water for recharge may be treated wastewater or imported surface water from other locations. There are already many surface distribution systems for large scale water conveyance, e.g., the California Aqueduct, the Colorado River Aqueduct, and the Central Arizona Project. While providing much needed water, conveyance over long distances is expensive. Construction and

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[72] U.S. Geological Survey. (2024 August 30). Developing the Next Generation of USGS Water Monitoring Technologies.

[73] Ulibarri, N., et al. (2021 January 16). Assessing the Feasibility of Managed Aquifer Recharge in California. *Water Resources Research*.

[74] Levintal, E., et al. (2022). Agricultural Managed Aquifer Recharge (Ag-MAR)—A Method for Sustainable Groundwater Management: A Review. *Critical Reviews in Environmental Science and Technology*.

maintenance costs are high. The energy consumption to operate the delivery system, especially over complex terrain, also raises the price of water delivered.

Currently, expertise about MAR is dispersed across state and local water districts, and across federal agencies. **PCAST recommends that the Interagency Working Group on Groundwater Security and Sustainability convene a national initiative on MAR, to share knowledge about design and implementation of existing MAR projects across the Nation, to understand the barriers to implementation, and to share lessons learned.** The initiative should also devise metrics for assessing the MAR projects' sustainability, their risks, as well as their environmental impacts. The initiative should guide a research program to advance technologies and strategies for managed aquifer recharge that would be appropriate for different site conditions, land use, and needs that could be scaled up for widespread applications. The research should include technologies to remove harmful pathogens and other toxic substances in the recharge. **In addition, PCAST recommends enhancing research into new cost-effective ways to deliver water to replenish aquifers. These include technologies and strategies for managed aquifer recharge, long-distance pipeline transport of water, desalination, among things.** The program should also provide training and resources to managers to increase their technical capability.

Recommendation 2.3 Support research that emphasizes sustainable use of groundwater to enhance food security and biodiversity.

In the face of ever-changing precipitation and seasonal climate, farm operators have to decide what crops to plant, how much acreage to plant, and/or the number of animals a ranch can support to optimize water availability and economic return. In the dry Southwest, avoiding drilling additional groundwater wells will likely involve trade-offs between small acreage of high-value, more water intensive crops and large-scale plantings of less water intensive crops. In the wet Southeast, there will be different trade-offs.

PCAST recommends that USDA's Agricultural Research Service (ARS) and Economic Research Service (ERS) co-sponsor research programs that would provide the scientific underpinning for farm operators to adapt their operations to maintain sustainable use of groundwater. The research should include high-value crops that are water-efficient and suitable to the changing climate. The research should also include technologies and economics of recycle, recharge, and reuse of groundwater.

III. Incentivizing Sustainable Management of Groundwater

Implementation of Recommendations 1 and 2 would provide a greatly enhanced national database and tools that would allow states, communities, Tribes, and private citizens to better understand their groundwater use, current groundwater resources, rates of recharge and, for farmers, a more sustainable and profitable business plan. Recommendation 1.2 would also provide state of the art models able to assess future groundwater availability as impacted by climate change, how groundwater availability is connected to surface water use, and the efficacy of conservation measures and recharge enhancements. Together the enhanced data and modeling tools would allow local communities to determine if practical recharge enhancements or reduced withdrawals would permit sustainable water extraction, and how the various consumers of groundwater would be benefited. They would also allow communities to determine if current or expected future patterns of extraction will cause groundwater to run out and what measures would allow the largest sustainable extraction.

While the federal government has limited authority to regulate groundwater, there are important federal levers such as financial incentives, technical assistance, and convening power, that can be deployed to enhance and accelerate sustainable management of groundwater. Recommendations 1 and 2 propose incentives to instrument and meter wells on private lands for this reason (and because funding currently limits the number of wells in the USGS National Groundwater Monitoring Network). Every water management group that PCAST consulted during the fact-finding for this report emphasized the need for additional funding for measurements and decision support, as well as funding for practices and infrastructure that would reduce unproductive water losses from evaporation and runoff and that would enhance recharge. Estimates of the total need are impractical given the constraints of a likely level federal budget. At the same time, Appendix A also outlines the very considerable federal funding initiatives currently available.

