THE GEOLOGICAL SOCIETY OF AMERICA®

GSA Position Statement

WATER RESOURCES: QUANTITY

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Position Summary. Population growth drives decisions about water use for industrial, agricultural, municipal, and recreational purposes. Increasing demands and a changing climate pose significant, immediate challenges to ensuring sustainability of surface- and groundwater resources in the United States and globally. Broad, outcome-oriented water-resource science policies and initiatives are needed to address these issues.

This position statement (1) summarizes the consensus views of GSA on water-resource issues, specifically the quantity of surface- and groundwater available to meet societal needs; (2) advocates for improved adaptive management of the availability of existing and future water resources through collaboration of water professionals, concerned citizens, and decision makers at all levels of government; and (3) provides a communications tool for geoscientists.

Conclusions and Recommendations

Mitigating present-day and future, anticipated water shortages and managing water resources for the coming decades requires broad, sustained efforts and active collaboration among geoscientists, engineers, water-resource managers, planners, policy makers, and industry, who should seek to

- **Improve the fundamental understanding of the quality, quantity, distribution, and use of water resources to increase the reliability and use of water-resource management tools.** Critical to this is an increased understanding of (1) the interactions between geological, biological, and ecological systems and that quantity also refers to useable quality (water fit for human and ecological consumption); and (2) the impacts of climate change on the water cycle and water resource distribution, including the role of soil moisture in the hydrologic cycle, changes in type and duration of precipitation, and surface water–groundwater interaction.
- **Increase public investment in data collection and access to improve the scientific understanding of water resources.** A comprehensive understanding can be achieved by maintaining current hydrologic data and monitoring capabilities; developing new data sets and ground- and space-based collection capabilities at the spatial and temporal resolution needed to support model analyses and decision making from local to regional scales; organizing data collection and management by surface-water and groundwater hydrologic basins; and facilitating open access to these data sets.
- **Support computational, risk-based analyses to optimize data acquisition and enhance the scientific and socioeconomic basis of decision making for water resources management.**
- **Identify viable twenty-first–century approaches and alternatives when developing regulations, laws, compacts, or treaties involving the allocation and use of water resources.** An understanding of the natural behavior, distribution, and variability of surface-water and groundwater is fundamental to the development of these approaches.

Rationale

Surface-water and groundwater resources are inextricably linked; changes in one impact the other. Climate change exacerbates these impacts by directly affecting the hydrologic cycle on local to global scales. Increases in temperature accelerate evaporation from open water, soils, and vegetation. Additional water in the atmosphere combined with heat fuel extreme weather events, change water distribution patterns, intensify precipitation, decrease snowpack, and alter the timing of peak snowmelt. Temperatures in the U.S. increased by 0.7 °C for the period 1986–2016 relative to 1901–1960, with the largest increases seen in Alaska and the western U.S., and projected late-century increases are even greater[1,2]. Water distribution patterns will change as climate changes, resulting in too much water in some locations and too little water in others. A changing climate coupled with mis- or un-informed policy decisions further aggravate the problem.

Specifically, climate change will increase the frequency, intensity, and duration of drought in the western U.S., particularly the Southwest, with adverse impacts to water resources[1]. The Colorado River Basin and other major river basins in the western U.S. are undergoing aridification, or the ongoing, permanent transformation to a drier environment, to varying degrees[3]. Impacts of droughts

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include reduced surface-water flow and groundwater storage, reduced agricultural productivity, loss of biodiversity, soil degradation and loss, wildfires, increases in invasive species and disease, and increases in heat-related human deaths[4]. Droughts are the second costliest weather- and climate-related disaster in the U.S. Between 1980 and 2021, 29 drought episodes resulted in at least US$1 billion in total damages for each event, with an average loss of $9.7 billion per event[5].

Climate change will also lead to an increase in the frequency and intensity of heavy rainfall events (>99th percentile of daily values), most notably in the Midwest and in the Northeast, where changes average as much as 42% and 55% (compared to data available from 1958)[1]. Additional increases exceeding 40% are projected by the end of the century (relative to 1986–2015)[1]. Heavy rainfall events lead to increased runoff, flash flooding, mudflows and landslides, and sediment erosion and loading into the nation's waterways, all with associated impacts to infrastructure (levees, dams, stormwater management systems, etc.) or agriculture. Long periods of heavy rainfall can also reduce the capacity of the soil and underlying geologic substrate to absorb water, thereby challenging the recovery and replenishment opportunities in aquifers. In addition to the challenges offered by flooding events (see the GSA Position Statement: U.S. Flood Risk Management), significant changes in the timing and volume of precipitation can lead to agricultural drought conditions (as opposed to meteorological drought), where peak water availability may be out of phase with the growing season[6].

