

Brackish Groundwater and its Potential to Augment Freshwater Supplies

By Jennifer S. Stanton and Kevin F. Dennehy

Secure, reliable, and sustainable water resources are fundamental to the Nation's food production, energy independence, and ecological and human health and well-being. Indications are that at any given time, water resources are under stress in selected parts of the country. The large-scale development of groundwater resources has caused declines in the amount of groundwater in storage and declines in discharges to surface water bodies (Reilly and others, 2008). Water supply in some regions, particularly in arid and semiarid regions, is not adequate to meet demand, and severe drought intensifies the stresses affecting water resources (National Drought Mitigation Center, the U.S. Department of Agriculture, and the National Oceanic and Atmospheric Association, 2015). If these drought conditions continue, water shortages could adversely affect the human condition and threaten environmental flows necessary to maintain ecosystem health.

In support of the national census of water resources, the U.S. Geological Survey (USGS) completed the national brackish groundwater assessment to provide updated information about brackish groundwater as a potential resource to augment or replace freshwater supplies (Stanton and others, 2017). Study objectives were to consolidate available data into a comprehensive database of brackish groundwater resources in the United States and to produce a summary report highlighting the distribution, physical and chemical characteristics, and use of brackish groundwater resources. This assessment was authorized by section 9507 of the Omnibus Public Land Management Act of 2009 (42 U.S.C. 10367), passed by Congress in March 2009. Before this assessment, the last national brackish groundwater compilation was completed in the mid-1960s (Feth, 1965). Since that time, substantially more hydrologic and geochemical data have been collected and now can be used to improve the understanding of the Nation's brackish groundwater resources.

What is Brackish Groundwater?

All water naturally contains dissolved solids that, if present in sufficient concentration, can make a surface-water or groundwater resource "brackish". In general, brackish groundwater is groundwater that has a dissolved-solids content greater than freshwater but not as much as seawater; however, a variety of classification schemes have been used to quantitatively describe waters that have different dissolved-solids concentrations. Dissolved solids (also referred to as total dissolved solids) is a measure of the concentration of all organic and inorganic dissolved substances (like minerals, metals, and salts) present in a water sample. The U.S. Environmental Protection Agency secondary maximum contaminant level, a nonmandatory standard that only applies to public water systems, advises a level of 500 milligrams per liter (mg/L) for dissolved solids (U.S. Environmental Protection Agency, 2015), although numerous water supplies exceed this level. Water with dissolved-solids levels exceeding 1,000 mg/L is generally considered undesirable for human

consumption. Water that is high in dissolved solids may taste bitter, salty, or metallic; smell unpleasant; or may be toxic. Water with higher dissolved-solids concentrations can be used for a variety of purposes other than drinking water. For the national brackish groundwater assessment, brackish groundwater was quantitatively defined as having a dissolved-solids concentration between 1,000 and 10,000 mg/L. Saline groundwater commonly refers to any waters having dissolved-solids concentrations of at least 1,000 mg/L and includes the brackish concentration range and higher salinity water. For comparison, seawater has a dissolved-solids concentration of 35,000 mg/L (table 1).

Table 1. Water categories based on dissolved-solids concentration.

Categories of water ¹	Dissolved-solids concentration, in milligrams per liter
Fresh	Less than 1,000
Brackish	1,000 to 10,000
Highly saline	Greater than 10,000

¹Seawater contains about 35,000 milligrams per liter.

Where is Brackish Groundwater?