Recommendation 3. Establish a network of groundwater engagement hubs to provide technical assistance in planning sustainable groundwater use, with a portion of the network dedicated to assisting Tribal Nations. Personnel in this network would also engage the public in events like town halls, to advance understanding of local groundwater dynamics and use patterns.

The Interagency Working Group on Groundwater Security and Sustainability should coordinate the establishment and funding of the network of groundwater engagement hubs. Each hub in the network should be tailored to the local conditions and needs, and establish easily accessible platforms for local communities to understand their available groundwater resources. They should also provide access to the latest research into groundwater recycling, recharge, and reuse, as well as data to support informed decision-making on development, agriculture, and business expansion. The hubs in the network should share tools and strategies and lessons learned. The hubs could be modeled on USDA's regional Climate hubs and existing Extensions Services of land grant universities, and jointly administered by the USDA's National Institute of Food and Agriculture, which currently funds Extension Services, and by a new program within the USGS to cover non-agricultural stakeholders.

Multiple Groundwater Engagement Hubs should be established exclusively for Tribal Nations. The Biden-Harris Administration recognizes Tribal water rights, and has included in the Bipartisan Infrastructure Law stable and dedicated funding for Tribal water rights settlements, "which is crucial for safe, reliable water supplies to improve public and environmental health and support economic opportunity in Tribal Communities."[75] The Tribal Nations Groundwater Engagement Hubs should

[75] The White House. (2024 March 11). FACT SHEET: The President's Budget Delivers on His Commitment to Tribal Nations and Native Communities.

provide Tribal nations with technical, decision support and planning assistance. The activities of this hub should include addressing historical inequities and building trust through transparent communication and collaborative decision-making.

Box 2 provides several examples in which communities have already implemented effective scientifically grounded measures to manage groundwater, from the state of California to a coalition in Western Kansas, and a grassroots effort in New Mexico. PCAST also repeatedly heard that these efforts were strongly limited by available funds and thus could not undertake ambitious implementation of techniques that have been shown to work at smaller scales—for example a comprehensive attempt to enhance recharge enough to refill depleted aquifers and to increase sustainable withdrawals. It is likely that many other communities would initiate a transition to science-based groundwater management if funds and technical assistance were available to facilitate this transition. At the same time, significant portions of the country are not yet ready to make these kinds of changes.

Recommendation 4. Create a competitive grants program to assist managers of a linked groundwater–surface water system to incentivize improved science-based planning, sustainable management, and restoration.

Competitive proposals should have the following characteristics:

(1) A plan based on quantitative data and a scientifically sound dynamical model of the system.

(2) A multi-use strategy designed to allow the largest possible *sustainable* withdrawals for healthy human consumption, economic development, agriculture, energy production including fossil fuels and power plant cooling, industry, wildlife and ecosystem services.

(3) A focus on restoration where aquifers are recharged by safe means and are resilient to changing patterns of precipitation and evaporation. Water conveyance from water-rich areas should be evaluated and recharging the aquifers through the best means.

(4) High impact and cost effectiveness.

The program should be a component of the America the Beautiful Initiative and be coordinated by the Interagency Working Group on Groundwater Security and Sustainability. It should jointly be funded by the agencies that currently host incentives for groundwater management (DOI, USDA, EPA, DOE, U.S. Army Corps of Engineers), initially by designating and pooling existing funds to support proposal development by interested teams of regional, state, local and private groundwater managers. Future budget requests by these agencies should include funding for winning proposals, some of which should come from appropriate existing programs. The funding should be primarily in the form of federal incentives for the non-federal entities who have the authority to manage an integrated groundwater and surface water system. The grants program would coordinate and amplify now separate federal efforts to improve the lives of people who depend on these water systems, and in so doing create state and local political momentum to continue sustainable management.

Recommendation 5. Integrate the valuation of groundwater resources into natural capital accounting and incorporate these estimates into all federal cost-benefit analyses and planning.

