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Minimizing exposure to legacy wells and avoiding conflict between storage projects: Exploring area of review as a screening tool

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Abstract

Elevated pressure from large-volume injection is a key driver of risk and project cost. If transmissive features (e.g., non-isolating wells or fracture systems) are present, increased injection-zone pressure can drive fluids from depth toward protected freshwater resources. In US Carbon Capture and Storage (CCS) law, the area at risk is known as the Area of Review (AoR). The size and number of potentially transmissive features to be evaluated and possibly remediated or managed is a function of the size and location of the AoR. The size of the AoR depends on several variables, including properties of the injection zone, properties of protected resources, and injection rate and duration. Evaluation of the intersection of these variables across a portfolio of sites highlights the injection zone depth and boundary conditions as top-level controls. Deep injection, use of multiple stacked injection zones, reduced injection rate and choice of injection well location can all be used to minimize AoR and the number of potentially transmissive features within it. We introduce the concept of pressure space (defined as connected pore volume times pressure) as the key subsurface commodity for CO_2 storage and we suggest that it forms a more robust basis for leasing and regulation than pore space alone.

Introduction

Among regulators, operators and even the general public, considerable attention is focused on the spread of injected CO_2 in the subsurface. To some degree, this concern is understandable. CO_2 is, after all, an introduced substance and the success of geologic carbon sequestration rests on the assurance of permanent sequestration. Indeed, monitoring of the injected plume is a common regulatory requirement (Directive 2009/31/EC, 2009; UIC Class VI, 2010; ISO/TC265, 2017). However, CO_2 injection also elevates pressure, which often spreads much farther than the CO_2 itself and may be far more consequential. Elevated pressure can drive displacement of existing formation brines which may be much more hazardous than the CO_2 itself if released to the environment (Kreitler and Richter, 1986; Jiang et al., 2022). At a minimum, these brines are highly saline and they may also contain trace heavy metals, naturally-occurring radioactivity, and/or hydrocarbons, any of which could be damaging to fresh-water resources. In the presence of critically-stressed fractures, pressure build-up may also trigger induced seismicity (e.g., Weingarten et al., 2015; Hennings et al., 2019). Last, pressure build-up may cause loss of injectivity, possibly impacting neighboring storage projects as well (e.g., Frei-Pearson and Bryant, 2014; Grude et al., 2014).

At least in part because of its roots in the Safe Drinking Water Act (Safe Drinking Water Act, 1974), the US Underground Injection Control (UIC) program places strong emphasis on pressure elevation and the associated risks to fresh water aquifers,[1] within an Area of Review (AoR; UIC Class VI, 2010; USEPA, 2013). For CO_2 injection wells (UIC Class VI) this AoR is defined as the map-view extent of pressure elevation sufficient to lift injection zone brines to the lowest freshwater aquifer through a (hypothetical) open wellbore (Fig. 1). Put another way, the AoR "is the area around an injection well where, during injection, the [hydraulic] head of the formation fluid in the injection zone is equal to or greater than the [hydraulic] head of USDWs" (Thornhill et al., 1982 as quoted by USEPA, 2013). Prior to receiving an injection permit, a project developer must define the AoR with computational modeling, review all legacy penetrations and perform any corrective action needed to ensure their integrity under elevated pressure. During injection operations, the AoR delineation must be periodically reviewed and updated, with remediation of additional legacy penetrations as needed (USEPA, 2013). Indirectly, AoR is a primary control on project cost, as it will determine the number of legacy wells needing review and possible remediation, the monitoring footprint of the project and possibly the acreage required, depending on the applicability of the rule of capture with regard to pressure space (e.g., Kramer and Anderson, 2005; Gibbons and Wilson, 2007). For all of these reasons, the size of the AoR and its geographic location may be significant factors in project success.

Although not defined as such, AoR also offers a pragmatic definition of a project's extent. CCS projects to date have been mainly pilots, demonstration projects and first-movers, sited far from competing uses and dense clusters of legacy wells. Even those projects sited in depleted fields have generally chosen fields with few wells and clear geologic boundaries that limit pressure propagation. However, as CCS transitions from limited, government-supported pilot projects to large-scale commercial enterprises, dealing with competing subsurface uses will likely become ever more important. These might include legacy well clusters, active hydrocarbon production, other storage projects, hazardous waste disposal and geothermal projects. Figuring out how to site storage projects to meet their goals and minimize conflicts will impact project risk, economics and potentially leasing requirements and liabilities.