The national brackish groundwater assessment focused on defining the occurrence of brackish groundwater at depths less than 3,000 feet (ft) below land surface because few data were readily available below that depth. Groundwater-chemistry data for about 380,000 groundwater samples were compiled from 33 sources (Qi and Harris, 2017) for this assessment. Those data were summarized with a coarse, three-dimensional grid that indicated occurrences of brackish groundwater at some depth within 3,000 ft below land surface in every State except New Hampshire and Rhode Island (fig. 1). Most of the known brackish groundwater is within in the Western Midcontinent region. Other significant occurrences of brackish groundwater generally are in the Coastal Plains, Eastern Midcontinent, and Southwestern Basins regions (fig. 1). States along the Atlantic coast have the largest number of observations; however, the groundwater in these States is generally freshwater with little brackish groundwater occurrence except along the coastline. In general, dissolved-solids

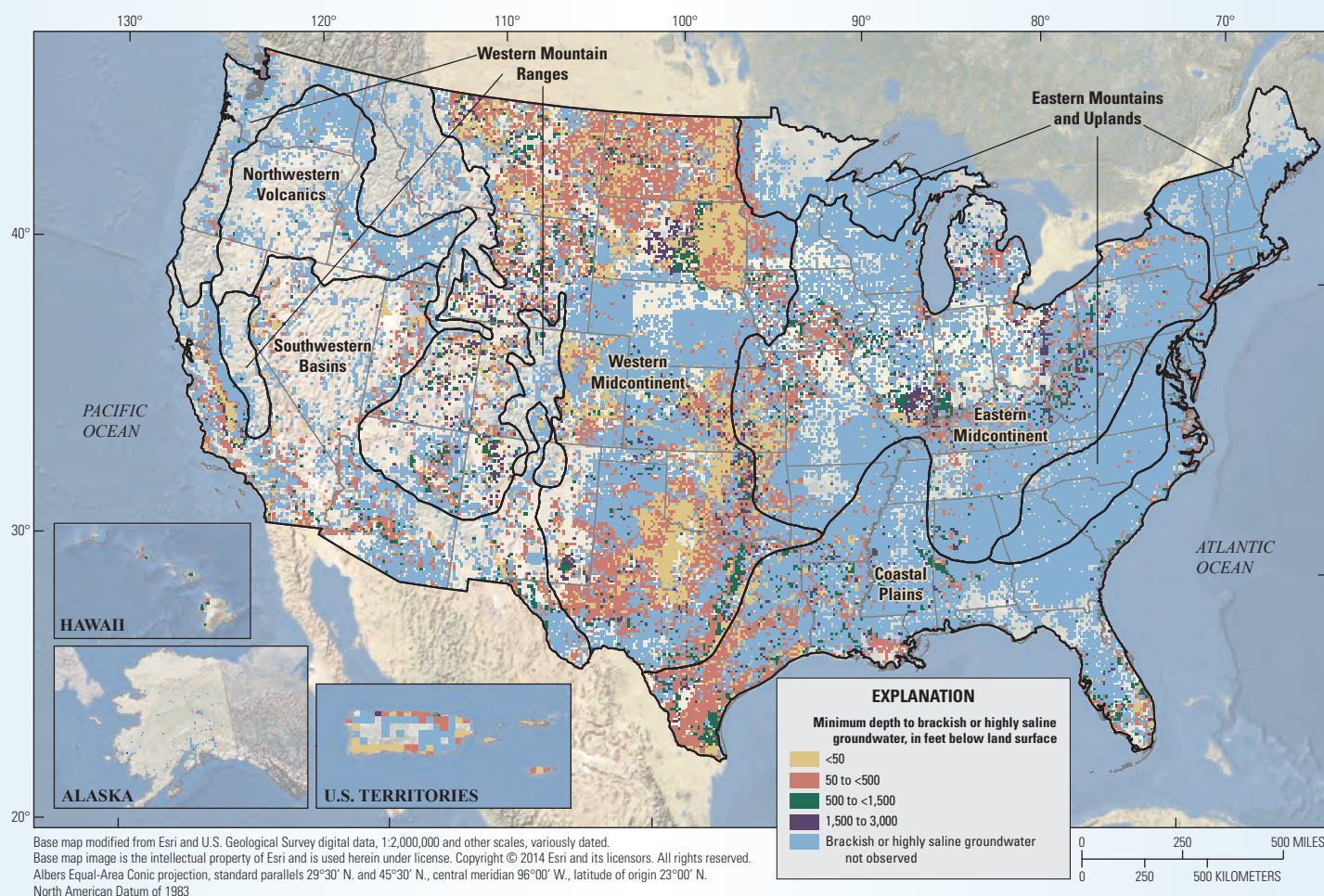


Figure 1. Observed minimum depth to brackish or highly saline groundwater between 0 and 3,000 feet below land surface.

