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Brackish Groundwater: Current Status and Potential Benefits for Water Management

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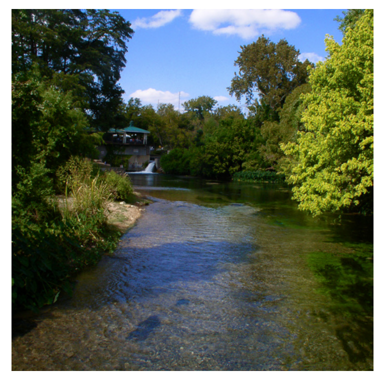
Many areas of the world face the task of providing water for rapidly growing populations in environments where new water supplies are not readily available. Some stakeholders have proposed using unconventional water resources, including brackish groundwater, in order to meet these emerging demands (Hightower et al. 2005). This issue brief describes the current state of brackish groundwater use and development in the United States. Because water is regulated primarily at the state level, we consider four examples of states with specific regulations for brackish groundwater resources—Texas, Florida, Arizona, and New Mexico—and discuss management objectives and policy recommendations that will encourage the responsible utilization of this resource. Development of brackish groundwater, if carried out responsibly, can augment supplies and relieve growing stress on freshwater resources.

Brackish groundwater has a high concentration of total dissolved solids (TDS)[1]—including the common salt, sodium chloride. It is often defined as water containing between 1,000 and 10,000 parts per million (ppm) TDS. (For reference, seawater contains ~35,000 ppm TDS, and the secondary standard for drinking water in the United States is 500 ppm TDS.) The cost of extracting groundwater is proportional to its depth, and many regions of the United States have brackish groundwater within 1,000 feet of the land surface.[2] In general, brackish groundwater is (1) fresh groundwater that acquired salts as it migrated through aquifer matrices (e.g., halite or gypsum); (2) intruded saline groundwater that was diluted in freshwater aquifers (often a result of over-pumping fresh coastal aquifers or open well boreholes that allow mixing between strata); (3) shallow, often unconfined aquifers that have increased salinity as a result of agricultural/industry practices or road salt use; or (4) water in isolated, often deep connate or "fossil aquifers" that are no longer recharged by surface water (U.S. Geological Survey 2014a). Due to differences in brackish groundwater sources, recharge rates, and connectivity with fresh aquifers, policy development requires a detailed understanding of hydrogeology, and regulation of brackish aquifers may vary depending on the aquifer type. In fact, different states have chosen different definitions for brackish or impaired aquifers, resulting in a variety of approaches to regulating the resource, as discussed below.

Because brackish groundwater contains a high level of salts, it requires advanced treatment prior to most common uses. Treatment of brackish groundwater is normally accomplished with reverse osmosis, whereby water is forced under



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high pressure through a salt-rejecting membrane.[3] As TDS concentration increases, higher pressure is needed, increasing operational costs (i.e., electricity). Some industries may use brackish groundwater with minimal or no treatment. Untreated, low-salinity brackish water may be used for irrigation (Texas House Natural Resources Committee 2015), and higher-salinity waters may be used for power plant cooling (Maulbetsch and DiFilippo 2010). Several oil and gas well operators in Texas are turning to brackish groundwater (that is, water with >1,000 ppm TDS) as an alternative source of water. The use of brackish water for hydraulic fracturing operations has increased, especially in the Eagle Ford, Permian, and Anadarko basins (Nicot et al. 2012). Brackish water is more commonly used for hydraulic fracturing in the more arid parts of the Texas, which lack easy access to fresh water (Nicot et al. 2012).

The economics of brackish groundwater are also becoming more favorable for water suppliers, such as municipalities and water utilities, who must remove salt prior to distribution. In Texas, the construction of new groundwater RO desalination plants (Figure 1) indicates that water suppliers are willing to pay more to treat impaired or brackish groundwater. These municipalities choose to pay the costs of advanced treatment rather than incur the costs of building additional water storage and transportation infrastructure (dams, canals, and pipelines) or securing additional water rights.

To be successful, policy initiatives must work largely within the current institutional structure while incentivizing actors to change the way they manage and use water.

However, the development of brackish groundwater carries with it a variety of challenges. Although an isolated geologic formation may contain only brackish groundwater, a salinity gradient is observed across some aquifers, which may make regulation and management more complex. Disparate treatment of fresh and brackish groundwater may be difficult where the waters are in close proximity, as pumping from the brackish section of the aquifer may have direct and potentially adverse effects on water in the fresh part of the aquifer. Variations in aquifer depth and TDS concentrations have important implications for the cost to acquire and treat water, as costs increase with both TDS and depth. Thus, these costs depend not only upon the target aquifer but also the location within the target aquifer.