Nature enters every aspect of everyday decision making.[76] **PCAST fully endorses the whole-of-country Natural Capital Accounting Strategy and efforts to account for the value of natural assets and to use these valuations when making economic decisions across the federal government.**[77,78] Obviously, water resources are valuable assets, and need to be monetized as part of this effort. By including the value of groundwater resources in all federal cost-benefit analyses and planning, the federal government will need to become a more effective steward of the nation's groundwater, particularly on public lands where it has some regulatory authority, but also by more effectively aiding state and local managers elsewhere. The formal rigor of cost-benefit analysis will encourage the use of the best available science and technology for sustainable groundwater use and recharge, including the information and technology developed under recommendations 1 and 2.

Recommendation 6. Launch a comprehensive campaign to recruit, develop, and retain a skilled workforce in groundwater science, management, and stakeholder engagement.

Addressing the challenges of groundwater sustainability and security requires a comprehensive and collaborative approach. It requires a scientifically and technically conversant workforce that is comfortable with the latest advances in measurement techniques and engineering advances for withdrawal, recharge and reuse. The Interagency Working Group on Groundwater Security and Sustainability should lead a concerted effort to engage with stakeholders and educate the public about the value of groundwater hidden in their food and other products. Trusted messengers are needed to communicate the vulnerabilities of groundwater depletion and to collaborate with the local community to figure out the best management strategies that work for the future of the community.

Building a skilled workforce is equally important for the sustainable management and security of groundwater resources. **PCAST recommends that all federal agencies with responsibilities for and activities in groundwater should invigorate campaigns to recruit, develop, and retain workforce in groundwater science and management and stakeholder engagement.** The federal government should invest in educational and training programs that focus on hydrogeology, hydrogeodesy, and the latest technologies and best practices in groundwater management. Partnerships with academic institutions, industry experts, and professional organizations can help create a pipeline of well-trained professionals equipped to address current and future challenges.

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[76] Tallis, H., et al. (2024 August 1). Mainstreaming Nature in U.S. Federal Policy. *Science*.

[77] The White House Office of Science and Technology Policy, Office of Management and Budget, Department of Commerce. (2023 January). National Strategy to Develop Statistics For Environmental-Economic Decisions: A U.S. System of Natural Capital Accounting and Associated Environmental-Economic Statistics.

[78] The White House. (2024 April 23). A Successful Inaugural Year for Natural Capital Accounting in the United States.

Furthermore, offering incentives such as scholarships, internships, and career development opportunities can attract new talent to the field. By prioritizing workforce development and stakeholder engagement, the government can ensure that there is a robust and capable team dedicated to maintaining the health and sustainability of the nation's groundwater resources.

Conclusion

Groundwater is an indispensable resource to the United States, sustaining communities, agriculture, industry, and ecosystems. This report describes opportunities to improve the long-term availability and quality of this important resource, while recognizing the regional contexts and priorities that shape its management.

The stewardship of groundwater has long been shaped by state, Tribal, and local leadership. This report affirms the importance of these jurisdictions and highlights how federal support—through improved data infrastructure, strategic research, and targeted incentives—can enhance decision-making and capacity at all levels. Groundwater challenges are complex and heterogeneous, influenced by a combination of environmental, economic, and technological factors. Effective groundwater management requires a coordinated, multifaceted approach that acknowledges and uplifts local efforts, while addressing broader challenges across the nation. The recommendations herein are designed to enhance existing efforts by offering practical avenues to manage competing demands while ensuring sustainability for the future.

Our findings reflect the urgent need for a more in-depth, integrated understanding of groundwater systems and the development of innovative strategies to address challenges such as depletion and contamination. These challenges are not insurmountable, but they demand significantly more attention and investment to ensure access to this essential resource now and into the future.