The Gulf of Mexico (GoM) offers a prime example of the need to reconcile storage projects with competing subsurface uses. The states of Texas and Louisiana lead the nation in point-source CO_2 emissions, many of which are concentrated along the coast from Corpus Christi to New Orleans (Fig. 2; USEPA, 2020). These emissions are in part a reflection of the underlying resources—the GoM is one of the most prolific petroleum basins in the world, with production at every level from the Jurassic to the Pleistocene and ~1.1 million wells, including hydrocarbon production, gas storage and waste disposal wells (IHSMarkit Inc., 2020; USEPA,2020; Fryklundand Stark,2020). Recent enhancements to the 45Q tax credit have spurred interest in CO_2 storage development from a wide variety of operators, and simple economics precludes long-distance transport (GCCSI,2022; CleanAir Task Force,2023). Figuring out how to create successful storage projects in this environment is a timely problem with potential future application to other industrialized petroleum basins, such as the Los Angeles, Denver, Appalachian foreland, Aquitane, Panonian, Volga-Ural, Timan-Pechora, Caspian and Bohai Bay Basins. The purpose of this paper is to explore the calculation of AoR, its use as a screening tool and the strategies to minimize it. We address the problem in two steps, using the GoM basin as an example. First, we look calculation of the critical pressure elevation and how it varies with choice of geography and injection zone. Second, we apply the resulting values to determination of AoR and the challenge of minimizing exposure to legacy wells and competing uses.

Section snippets

The Gulf of Mexico

Geologically, the GoM is a prograding passive margin (Fig.3). The basin opened in the Triassic and has since served as the primary sediment sink for river systems draining interior North America (Galloway,2008). With the notable exceptions of Jurassic evaporites and thick Cretaceous carbonate deposits, the fill is dominantly clastic. Over time, fluvial-deltaic and shore zone systems have built out over older slope and deep-water deposits. The presence of mobile salt has created a constantly…

Critical pressure

As a necessary first step toward estimating the AoR, we focus first on calculation of ΔP_{crit}, the critical pressure elevation that determines the limits of the AoR. In principle, ΔP_{crit} depends on the differences in depth and fluid density between injection zone and the lowest USDW. Depth is straightforward; brine density is less so. The latter is directly proportional to salinity and pressure and inversely proportional to temperature (Rogersand Pitzer,1982). For a given salinity, brine…

Critical pressure

As a first pass, we looked at injection at 2500m depth in six sites, based on the GoM geology shown in Fig.3 and chosen to represent a range of storage possibilities:

A Onshore with deep USDW (2000m at base)…

B Onshore with typical USDW (700m at base)…

C Onshore with shallow USDW (100m at base)…

D Offshore, shallow water (10m depth), no USDW…

E Offshore, shelf edge (100m water depth)…

F Offshore, deep water (1000m water depth)…

For the offshore scenarios, we considered the seawater column to be a protected…

Discussion

We began this work with the goal of exploring the calculation of AoR, its potential use as a screening criterion and ultimately, its application to minimizing conflict between storage projects and other subsurface uses, including legacy wells. Clearly the critical pressure varies between locations but the differences between locations are generally minor compared with the differences between injection depths. Our work may exaggerate that conclusion as we have imposed the same injection zone…

Conclusions

Increased injection zone pressure and AoR are critical parameters in site screening, both to avoiding interference between projects and to mitigating risk. Screening-level estimation of critical pressure and AoR is straightforward and provides important considerations for both site selection and injector design. While the economics of transport are likely to limit geographic flexibility, consideration of pressure and AoR might well rule out some areas (e.g., those with unpalatably high numbers…

CRediT authorship contribution statement

Alexander P. Bump: Conceptualization, Methodology, Formal analysis, Writing – review & editing. **Susan D. Hovorka:** Conceptualization, Funding acquisition, Writing – review & editing.…

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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