concentrations are higher and brackish groundwater is more frequently detected with increasing depths below the land surface. Across the United States, for example, about 70 percent of sampled wells between 1,500 and 3,000 ft below land surface produced brackish or highly saline groundwater; whereas, less than 20 percent of sampled wells between 0 and 50 ft below land surface had brackish or highly saline groundwater. Similarly, the median dissolved-solids concentration observed across the United States is 334 mg/L for all wells between 0 and 50 ft below land surface and 3,692 mg/L for all wells between 1,500 and 3,000 ft below land surface.

What Chemical Factors Affect the Usability of Brackish Groundwater?

In addition to limitations caused by high dissolved-solids concentrations, other chemical constituents can be present that affect the usefulness of brackish groundwater. The chemical composition of brackish groundwater is spatially variable because it depends in part on local geologic, hydrologic, and climatic conditions. Chemical variations in brackish groundwater are important because they can have implications for the feasibility, treatability, and associated cost of using brackish groundwater (McMahon and others, 2015). Specific chemical constituents in brackish groundwater can exceed standards for a particular use, and identifying the constituents is important to determine if brackish groundwater must undergo specialized treatment beyond what is required to reduce overall salt content.

For example, arsenic can exceed the U.S. Environmental Protection Agency primary drinking-water standard of 10 micrograms per liter for drinking water (fig. 2). Other chemical characteristics also can limit brackish water use; for example, mineral scaling can impede conveyance, storage, and treatment of brackish groundwater.

Mineral scaling refers to the deposition or precipitation of minerals on a surface or membrane that stores, transmits, or filters water and can impede flow. For example, scaling can precipitate minerals along the walls of pipes, reducing the interior diameter of the supply lines. Corrosion, which is less common with brackish groundwater, can cause deterioration of metal surfaces. Water treatment is commonly necessary to remove constituents that are related to scaling or that exceed health benchmarks. Reverse osmosis is the most common form of desalination treatment in the United States. Reverse osmosis systems include a thin, semipermeable barrier that transmits water under pressure, while excluding solutes. Without proper treatment of source water to reduce scaling potential, reverse osmosis systems can fail; therefore, information about the minerals that are present and their concentrations will enable a cost/benefit analysis of the resource and a given treatment technology.

Detailed information about brackish groundwater chemical characteristics and scaling potentials was derived from geochemical modeling (Parkhurst and Appelo, 1999) and other approaches. For example, the Langelier saturation index is an indicator of the degree of saturation of water with respect to calcite and is commonly used by the water-supply industry to

determine potential for corrosion or scaling (Langelier, 1936). A negative Langelier saturation index value indicates the water is not likely to precipitate calcite and, thus, could lead to corrosion; whereas, a positive index value will indicate the water is likely to deposit calcite in the distribution or treatment system. Only 4 percent of the evaluated groundwater samples (n=14,380) with a dissolved-solids concentration of 1,000 mg/L or more exceeded a Langelier saturation index value of 1 (increased scaling potential), and only 2 percent of samples had an index value less than -1 (increased corrosion potential) (fig. 3). Some minerals identified as potential scaling components include calcite, barite, and chalcedony, depending on the source of the water.