Thermoelectric power, irrigation, and public supply account for 90% of all surface-water and groundwater withdrawals in the U.S. (41%, 37%, and 12%, respectively)[7]. Although many renewable energy sources such as solar and wind reduce or eliminate the need for water in electricity production, reservoir hydropower and biofuel sources may have a large water footprint[8]. In addition, water is crucial for mining and processing minerals used in the manufacture of green technologies[9].

Given the longer residence time of groundwater (compared to surface water), aquifers can be slow to respond to stresses, and problems may not be noticed and remedied for many years[10]. About 70% of groundwater withdrawals in the U.S. are used for agriculture, and the extraction rate increasingly exceeds the replenishment rate in many areas, resulting in decreased groundwater storage[7]. Total groundwater depletion in the U.S. from 1900–2008 was about 1000 km^3, with faster depletion rates during 2000–2008[10]. Two-thirds of the depletion is from the High Plains aquifer (the largest in the U.S.), the Gulf Coastal Plain aquifer system (Mississippi Embayment section), and the Central Valley aquifer in California[10,11]. Sustained groundwater withdrawals and subsequent lowering of the water table can result in the loss of connectivity with and decreased flow of surface water. Streamflow losses can extend far beyond the region of pumping[12]. Drilling deeper is not a sustainable solution; deeper aquifers tend to be more saline and require treatment, and deeper wells tend to have higher construction costs and energy demands[13]. Furthermore, deeper aquifers may contain fossil groundwater, where recharge could take thousands of years.

Mitigating groundwater depletion will require reducing demand, particularly in irrigated agriculture, and increasing supply through artificial aquifer recharge and other methods[10]. Efforts at the municipal level to capture stormwater and use gray water can enhance local water supplies and show promise for sustainable urban water management[14]. Any mitigation strategy is complicated by the fact that local groundwater conditions can be highly variable and cross geopolitical boundaries. Scientific and technical issues are often coupled with political, legal, and socioeconomic considerations and constraints[10]. Given these complexities, we must recognize that one technical approach is not appropriate for all aquifers, and solutions will require comprehensive and integrated analysis and discussion.

Comprehensive and robust data sets with high spatial and temporal resolution, including basin- and aquifer-scale geophysical data and three-dimensional geologic maps are needed to inform groundwater modeling and address the issues outlined above. The U.S. Geological Survey (USGS) has developed and maintained extensive surface- and groundwater monitoring networks[15] and databases such as the National Hydrography Dataset[16], but gaps in coverage and data remain[17]; the USGS is currently developing a Next Generation Water Observing System (NGWOS) that will address these gaps and eventually "provide high temporal and spatial resolution data on streamflow, evapotranspiration, snowpack, soil moisture, water quality, groundwater/surface-water connections, stream velocity distribution, sediment transport, and water use."[17] At regional and global scales, satellites such as the Gravity Recovery and Climate Experiment (GRACE) launched in 2002 and GRACE Follow-On (GRACE-FO) launched in 2018 provide terrestrial water storage information based on changes in Earth's gravitational field[18]. Such data combined with ground- and model-based approaches are critical for understanding causes and variations in surface- and groundwater quantities, seasonal to decadal variations, and opportunities for storage and replenishment in the face of climate change, drought, flooding and runoff, and anthropogenic influence.

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About the Geological Society of America

The Geological Society of America, founded in 1888, is a scientific society with members from academia, government, and industry in more than 100 countries. Through its meetings, publications, and programs, GSA enhances the professional growth of its members and promotes the geosciences in the service of humankind. Headquartered in Boulder, Colorado, USA, GSA encourages cooperative research among earth, life, planetary, and social scientists, fosters public dialogue on geoscience issues, and supports all levels of earth science education. Inquiries about GSA or this position statement should be directed to GSA's Director for Geoscience Policy, Kasey S. White, at +1-202-669-0466 or kwhite@geosociety.org.

OPPORTUNITIES FOR GSA AND ITS MEMBERS TO HELP IMPLEMENT RECOMMENDATIONS

To facilitate implementation of the goals of this position statement, The Geological Society of America recommends that its members take the following actions:

- Engage with policy makers to support efforts to mitigate present-day and future anticipated water shortages.
- Contact stakeholders (water managers, land managers, water users, policy makers, and regulators) to identify information and research needs and collaborate on the development of sustainable water-resource management goals and plans.
- Participate in public-education activities to foster partnership and collaboration among local, state, and federal governments; educational and research institutions; energy, industrial, and agricultural users; and the public.
- Participate in professional forums to educate peers and the public about regional water quantity issues, including the role of climate change in altering the hydrologic cycle, and identify ways that better data and analyses can improve water-resource management.
- Ensure that water footprint[19,20] (both direct and indirect water use) informs both personal and professional decisions every day as well during future planning efforts.
- Improve communication with decision makers and the public about water resource availability issues. Communication is aided by analogies and examples relevant to the affected stakeholders/populations.

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