Assessing the impacts of future demand for saline groundwater on commercial deployment of CCS in the United States

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Abstract

This paper provides a preliminary assessment of the potential impact that future demand for groundwater might have on the commercial deployment of carbon dioxide capture and storage (CCS) technologies within the United States. A number of regions within the U.S. have populations, agriculture and industries that are particularly dependent upon groundwater. Moreover, some key freshwater aquifers are already over-utilized or depleted, and others are likely to be moving toward depletion as demand grows. The need to meet future water demands may lead some parts of the nation to consider supplementing existing supplies with lower quality groundwater resources, including brackish waters that are currently not considered sources of drinking water but which could provide supplemental water via desalination. In some areas, these same deep saline-filled geologic formations also represent possible candidate carbon dioxide (CO₂) storage reservoirs. The analysis presented here suggests that future constraints on CCS deployment – due to potential needs to supplement conventional water supplies by desalinating deeper and more brackish waters – are likely to be necessary only in limited regions across the country, particularly in areas that are already experiencing water stress.

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1. Introduction

Groundwater is a crucial resource for much of the United States, supplying economically important water for irrigation and livestock in key agricultural regions as well as making up large fractions of the public and private drinking water supply in many urban and rural areas [1]. In still other areas, a growing dependence on groundwater resources is expected as populations expand and existing water supplies remain static or dwindle. The issues associated with those surface and groundwater supplies that are already overextended, depleted or in danger of depletion may be amplified by population growth as well as by changing climatic conditions impacting water availability [2, 3, and 4]. Balancing water use and supply is often a complex issue on its own, but as supplies

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become severely constrained due to one or a combination of these factors, communities and regions may find themselves looking more towards technological options for addressing water scarcity, including the use of waters of marginal or low quality via desalination [5].

Under the Safe Drinking Water Act (SDWA) of 1974, Congress mandated that the U.S. Environmental Protection Agency (EPA) regulate injection of fluids into the subsurface in order to protect underground sources of drinking water (USDWs) [6]. Defined in the Underground Injection Control (UIC) program statutes, a USDW is an aquifer or portion of an aquifer containing waters with less than 10,000 milligrams per liter of total dissolved solids (TDS). Though the water resources currently used to supply the U.S. with drinking water generally contain far lower concentrations of dissolved solids (typically well below 3,000 mg/L), the UIC statutes were designed to protect aquifers that, due to improvements in treatment technologies, could potentially be valued as sources of drinking water over time despite salinities in the 3,000-10,000 mg/L range. The UIC statutes also contain provisions for select aquifers or portions of aquifers to be exempted from such rules thus allowing these formations to be used for other purposes, provided that they meet specified criteria that ensure that they are not currently and are not reasonably expected in the future to be used for public drinking water supply.

The community of researchers focused on carbon dioxide capture and storage (CCS) technologies must consider industrial best practices along with these guiding regulations when discussing the use of deep geologic CO₂ storage formations and in particular when discussing deep saline-filled geologic formations (DSFs), which are often seen as the most promising class of CO₂ storage formations [7, 8]. Thus, there is already an underlying understanding that waters in this range of salinities will, in large part, be unavailable for use as geologic storage formations for CO₂ or other fluids. However, the potential need to protect certain higher-salinity water resources for future use may impact the permitting of some CCS projects in select deep geologic formations containing waters exceeding 10,000 mg/L which are not protected under the SDWA. The following is a discussion of the factors that will likely come to bear, in full or in part, on the potential for competition over the demand and utilization of select portions of the resource represented by these deep, brackish water geologic formations.

2. Factors impacting the likelihood of CCS groundwater demand conflicts

There are a number of factors that may contribute to a desire to protect certain high-salinity waters of otherwise candidate deep geologic CO₂ storage reservoirs from such use. Several of these are discussed in this section.