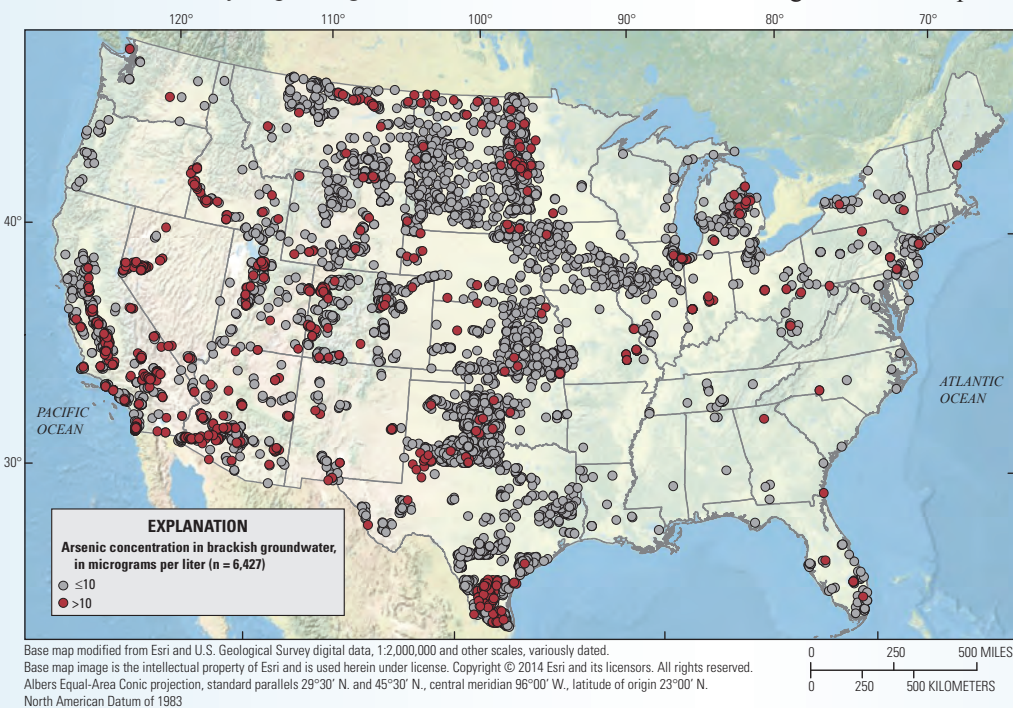


Figure 2. Concentrations of arsenic in brackish groundwater in the conterminous United States (modified from McMahon and others, 2015).

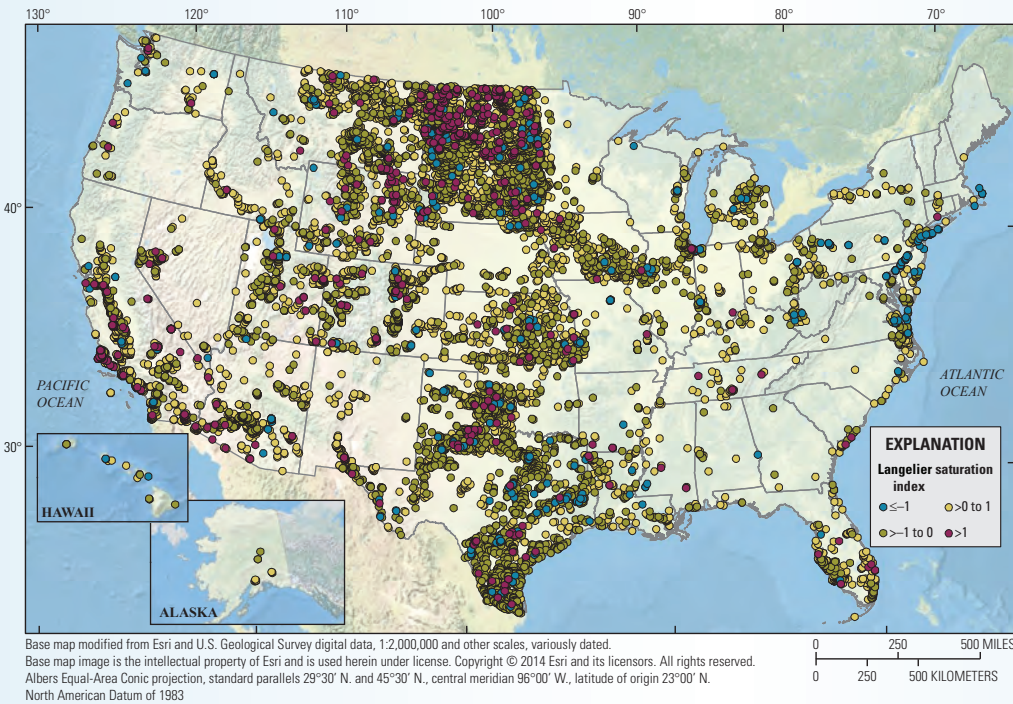


Figure 3. Distribution of Langelier saturation index values in brackish groundwater.