Appendix A: Water-Related Directives in the Bipartisan Infrastructure Law and Inflation Reduction Act

A.1 Bipartisan Infrastructure Law (Infrastructure Investment and Jobs Act 2021)[79]

Division	Title	Topic	Areas
D- Energy	Title IX	Western Water Infrastructure	Water Storage, Groundwater, Watershed, Water Recycling
D- Energy	Title X	Authorization of Appropriations for Energy Act of 2020	Water Power Projects
E- Drinking Water and Wastewater Infrastructure	Title I	Drinking Water	Drinking Water, Water Infrastructure, Lead
E- Drinking Water and Wastewater Infrastructure	Title II	Clean Water	Wastewater, Water Infrastructure, Water Data Sharing, Water Reuse
G- Other Authorizations	Title I	Indian Water Rights Settlement Completion Fund	Indian Water Rights
J- Appropriations	Title III	Energy and Water Development and Related Agencies	Appropriations for USACE

[79] 117th Congress. Public Law 117-58. (2021 November 15). Infrastructure Investment and Jobs Act.

A.2 Inflation Reduction Act (2022)[80]

Division	Part	Topic	Areas
Title I, Subtitle D- Energy Security	Part 1	Clean Electricity and Reducing Carbon Emissions	Marine and Hydrokinetic Renewable Energy
Title I, Subtitle D- Energy Security	Part 1	Clean Electricity and Reducing Carbon Emissions	Water Treatment Works Facility
Title I, Subtitle D- Energy Security	Part 3	Clean Energy and Deficiency Incentives for Individuals	Heat Pump Water Heaters
Title I, Subtitle D- Energy Security	Part 4	Clean Energy and Deficiency Incentives for Individuals	Building Retrofit Hot Water Systems
Title I, Subtitle D- Energy Security	Part 5	Investment in Clean Energy Manufacturing and Energy Security	Above-ground Water Turbine
Title II, D- Forestry		National Forest System Restoration and Fuels Reduction Project	Restoring Watershed Protections
Title III, Committee on Banking, Housing, and Urban Affairs		Improving Energy Efficiency or Water Efficiency or Climate Resilience of Affordable Housing	Water Efficiency
Title V, Subtitle B- Natural Resources	Part 3	Drought Response and Preparedness	Water Supply
Title V, Subtitle B- Natural Resources	Part 3	Canal Improvement Projects	Water Conveyance Facilities
Title V, Subtitle B- Natural Resources	Part 3	Drought Mitigation in the Reclamation States	Division of Water or Consumptive Water Use
Title VI, Subtitle E- Transportation and Infrastructure		Neighborhood Access and Equity Grant Program	Stormwater Runoff
Title VIII-Committee on Indian Affairs		Emergency Drought Relief for Tribes	Reclamation Water Projects for Tribes

[80] 117th Congress. Public Law 117-169. (2022 August 16). Inflation Reduction Act of 2022.

Appendix B: Agencies with Activities Related to Water Resources

Agency	Component/Bureau/Office	Water Supply Development	Ground-water Supply	Other Irrigation Assistance	Rural/Other Water Supply Programs	Water Conservation	Water Reclamation and Reuse
DOD	U.S. Army Corps of Engineers	X				X	X
DOE	Federal Energy Regulatory Commission					X	
	Office of Energy Efficiency and Renewable Energy					X	
DOI	Bureau of Reclamation	X	X	X	X	X	X
	Bureau of Indian Affairs			X			
EPA	Environmental Protection Agency					X	X
HHS	Indian Health Service	X					
USDA	Natural Resources Conservation Service			X		X	
	Risk Management Agency					X	
	Rural Utilities Service				X		
	Agricultural Marketing Service					X	
	Agricultural Research Service			X			
	Economic Research Service			X			
	National Agricultural Statistics Service			X			
	National Institute of Food and Agriculture			X			

Appendix C: Agencies with Activities Related to Water Quality

Agency	Component/Bureau/Office	Surface Water Quality	Drinking Water Quality	Groundwater Quality	Source Water Production	Nonpoint Source Pollution	Water Quality Infrastructure
DOC	National Oceanic and Atmospheric Administration					X	X
	Economic Development Administration						X
DOI	United States Geological Survey	X		X			
EPA	Environmental Protection Agency	X	X	X	X	X	
HHS	Indian Health Service		X				X
HUD	Housing and Urban Development						X
USDA	Farm Service Agency				X	X	
	Natural Resources Conservation Service					X	
	Rural Utilities Service						X