2.1. Reliance on groundwater resources

In some parts of the country, surface water supplies are plentiful and of sufficient quality that there is currently little reliance on groundwater resources for current public supply, agriculture, or industry. In these areas, unless the existing surface water resources are in danger of becoming overburdened by demand or compromised in terms of water quality, or if existing freshwater aquifer resource is limiting, it is unlikely that high-salinity aquifers will be of interest as supply waters. Conversely, in areas where a large portion of the water supply is derived from groundwater sources, there is more potential for future demand of lower-quality (non-USDW) groundwater, and greater potential for competing desires between CCS projects hoping to secure permits and local governments or other stakeholders seeking to protect those lower-quality waters for future use. The fraction of the total population served by groundwater (public supply) is a useful proxy for the overall importance of groundwater in an area, and is shown in Figure 1 below to illustrate the varied importance of groundwater across the U.S [9].

As Figure 1 illustrates, some areas of the U.S. use very little groundwater to supply their populations with drinking water. In particular, Appalachia, the Northeast and certain areas in the Midwest and Pacific Northwest rely predominantly on surface waters to meet their public supply needs. In other areas, however – particularly the Southwest, Gulf Coast and Florida, and certain other parts of the Midwest – groundwater provides a large fraction of the total public water supply, well over 50 percent in many areas. It is also worth noting that the use of groundwater to supply public drinking water appears to be on the rise. In 1985, 379 counties in the U.S. supplied more than 80 percent of their population with groundwater; in 1995 there were 436, a 15 percent increase [9].
2.2. Diminishing groundwater resources

In a number of areas across the U.S., public supply aquifers are experiencing withdrawals in excess of recharge rates and as a result some water tables are dropping. In some of these areas where key potable to low-salinity aquifers are experiencing this type of drawdown, the sustainability of the groundwater resource may be threatened, increasing the potential that lower-quality waters may be accessed and treated for additional supply in the mid- to long-term. While it is likely that select regions of large aquifer systems may be most impacted, the principal aquifers of the United States, as defined by the United States Geological Survey (see Figure 4) provide an informative basis for a discussion of key groundwater use areas [1, 9]; several are discussed in greater detail in Section 3.

2.3. Growing water demands

Perhaps the best proxy for predicting future changes in the demand for water resources is the forecast change in population in the near- to mid-term [2, 10]. Based on U.S. Census Bureau state population growth forecasts, several of the fastest-growing states are also in areas that are already experiencing water resource constraints. The four fastest growing states, according to the Census projections, are Nevada, Arizona, Florida and Texas, with growth rates of 114, 109, 79, and 60 percent respectively by 2030 [11]. In these states in particular, but also in others projected to experience moderate to high growth over the next 20 years, there may be potential for water boards to try to protect geologic formations containing water in excess of the USDW threshold of 10,000 mg/L in order to reserve these waters as potential desalination feedstocks. Figure 2 shows the population growth projections for 2030, by state.
2.4. Proximity to other potential saline water sources

Groundwater is not the only potential source of saline water to feed desalination facilities, and in many cases, it is not even the best. For regions lying near the ocean – the Gulf Coast region and Florida in particular – seawater may be a far more economical and logistically beneficial alternative [5]. In these areas, it is unlikely that groundwater will be demanded for desalination, although again it is difficult to entirely rule out the potential that saline groundwaters may be demanded for this or other future uses. Instead, the potential for demand conflicts may be lower in these areas than in regions where no other readily available source of saline water exists.