What Physical Factors Affect the Usability of Brackish Groundwater?

When evaluating brackish groundwater as a potential resource, understanding the ability of brackish groundwater-bearing aquifers to store and transmit usable amounts of water is important. This ability is controlled by the physical properties of the aquifer sediments, such as hydraulic conductivity, storage coefficient, specific yield, and porosity. Information about these properties is limited for most brackish zones; therefore, well-yield data (available for about 16 percent of wells) were used to determine some measure of the ability of wells producing brackish groundwater to provide usable amounts of water.

Although compaction and cementation of deeper sediments could limit development of brackish groundwater resources in some areas, reported well yields indicate that shallow and deep wells could produce brackish groundwater at sufficient rates for many uses. In the regions with the most brackish groundwater, many of the sampled wells that produce brackish groundwater have reported well yields that are at least 10 gallons per minute. In the Southwestern Basins region (fig. 1), a large part of the sampled wells producing brackish groundwater can provide yields of at least 100 or 1,000 gallons per minute (fig. 4). These results probably represent minimum values because data are from reported pumping rates and do not represent maximum potential well yields. However, high yields do not guarantee sustained production or production without adverse consequences.

Information about additional physical features of the hydrologic system, such as areas of recharge and discharge and the connection between brackish groundwater and fresh groundwater or surface water, also is needed to evaluate the sustainability of developing brackish groundwater. An understanding of these characteristics provides the ability to assess the potential for extraction of brackish groundwater to cause (1) enhanced movement of more mineralized water into freshwater zones, and vice versa; (2) substantial groundwater-level declines and land subsidence; and (3) cascading effects on streamflow and other surface water bodies as the hydrologic system attempts to adjust to these new withdrawals.

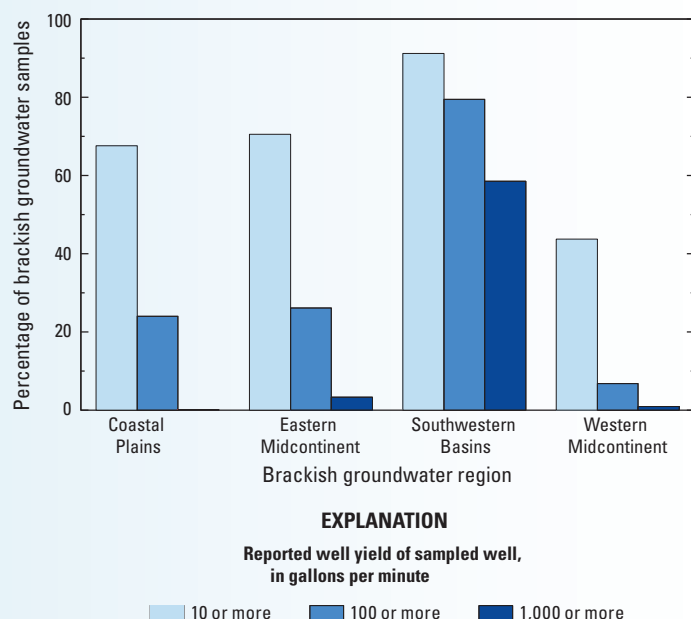


Figure 4. Percentage of brackish groundwater samples that are from wells that meet or exceed reported well yields of 10, 100, and 1,000 gallons per minute.

Can Brackish Groundwater be Used as an Alternative to Freshwater Resources?