Appendix D: Examples of Groundwater Data Collections and Models

Publisher	Name of Tool (Hyperlinked)	Short Description
Data/Dashboards		
USGS	National Water Dashboard (NWD)	Real-time stream, lake and reservoir, precipitation, and groundwater data from more than 13,500 USGS observation stations across the country.
USGS	National Groundwater Monitoring Network	Compilation of selected groundwater monitoring wells from federal, state, and local groundwater monitoring networks across the nation.
USGS	The Hydrologic Toolbox	Desktop software program that provides a graphical and mapping interface for analysis of hydrologic time-series data with a set of widely used and standardized computational methods.
USGS	Groundwater Data for the Nation	A framework to obtain data on the basis of category, such as surface water, groundwater, or water quality, and by geographic area. It is not, however, configured to present all NWIS data.
USGS	Estimated Use of Water in the United States County-Level Data for 2015	Water-use estimates aggregated to the State level. This dataset contains county-level data for public supply, domestic, irrigation, thermoelectric power, industrial, mining, livestock, and aquaculture water-use categories.
EPA	EnviroAtlas	Summarizes several USGS water budget and surficial groundwater datasets by 12-digit HUC. It includes average rates of evapotranspiration, quick-flow runoff, effective recharge (which reflects the quantity of water available to replenish the groundwater table), and total recharge (which also includes an estimate for the recharge quantity that was subsequently intercepted by riparian vegetation and converted to evapotranspiration) based on the USGS 800m water budget estimates for the Conterminous United States.
Academia/ Google Earth Engine	United States Groundwater Well Database (USGWD)	A comprehensive database of groundwater well records collected from state and federal agencies. This dataset comprises over 14.2 million well records with attributes, such as well purpose, location, depth, and capacity, for wells constructed as far back as 1763 to 2023.
Academia/ NSF	HydroGEN	Explore current and future watershed conditions across the U.S.

Texas Water Development Board	Texas Water Development Board Groundwater Data	Inventory of nearly 140,000 water wells (including ~2,000 springs) containing information on location, depth, well type, owner, driller, construction and completion data, aquifer, water-level and water quality data.
UC-Santa Barbara	United States Aquifer Database	A geospatial dataset representing local- and regional-scale aquifer system boundaries, defined on the basis of an extensive literature review and published by GebreEgziabher et al. (2022 April 19). Widespread and increased drilling of wells into fossil aquifers in the USA. *Nature Communications*, 13, 2129.
CA Department of Water Resources	NOAA Sustainable Groundwater Management (SGMA) Data Viewer (California Department of Water Resources)	This interactive tool shows California groundwater level data, including depth below ground surface, groundwater elevation, and groundwater change in elevation.
NGO	CA Water Data Consortium	The California Water Data Consortium is an independent, nonprofit organization that supports data-informed water management decisions in California in the face of climate change and other pressures on water resources. We amplify efforts to improve water data infrastructure by creating a neutral organizational space to build trust and facilitate collaboration across sectors. The California Water Data Consortium provides an independent space for ongoing collaboration and sustained engagement between state agencies, water agencies, industry, NGOs, Tribes, academia and others. We work collaboratively to increase access to high quality, comprehensive and interoperable data for a more resilient water future for all Californians.
NCSU	North Carolina Water Supply Dashboard	database of NC water sources and use; includes surface and ground water. Dashboard has interactive icons to give information by location. Water-realted topics include water utlities, maps by counties, location of river basins/sub-basins, water sources, rivers, stream gages, reservoirs, wells (gives info on aquifers/well depth/status), weather stations/rainfall amounts, drought, precipitation and temp outlook 6-10 day
Jet Propulsion Laboratory	NASA: JPL VIRGO Groundwater Tool	An online mapping tool that enables water managers and end-users to explore groundwater changes in California. The tool displays trends in groundwater over management districts called Groundwater Sustainability Agencies (GSAs).