POLICY GOALS

To be successful, policy initiatives must work largely within the current institutional structure while incentivizing actors to change the way they manage and use water. Although municipalities must desalinate the water or blend brackish water with freshwater prior to use, industries such as oil and gas (and, in a few cases, agriculture) that are able to operate using water with higher levels of TDS may choose to use brackish groundwater if it is technically viable and makes economic sense. These users, by switching to brackish groundwater, can reduce fresh water demand without incurring a high cost, making incentives to use brackish groundwater a potentially strong water policy tool to augment water supply and ease fresh water demand in some regions.

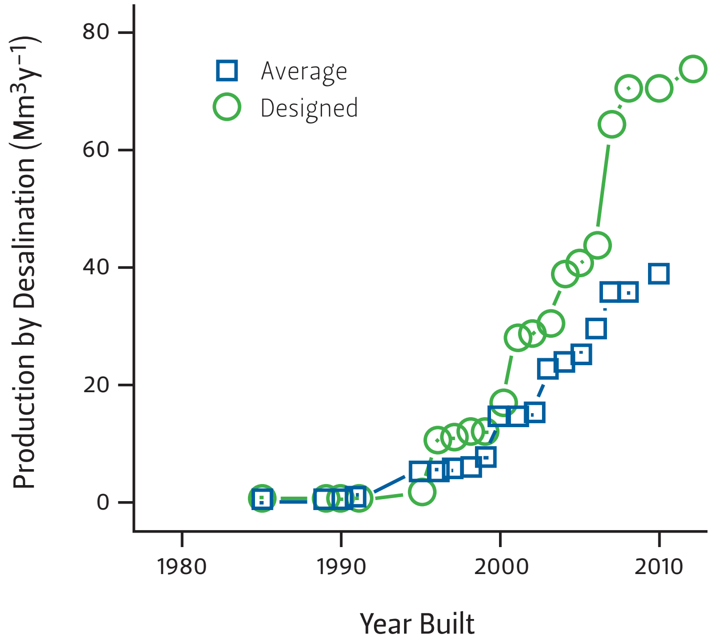
Given the benefits of responsible brackish groundwater development for water supplies, we posit that good management of brackish groundwater would include the following objectives:

1. facilitating access to and incentivizing the development of brackish groundwater supplies to increase the water supply and relieve demand on freshwater aquifers that suffer from over-subscription by streamlining regulatory and bureaucratic requirements and costs;
2. creating regulatory certainty for all stakeholders so they know the quality and quantity of their water supplies are secure;
3. ensuring that freshwater aquifers are protected from the consequences of producing brackish groundwater withdrawn from the same or a nearby aquifer;
4. ensuring that brackish aquifers are protected from contamination by injection wells for waste disposal; and
5. respecting private property rights in accordance with applicable law.

REGULATION OF BRACKISH GROUNDWATER: CASE STUDIES

Brackish groundwater is withdrawn for consumptive use in many parts of the United States, including Texas, Florida, Arizona, and New Mexico. These states rely on the desalination of brackish groundwater for portions of their water supply or have substantial brackish groundwater resources that may provide such supplies in the future. The states regulate and manage brackish groundwater in a variety of ways, but none of them give brackish groundwater extensive or detailed treatment in the law disparate from that generally governing groundwater. They do, however, provide for lower regulatory hurdles to facilitate the development and use of brackish groundwater.

FIGURE 1 — CUMULATIVE PRODUCTION OF GROUNDWATER DESALINATION PLANTS IN TEXAS



SOURCE Data from the Texas Water Development Board Desalination Plant Database (TWDB 2010)

BRACKISH GROUNDWATER FOR MUNICIPALITIES AND OIL AND GAS IN TEXAS

Advancements in the economic development of brackish groundwater depend in great part on the institutional structure surrounding the management and use of groundwater in a jurisdiction. Brackish groundwater in Texas is situated within a complicated and potentially unsustainable governance regime for groundwater. In Texas, groundwater is the private property of the land surface owner. The central tenets of groundwater law in Texas are the absolute ownership doctrine and its corollary, the rule of capture. In short, these rules provide that a landowner owns the water under his or her land, may take all the water available for capture under the land, and incurs no liability to neighboring landowners, even if the landowner's actions deprive neighbors of the water's use.[4]