2.5. Geologic CO₂ storage potential and demand

In areas of the U.S. with significant candidate deep geologic CO₂ storage capacity, the potential for there to be competition between these two uses of deep saline-water formations would likely be less as the resource in question (deep brackish waters) is large enough to accommodate multiple uses in different parts of the overall formation. However, simply noting that a given region has a large aggregate CO₂ storage capacity is an imperfect metric for the question at hand. A more robust measure is to look at the expected demand for this potential CO₂ storage resource in a given region compared to the aggregate total storage capacity. The left pane of Figure 3 shows the distribution of large, candidate CO₂ storage capacity in the U.S. [7]. The right pane in Figure 3 depicts the resulting distribution of demand for CO₂ storage capacity under a WRE550 scenario through 2050 [12]. This is one example of our research where we have explicitly modeled the commercial deployment of CCS by the U.S. electric utility industry in the face of various greenhouse gas emissions constraints and then examined how these entities access the nation’s large theoretical CO₂ storage potential over time [12 and 13]. A key result of this research is the degree to which spatial
and temporal heterogeneity will characterize the commercial deployment of CCS within the U.S. For example in a paper we published in 2007, CCS deployment was modeled within the continental U.S. across four different energy and climate policy scenarios and only one region in the far northeast used up to 50 percent of its total theoretical geologic CO₂ storage capacity by mid-century, while for the majority of the remaining regions less than 10 percent of the potential storage capacity was demanded over this time frame [13]. This negates the idea that simply because there may be potential CO₂ storage capacity in an area with water resource concerns, that there will be competing demands for deep saline formations; it is the likely demand for CO₂ storage that is important. This further reinforces the importance of site-specific assessments (in this case of local water supply and CO₂ storage demand issues in addition to other factors) when investigating the CCS potential for a given locale.

![Figure 3. Potential CO₂ storage capacity in major storage formations in the U.S. (left pane) and modeled demand for CO₂ storage capacity by the U.S. electric utility industry through 2050 under a WRE550 scenario (right) [13].](image)

3. Preliminary look at seven principal U.S. aquifers

The following sections provide a discussion of seven of the principal aquifers in the U.S. and the factors that may impact the potential for conflicting demands for the saline waters underlying them.

3.1. High Plains/Ogallala

Widely considered one of the most depleted large, economically important aquifers in the country, the High Plains aquifer provides water crucial to sustain populations and agriculture in key agricultural states including Kansas, Nebraska and Oklahoma. The aquifer is heavily over-utilized in many areas. In some of the least impacted areas, withdrawals are double the annual recharge rate; in the highest-use, lowest-recharge areas, withdrawal rates are 100 times higher than recharge rates [14]. It is unclear whether treatment of brackish groundwater for irrigation will be an economically viable strategy in the U.S., but given the centrality of agriculture to the region’s economy this area may become a testbed for innovative irrigation options, possibly including treatment and use of deep aquifer waters exceeding the USDW threshold [15]. If so, this would increase the likelihood of a potential demand conflict for waters inhabiting DSFs and other potential geologic CO₂ storage formations in the High Plains region.

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1 This map does not include all possible CO₂ storage reservoirs, and there may be additional local storage targets that are not shown. The absence of a reservoir here does not preclude the possibility of CCS projects at a given site; rather, the map is intended to highlight the current assessment of areas where CCS is more likely to be pursued at a commercial scale.
3.2. Williston Basin

This region is home to the Madison and Fox Hills DSFs, both considered major deep saline formations that have been examined as possible candidates for CO₂ storage. The Fox Hills contains relatively fresh waters (< 5,000 mg/L) across the entire formation, and wells in Montana, Wyoming and North Dakota produce fresh water from the Madison. However, population growth is expected to be moderate and there is likely to be little future demand for Madison waters exceeding the 10,000 mg/L USDW threshold. In areas where the Madison and Fox Hills are fresher than 10,000 mg/L, current and projected future water demand may be low enough to support CO₂ storage in parts of these formations that do not serve drinking and irrigation water wells.

Figure 4. Principal aquifers in the U.S., with key groundwater use areas discussed in this paper identified by color.