Models		
USGS	MODFLOW	A modular hydrologic model for simulating and predicting groundwater conditions and groundwater/surface-water interactions.
Academia/ NSF	HydroFrame	A national framework for hydrologic modeling and scientific discovery.
USACE in cooperation with EPA and NRC	USACE Groundwater Modeling System	Software to visualize project sites, evaluate cleanup alternatives, and predict their effectiveness. provides an interface for the codes ART3D, ADH, FEMWATER, MODAEM, MODFLOW, MODPATH, MT3DMS, RT3D, SEAM3D, SEEP2D, UTCHEM, UTEXAS and WASH123D.
Other Resources		
CA State Water Board	GAMA: Groundwater Ambient Monitoring and Assessment Program	Comprehensive groundwater quality monitoring program for the state of California based on information and contributions from State and Regional Water Boards, CA Department of Water Resources, Department of Pesticide Regulations, U.S. Geological Survey, Lawrence Livermore National Laboratory, University of CA and CA State University, and cooperation with local water agencies and well owners.
USGS	USGS Sustainable Groundwater Management Resources	Resource database contains data, case studies, technical and investigative reports, software, and other information and tools produced and used by the USGS as well as related resources from local, state and federal agencies, educational institutions, and others. Regularly updated.
European Commission	The Urban Water Atlas: How Europe Does Water Management	The atlas is an attempt to involve the public in understanding and taking action with regards to water sustainability. Provided in an easily digestible format, the document makes use of infographics to provide information at a glance.

Aspen Institute Energy and Environment Program, Nicholas Institute for Environmental Policy Solutions at Duke University, and Redstone Strategy Group	Internet of Water Coalition	The Internet of Water (IOW) would be a digital network of collective data from all sources, large and small, that would be compiled and managed in a national database that is accessible by all data users. The Internet of Water Coalition has built strong partnerships with state, local, and Tribal government agencies, water utilities, non-profits, and community science organizations across the country. Through these partnerships, we support the modernization of water data infrastructure and tools, giving water managers, policy-makers, and the public the ability to make informed decisions.
World Resources Institute	Aqueduct Water Risk Atlas	This tool uses open-source, peer reviewed data to map and analyzes current and future water risks across locations.
World Wildlife Foundation	WWF Water Risk Filter	The WWF Water Risk Filter is a risk assessment framework and tool that enables companies and investors to Explore, Assess, and Respond to water risks.
International Groundwater Resources Assessment Centre	Global Inventory of Managed Aquifer Recharge (MAR) Schemes	A global inventory of MAR schemes across more than 50 countries, with more than 1,200 case study examples.

Appendix E: All Organizations that Provided Input Considered in Developing this Report

In April 2024, PCAST solicited public input to better understand and address America's groundwater challenges.[81] PCAST also held a workshop at the University of Arizona, Tempe, Arizona on July 22, 2024 to obtain feedback from external practitioners, communities, and water experts on the PCAST Groundwater Working Group draft recommendations. Governor Stephen Roe Lewis of the Gila River Indian Community delivered the Keynote at the workshop. Separately, PCAST also sought input from a diverse group of additional experts and stakeholders. Below is a comprehensive list of organizations that contributed to the public comment and feedback (denoted by ^), participated in the July 2024 workshop (denoted by *), or were consulted (denoted by °).

Acoma Pueblo^*
Agribusiness & Water Council of Arizona^
American Farm Bureau Federation^
Anne Arundel County*
Arizona Department of Agriculture*
Arizona Department of Water Resources^*
Arizona Farm Bureau Federation^
Arizona Governor's Office*
Arizona House of Representatives^
Arizona - Impact Water^
Arizona Municipal Water Users Association*
Arizona State University*
Arizona State University Global Futures Laboratory^°
Arizona State University Kyl Center for Water Policy^*
Arizona State University Water Innovation Initiative^*°
Association of Clean Water Administrators*
Association of State Drinking Water Administrators^*
Babbitt Center for Land and Water Policy*
Barncastle Law Firm^*°
Bureau of Reclamation
California Department of Water Resources^*°
CA State Water Resources Control Board*
Central Valley Project^
Central Valley Project Water Association^*
Central Valley Salinity Coalition^
Ceres^*
Circle of Blue*
City of Chandler^*
California Institute of Technology^
Central Arizona Project^
City of Las Cruces^
City of Tucson^
Colorado Open Lands^
Colorado Water Science Center^
Commission Shift^
Commonwealth of Virginia Hampton Roads Sanitation District^
DigDeep^*
Delaware Geological Survey*
Environmental Defense Fund^*
Florida State University*
Freeport-McMoRan*
Earth & Water Law^
Family Farm Alliance^
FMI^
Gila River Indian Community*
Great Lakes Commission*
Geological Society of America^
Ground Water Protection Council^
Homebuilder's Association of Central Arizona^
Idaho Water Users Association^*
Illinois Farm Bureau^*
Intel^*