Groundwater rights in Texas are still subject to some degree of control by the legislature and the courts. The Texas Legislature has elected to fulfill the Texas Constitution's mandate that the state preserve and conserve water resources for the benefit of the people by authorizing the creation of groundwater conservation districts (GCDs) (Texas Const. art. XVI, §59(a); Texas Water Code §36.0015). Under the Texas Water Code, GCDs are authorized to adopt rules to achieve specific management objectives (Texas Water Code §36.0015). Approximately 100 GCDs have been created in Texas, but there remain portions of the state that are not within the jurisdiction of a district. Thus, groundwater regulation and management in Texas depend, in great part, on the location of the groundwater.

A number of case law decisions over the years have created uncertainty about the extent to which GCDs may use their authority to limit production by landowners without the restriction constituting a regulatory taking that requires compensation.[5] These precedents open the possibility of enormous financial liabilities for groundwater districts and will make it difficult, if not impossible, for the districts to fulfill their responsibilities of managing and protecting groundwater in Texas.

In 2015, the Texas Legislature adopted a bill requiring the Texas Water Development Board to designate certain areas of the state as "brackish water production zones" (BWPZs). To be designated as a BWPZ, an area must have moderate to high brackish groundwater availability and hydrogeological barriers that prevent interaction with surrounding fresh aquifers or fresh subsections of aquifers. Other requirements also apply.[6] The bill, as passed, did not incentivize brackish groundwater production.

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Although Texas statutory and case law do not provide for disparate regulation of brackish groundwater, nine GCDs (9.4%) have adopted rules addressing the resource specifically. Future development of brackish groundwater in Texas will require operating within a current system that does not appropriately value fresh groundwater—which is often more easily accessed and used than would be brackish groundwater. Water pricing in this system fails to reflect water quality or scarcity, resulting in an over-allocation of water, as the price for water is kept artificially low. This over-allocation of water results in groundwater extraction at a rate that exceeds recharge—a situation that, by definition, is unsustainable.

Because the obstacles described above prevent market forces in Texas from setting the price of water, policies must be put into place to enable watershed-, aquifer-, or state-wide water markets or otherwise resolve the discrepancy between supply and demand. The current water management strategy in Texas appears to be a combination of incentives for increasing water use efficiency and support for projects that increase water supply, including alternative water supplies like brackish groundwater. The use of brackish groundwater—if properly managed and incentivized—could offer Texas a way to both expand water supplies and reduce demand on existing freshwater sources.

LONGER PERMIT TERMS IN FLORIDA AND ARIZONA

Groundwater, like all water in Florida, is considered a public resource. In order to use groundwater in Florida, a person must obtain a consumptive use permit. The state offers additional flexibility in permitting requirements for alternative water supplies, including brackish groundwater. A person who wishes to develop these supplies may receive a permit for a longer term than the usual 20 years if there is sufficient data to show that permitting conditions—including the protection of nearby or connected fresh aquifers—will be met for that term. That term may be extended at the permittee's request to accommodate the need to retire bonds issued for construction of the project (Fla. Stat. §373.236[5]).

The Florida Legislature has stated explicitly that it sees alternative water supply development projects as vital to meeting anticipated water demands in the state, and offers 50-year permits to local governments and certain utilities that contract with a private landowner "for the purpose of more efficiently pursuing alternative public water supply development projects identified in a district's regional water supply plan and meeting water demands of both the applicant and the landowner" (Fla. Stat. § 373.236[6]). These more favorable permit conditions offer would-be developers of alternative water supplies—including brackish groundwater—greater regulatory certainty, thus facilitating the use of these supplies.

Arizona has an estimated 740,000 MCM of brackish water (defined as water containing 1,000 to 10,000 mg L^{-1} TDS) in its aquifers, mostly at depths of less than 366 m (McGavock and Collum 2008). Groundwater in Arizona is governed by the Groundwater Management Code, which designates as Active Management Areas (AMAs) parts of the state where groundwater depletion is known to be a problem (Ariz. Rev. Stat. §45-411). Within the AMAs, groundwater uses are determined by historic use during the five-year period before the AMA was created—i.e., rights are "grandfathered." There are three types of grandfathered rights, each of which is subject to different terms regarding where, how, and by whom water may be used (see Ariz. Rev. Stat. §45.461 et seq.). There are three exceptions to the "grandfathered" rule within an AMA. Municipalities, private water companies, and irrigation districts may serve customers within their service areas (Ariz. Rev. Stat. §45-491 et seq.). The code also establishes "irrigation non-expansion areas" (INAs), in which only land that was legally irrigated during a set period (or that has had significant capital investment for improvement during a specified time) in the past may continue to be irrigated (Ariz. Rev. Stat. §§45-431–45.440). Users of nonexempt wells[7] in INAs must meter and report water use (Arizona Department of Water Resources 2014; Ariz. Rev. Stat. 45.437).