3.3. Floridian Aquifers

In terms of both public supply and total water use, Florida is a large user of groundwater. Rising demand tied to a growing population has encouraged desalination technology deployment in Florida, and in early 2008 the nation’s largest desalination plant commenced full-scale operations in Tampa [16]. Desalination plants in Florida like the Tampa facility produce freshwater from seawater piped in from offshore. In comparison, potential CCS storage formations in this region appear to have total dissolved solids in excess of the 35,000 mg/L that is typical for seawater, indicating a low likelihood of demand for the saline waters inhabiting the storage formations.
3.4. Mississippi River Valley Aquifers

These aquifers provide an important source of irrigation water for the region. However, fast recharge rates help to keep the system in balance and it is unlikely that underlying, higher-salinity waters (including those of interest for CO₂ storage) will be targeted for desalination anytime in the near- to mid-term, particularly with the abundance of surface waters.

3.5. Ohio River Valley Aquifers

Because the most promising CO₂ storage resource in the Ohio River Valley does not underlie a major drinking water aquifer system in many areas of interest for CO₂ storage, there are unlikely to be significant conflicts regarding saline water use for CCS. However, the Mt. Simon Formation, one of the key CO₂ storage targets in this region, shallows to the northwest, in northern Illinois, where formation waters are fresh and the aquifer is an important groundwater source.

3.6. Basin & Range

The basin-fill aquifers of Nevada, and portions of Utah, Arizona, and southeastern California have been considered collectively as a potential CO₂ storage resource. However, portions of these aquifers supply fresh water in each of these states, many areas of which are very dry and experiencing significant population growth. These withdrawals are resulting in declining water levels in a number of important areas. Moreover, large swaths of this region receive very little precipitation to recharge surface or subsurface reservoirs, and are potentially too far from the ocean for seawater desalination to be a strong candidate for meeting future demand in the presence of declining groundwater availability. The deployment of CCS could be impacted in this region due to these water resource issues as well as other potential region-specific considerations.

3.7. Gulf Coast

This region possesses an enormous quantity of potential deep geologic CO₂ storage capacity in the Frio and Jasper DSFs, and is also moderately to heavily dependent upon groundwater in some counties. However, because of its proximity to the ocean, the economics would likely swing toward desalination of seawater rather than drilling wells to access the water in the Frio and Jasper, most of which have salinities equal to or greater than that of seawater in the areas considered suitable for CO₂ storage.

4. Discussion

Adapting to growing populations, declining water levels within key aquifers, and changing precipitation patterns may further strain heavily used groundwater resources in areas already impacted by water supply issues. Within certain regions of the nation, water scarcity concerns may prompt further consideration for targeting nearby high salinity or brackish water in deep aquifers for treatment by desalination technologies to augment more conventional supplies. Deep geologic formations that could be used as a permanent repository for anthropogenic CO₂ in climate change mitigation efforts via CCS contain highly brackish waters that in select regions might represent potential targets for future waters supplies (particularly if they are below the salinity of seawater, approximately 35,000 mg/L TDS). This possibility might present a competing use for these deep geologic formations, and should be examined to estimate the potential probability, location, and magnitude, of such impacts.

The likelihood that deep, saline groundwaters exceeding the USDW salinity threshold may be demanded as future sources of drinking or irrigation water increases in areas where groundwater currently supplies a significant portion of the region’s water supply; in areas with already constrained water supplies, such as the High Plains / Ogallala region; in areas where significant population growth is expected to overburden current surface and groundwater resources within the near- to mid-term, such as in parts of the Southwestern U.S. and areas of Texas; and in areas where there are limited other sources of saline waters (i.e., seawater) nearby. In areas that meet one or
more of these criteria and also have a significant potential demand for deep geologic CO₂ storage, there exists the possibility for differences of opinion regarding the best use of the saline groundwater underlying these regions. In such cases, permitting or garnering public acceptance for proposed CCS projects will require regulators and potential CCS operators to strike a balance between the future needs for high quality drinking and agricultural water, and the use of CCS in a given area as a climate change mitigation strategy. The insights and examples presented in this paper are intended only as a preliminary evaluation of this issue. While more detailed and site specific evaluation will be needed, this analysis suggests that such concerns are likely to be warranted in limited select regions across the U.S., particularly in areas that are already facing water scarcity.

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