Water providers are turning to brackish groundwater to augment or replace the use of freshwater for drinking and for other water uses, which include cooling water for power generation, irrigation, aquaculture and a variety of uses in the oil and gas industry such as drilling, enhanced recovery, and hydraulic fracturing. The use of brackish groundwater, however, has been hampered by the lack of basic knowledge concerning brackish groundwater distribution, accessibility, yield, chemical composition, use, treatment requirements, and effects on the environment.

A better understanding of the distribution and physical and chemical characteristics of brackish groundwater will help support efficient and sustainable economic development of the resource. Identification of new sources of brackish groundwater, especially in areas with limited freshwater resources, has the potential to enhance the Nation's water security. In some areas, the use of brackish groundwater could reduce effects on freshwater resources commonly used for drinking, business, and recreational activities. The strategic development and treatment of brackish groundwater to produce new supplies of differing quality for a variety of uses could help water-stressed regions stretch their limited freshwater supplies.

The national brackish groundwater assessment has provided updated basic information about the occurrence and characteristics of brackish aquifers and creates a foundation for focusing future research in locations that could be helpful for the development of the resource. The next challenge with regard to possible development of brackish groundwater is to acquire detailed information for specific brackish groundwater aquifers that is needed for evaluating sustainable brackish groundwater development, including the effects of brackish groundwater withdrawals on adjacent water resources.

For More Information

For more information about the national brackish groundwater assessment, go to <https://water.usgs.gov/ogw/gwrp/brackishgw/>, which includes downloadable data compiled from more than 30 national, regional, state, and local sources that were used to assess the Nation's brackish groundwater resources.

References Cited

- Feth, J.H., 1965, Preliminary map of the conterminous United States showing depth to and quality of shallowest ground water containing more than 1,000 parts per million dissolved solids: U.S. Geological Survey Hydrologic Atlas 199, 31 p., 2 plates, scale 1:3,000,000. [Also available at <https://pubs.er.usgs.gov/publication/ha199>.]
- Langelier, W.F., 1936, The analytical control of anti-corrosion water treatment: Journal of American Water Works Association, v. 28, no. 10, p. 1500–1521. [Also available at <http://www.jstor.org/stable/41226418>.]
- McMahon, P.B., Böhlke, J.K., Dahm, K.G., Parkhurst, D.L., Anning, D.W., and Stanton, J.S., 2015, Chemical considerations for an updated national assessment of brackish groundwater resources: Groundwater, v. 54, no. 4, p. 464–475, accessed February 3, 2017, at <http://dx.doi.org/10.1111/gwat.12367>.
- National Drought Mitigation Center, the U.S. Department of Agriculture, and the National Oceanic and Atmospheric Association, 2016, U.S. drought monitor for January 6, 2015: National Drought Mitigation Center, digital data, accessed March 13, 2016, at <http://droughtmonitor.unl.edu/>.
- Parkhurst, D.L., and Appelo, C.A.J., 1999, User's guide to PHREEQC (version 2)—A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations: U.S. Geological Survey Water-Resources Investigations Report 99–4259, 312 p. [Also available at <https://pubs.er.usgs.gov/publication/wri994259>.]
- Qi, S.L., and Harris, A.C., 2017, Geochemical database for the brackish groundwater assessment of the United States: U.S. Geological Survey data release, <https://dx.doi.org/10.5066/F72F7KK1>.
- Reilly, T.E., Dennehy, K.F., Alley, W.M., and Cunningham, W.L., 2008, Ground-water availability in the United States: U.S. Geological Survey Circular 1323, 70 p. [Also available at <https://pubs.usgs.gov/circ/1323/>.]
- Stanton, J.S., Anning, D.W., Brown, C.J., Moore, R.B., McGuire, V.L., Qi, S.L., Harris, A.C., Dennehy, K.F., McMahon, P.B., Degnan, J.R., and Böhlke, J.K., 2017, Brackish groundwater in the United States: U.S. Geological Survey Professional Paper 1833, 185 p., <https://dx.doi.org/10.3133/pp1833>.
- U.S. Environmental Protection Agency, 2015, Secondary drinking water standards—Guidance for nuisance chemicals: U.S. Environmental Protection Agency, accessed March 2, 2016, at <https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals>.