Outside of an AMA or INA, groundwater in Arizona is subject to limited regulation. A person may withdraw and use groundwater for reasonable and beneficial use, subject to restrictions on transportation to certain AMAs (Ariz. Rev. Stat. §45-543). The Arizona Department of Water Resources limits the quantity of groundwater that can be produced annually, and nonexempt users are required to pay a groundwater withdrawal fee for each acre-foot of groundwater pumped (Ariz. Rev. Stat. §§45-611–45-618). One may obtain a permit for "poor quality groundwater" for a term of up to 35 years for non-irrigation uses if that water cannot be used for other beneficial uses[8] at the time the permit is issued (Ariz. Rev. Stat. §45-516). This permit term is similar to Florida's 30-year permit for alternative water supplies and may offer some incentive to use brackish groundwater.

NON-POTABLE DEEP AQUIFERS IN NEW MEXICO

Groundwater resources in New Mexico belong to the public (N.M. Stat. §72-12-1). They are subject to the doctrine of prior appropriation[9] and managed by the Water Resources Allocation Program in the Office of the State Engineer. Under the state's Groundwater Code, the state engineer obtains control over groundwater by "declaring" a groundwater basin. As of 2006, the state engineer had declared all basins in the state (Bushnell 2012). Within a declared basin, a permit is required for new groundwater appropriations, alterations to existing uses, and drilling of supplemental or replacement wells (N.M. Stat. §§72-12-1–72-12-24).

New Mexico classifies water containing not less than 1,000 ppm TDS as "non-potable water" (N.M. Stat. §72-12-25). The state classifies as a "non-potable deep aquifer" an aquifer that has clearly defined boundaries and a top depth of at least 2,500 ft. (762 m) below ground and that contains non-potable water (N.M. Stat. §72-12-25). If the state engineer declares such an aquifer to be a groundwater basin, the aquifer is then subject to regulation by the state engineer (N.M. Stat. §72-12-25). Appropriations of groundwater from a declared non-potable deep aquifer for oil and gas, prospecting, mining, road construction, agriculture, electricity generation, industry, and geothermal use are exempted from most regulations (N.M. Stat. §72-12-25[B][1]), but other uses are subject to the same regulations as fresh water (N.M. Statutes §72-12-25[B][2]). Thus, production of brackish resources for heavier industry uses, by virtue of carrying less regulation, may be more attractive for certain users.

POLICY RECOMMENDATIONS

Allowing current groundwater governance regimes alone to control this resource means a missed opportunity to facilitate the expansion of water supply; incentivize smarter, targeted water use; and enable fresh water conservation. Disparate regulation of brackish groundwater is uncommon in the United States, and most groundwater regulation does not take into account differences in water quality or the ability of brackish groundwater to alleviate stress on fresh groundwater resources. With demand likely to increase over the next few decades as the population grows and industries such as oil and gas increase water demand in some regions, long-term water security depends on proper management of all water resources.

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Acquiring better knowledge and understanding of hydrogeological resources will allow policymakers to make better decisions about how to manage brackish groundwater resources and protect aquifers, both brackish and fresh.

Water resources should be regulated and managed in a way that encourages brackish groundwater development without adversely affecting freshwater resources, creates regulatory certainty, protects potential brackish groundwater resources for the future, and respects property rights. Furthermore, legislators and agency regulators must be careful to find the proper balance between deregulation that may lead to environmental harm and restrictions that may make the use of brackish groundwater economically unviable. Also important are laws that protect both freshwater sources and brackish groundwater sources, which are likely to serve as important water resources now and in the future.