[81] The White House. (2024 April 25). PCAST Welcomes Public Input on America's Groundwater Challenges.

Internet of Water Initiative^
Iowa State University^
Inside Climate News*
Kansas Farm Bureau^
Kansas Office of the Governor^
King Engineering & Associates Inc.^
LHR Consulting^
Little Big Horn College, Crow Nation^
Maryland Anne Arundel County Department of Public Works^
Miami-Dade Water and Sewer Department*
Montana State University-Bozeman^*
Matrix New World, Engineering^*
Napa County^
National Association of Home Builders^
National Audubon Society*
National Ground Water Association^
National High Magnetic Field Laboratory*
National Mining Association^
National Water Resources Association^
Navajo Nation^*
New Mexico Office of the State Engineer^
New Mexico State University Department of Water Resources Management^
Northern Arizona University^
Oregon Water Resources Department^*
Paloma Irrigation District^
Pennsylvania State University^
People for the Playa^
Princeton University High Meadows Environmental Institute°
Rohde Environmental Consulting, LLC^
Self Help Enterprises^
Sherman and Howard Law Firm*
Norse Sky Ranch^
South Florida Water Management District^*
St Johns River Water Management District^*
Stanford University^
Sustainable Waters^
Swinomish Indian Tribal Community*
Tampa Bay Water^*
Texas Alliance of Groundwater Districts*
Texas A&M University*
Texas A&M University School of Law^
Texas Water Development Board^*°
The Food Industry Association*
The Ground Water Protection Council^
The Nature Conservancy^
The World Bank^
Tohono O'odham Nation^*
U.S. Small Business Administration Office of Advocacy^
United States Senate, Committee on Energy and Natural Resources^*
U.S. Department of Agriculture Agricultural Research Service°
U.S. Department of Agriculture National Institute of Food and Agriculture^°
U.S. Department of Agriculture Natural Resource Conservation Service*°
U.S. Department of Agriculture Economic Research Service°
U.S. Department of Energy Office of Fossil Energy and Carbon Management°
U.S. Department of Energy Pacific Northwest Laboratory°
U.S. Department of the Interior*
U.S. Department of the Interior, Bureau of Indian Affairs°
U.S. Department of the Interior, Bureau of Land Management^
U.S. Department of the Interior, United States Geological Survey^*°
U.S. Environmental Protection Agency, Environmental Chemistry*°
U.S. Environmental Protection Agency, Office of Water*°
U.S. Environmental Protection Agency, Safe and Sustainable Water Resources Research Program°
University of Arizona^*
University of California-San Diego^
University of California-Santa Barbara*
University of Delaware^
University of Idaho*
University of Minnesota^*
University of North Carolina^*
University of Nebraska Water Center*°
University Nevada-Reno*
University of Washington^*
Utah Division of Water Rights^
Utah Farm Bureau Federation^
Utah Water Research Laboratory^
Utah State Engineering Office*

Virginia Tech University, Department of Civil and Environmental Engineering °
WateReuse Association^
Water Finance Exchange*°
Water Strategies LLC*
Western Governors' Association^
Western States Water Council^
Westlands Water District*
World Wildlife Fund^*

Appendix F: External Experts Consulted

PCAST sought input from a diverse group of additional experts and stakeholders. PCAST expresses its gratitude to those listed here who shared their expertise. They did not review drafts of the report, and their willingness to engage with PCAST on specific points does not imply endorsement of the views herein. Responsibility for the opinions finding, and recommendations in this report and for any errors of fact or interpretation rests solely with PCAST.

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Brian Clark
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