Introduction

Evaluating CO₂ storage capacity at the national scale requires the evaluation of large numbers of storage sites, so fast aquifer capacity estimation methodologies are needed. In recent years suitable methodologies have been developed that assess the efficiency with which the aquifer pore volume can be used to store CO₂, estimating the ‘effective’ storage capacity. The need for fast methodologies remains, however an increasing effort is being made in studies such as Gammer et al. (2011) to take account of reservoir or fluid properties that influence the flow dynamics in these estimates since the dynamics of storage can affect storage estimates by many multiples.

In this work we considered the effect of the top-surface structure and heterogeneity upon the dynamics of flow and subsequently the storage efficiency in open aquifers. In open aquifers the presence of large-scale structural closure can significantly increase storage efficiency and thus their capacity is often evaluated using distinct methodologies. However, at national-scale storage assessment, beyond these large and potentially well-known structures, it is difficult to account for the structural topography of very large potential storage units. Therefore in this work we consider what the effect of this potentially omitted top-surface structure is upon storage efficiency and the significance of its omission. In addition, we study the impact of reservoir heterogeneity.

Methodology

![Figure 1](image)

A 20 km x 40 km open aquifer section of the North Sea Forties sandstone member was identified as a base case and its geological model consisted of 450,000 cells so that it captured the channelised lithology and shale layers. To investigate the effect of top-surface structure and heterogeneity, storage capacities were estimated first for the complete geological model and then with the heterogeneity and top-surface structure sequentially removed as shown in Figure 1. This study was repeated for a variety of average reservoir dip and permeability combinations, to evaluate the effect on the different storage regimes as described in Gammer et al. (2011) and Table 1.

| Storage Regime 1 | Characterised by poor well injectivity due to a low permeability. Regime 1 and 2 are distinguished by a minimum permeability. |
| Storage Regime 2 | Characterised by both good CO₂ injectivity and combinations of average dip and permeability that lead to migration velocities of mobile CO₂ up-dip due to buoyancy of less than 10m/year after 1000 years. |
| Storage Regime 3 | Characterised by good CO₂ injectivity but combinations of average dip and permeability that lead to migration velocities of mobile CO₂ up-dip of more than 10m/year after 1000 years. The boundary between regimes 2 and 3 is set using an analytic estimate of the up-dip mobile CO₂ migration velocity. |

Table 1 Open aquifer storage regimes
To estimate the capacity in each case a dynamic model was constructed in ECLIPSE 100™. Injection was then modestly optimised into each model to satisfy the criteria set out in Gammer et al. (2011):

- 99% of injected CO₂ must remain within the storage site boundary after 1000 years;
- CO₂ migration velocities at 1000 years must be less than 10m/year and declining;
- Pressures must remain less than 90% of the estimated fracture pressure limit.

Each model simulated multi-well injection for 50 years and the post injection period up to 1000 years.

**Results**

The simulation models accounts for residual, dissolution and structural trapping. Any remaining CO₂ not captured by these mechanisms but still satisfying the open aquifer storage criteria was classified as ‘low migration velocity stored’. The effect of structure and heterogeneity on aquifers with average dip and average permeability characteristics typical of storage regime 2 and storage regime 3 are shown in Figure 2. The three bars in each graph correspond to the models a, b, and c from Figure 1.

**Figure 2** Effect of structure and heterogeneity upon storage capacity under storage regime 2 and 3

**Conclusions**

- Top-surface structure introduces both structural closures and regions of high dip. The effects of these regions compete to either increase or decrease storage efficiency respectively.
- In storage regime 2 low migration velocity stored CO₂ allows for higher storage. When top-surface structure was introduced the dominant influence came from the effect of new high dip regions reducing low migration velocity storage and therefore storage efficiency.
- In storage regime 3 there is little low migration velocity storage. When top-surface structure was introduced the dominant influence came from structural closures increasing capacity.
- Heterogeneity such as shale layers within the model were seen to increase lateral migration of the CO₂ plume, reservoir contact and therefore residual trapping and storage.
- In cases where storage was limited by injectivity, heterogeneity, and in particular the impermeable shales were seen to increase local pressure build up and decrease storage.

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**References**