Finally, acquiring better knowledge and understanding of hydrogeological resources will allow policymakers to make better decisions about how to manage brackish groundwater resources and protect aquifers, both brackish and fresh. All stakeholders, from water developers to agricultural interests, benefit from increased certainty, knowledge, and understanding of subterranean water resources. In fact, more information supports all the desired policy objectives: understanding more of the mysteries behind the "secret, occult, and concealed"[10] movement of groundwater and the interconnectedness of aquifers—both to other aquifers and to surface water resources—provides a firmer foundation for regulatory policy and permitting decisions. To this end, jurisdictions should continue to fund research and mapping efforts for aquifers—brackish and fresh—and expand modeling efforts that seek to understand the interplay between surface water and groundwater. This reduces risk for investors, improves society's ability to protect resources, promotes sustainable aquifer management, and—where applicable—helps to protect individual or collective rights.

Researchers have documented a growing disparity between water supply and demand, which is caused by a rapidly increasing population, economic growth, drought, and rising calls for environmental flows. The shortage, if left unaddressed, is likely to lead, ultimately, to crisis or conflict between water users, with the attendant effects on the economy and human well-being. Increased understanding and utilization of unconventional water resources will increase water security and assist economic growth into the future. Facilitating the responsible development of brackish groundwater will help relieve pressure on freshwater resources and mitigate potential water crises in the years to come.

ENDNOTES

1. TDS is often reported as parts per million (ppm). For example, 500 ppm would mean 500 parts salt per one million parts water.

2. A national study of brackish groundwater was completed in the 1960s. In an effort to update and improve understanding of the location and character of these resources, the U.S. Department of the Interior is conducting a national assessment, which is due in September 2016 (U.S. Geological Survey 2014b).

3. Although desalination is often done using RO, brackish groundwater may be treated using nanofiltration (NF), given the composition of the brackish groundwater and the effluent quality required. NF uses lower pressures and therefore less energy than RO. However, although NF removes ~90% of divalent ions, NF does not remove monovalent ions as well as RO (60–70% removal for NF; >97% removal for RO) (Schaep 1998; Hilal 2004). The lower selectivity of NF may be sufficient to meet drinking water standards for some brackish groundwater sources, and use of such systems could lower costs.

4. Case law has carved out a few minimal limitations on the rule of capture in Texas: a landowner may not (1) maliciously take water for the sole purpose of injuring a neighbor, (2) negligently cause subsidence of another's land by her or his production, or (3) wantonly and willfully waste the water (*City of Corpus Christi v. City of Pleasanton*; *Friendswood Development Co. v. Smith-Southwest Industries, Inc.*).

5. In *Edwards Aquifer Authority v. Day*, the Texas Supreme Court held definitively that landowners own the groundwater in place beneath their land and stated that a restriction on that ownership interest *could* constitute an uncompensated governmental taking under the Texas Constitution. In arriving at this conclusion, the court acknowledged the authority of GCDs to regulate groundwater production as authorized by law, but it failed to delineate specifically where proper regulation became an impermissible taking. *In Edwards Aquifer Authority v. Bragg* (2013), Glenn and JoLynn Bragg asked the courts to determine whether the Edwards Aquifer Authority's (EAA) reduction of the amount of groundwater they are permitted to produce from their land constitutes a taking of property rights without compensation. The district court found, and the Fourth Court of Appeals of Texas affirmed, that the EAA's action constituted a regulatory taking, though the two courts differed on the amount of and methodology for determining damages. In May 2015, the Texas Supreme Court declined to hear the case, and in February 2016, a jury ruled that the Braggs were owed $2.5 million in compensation because the denial of their groundwater permits resulted in a regulatory taking.

6. Designated areas may not be (1) a water source >1000 ppm TDS that is already serving as a significant source of water supply for municipal, domestic, or agricultural purposes at the time of designation of the zones; (2) located within certain political subdivisions; or (3) designated or used for wastewater injection through the use of injection wells or disposal wells (H.B. 30, 84th Reg. Session, 2015).

7. Wells with a capacity of < 35 gallons per minute are exempt. The water must be used for non-irrigation (generally domestic) purposes and may be used to water up to two acres of grass or garden.

8. Beneficial uses in Arizona are listed as "domestic (which includes the watering of gardens and lawns not exceeding one-half acre), municipal, irrigation, stockwatering, water power, recreation, wildlife including fish, nonrecoverable water storage, and mining uses" (Ariz. Rev. Stat. §45-151[A]).

9. The prior appropriation doctrine, often summarized as "first in time, first in right," provides that the first person to use water or divert water for a beneficial use or purpose can acquire individual rights to the water.

10. Houston & Texas. Cent. Ry. Co. v. East, 81 S.W. 279, 281 (Tex. 1904).

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