THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
CREATE CHANGE

The University of Queensland Surat Deep Aquifer Appraisal Project (UQ-SDAAP)

Scoping study for material carbon abatement via carbon capture and storage

Supplementary Detailed Report

Transition Zone behaviour test models

30 April 2019

Authors

Mr Iain Rodger, The University of Queensland
Dr Andrew La Croix, The University of Queensland
Prof Jim Underschultz, The University of Queensland
Prof Andrew Garnett, The University of Queensland

Acknowledgements

This working document was prepared for The University of Queensland Surat Deep Aquifer Appraisal Project (UQ-SDAAP), a 3-year, $5.5 million project funded by the Australian Government through the Carbon Capture and Storage Research Development and Demonstration (CCS RD&D) programme, by Coal 21, and The University of Queensland. UQ-SDAAP would like to acknowledge Schlumberger for providing its PIPESIM Steady-State Multiphase Flow Simulator for use by the project and Computer Modelling Group (GMG) for use of its GEM compositional and unconventional simulator.

Citation

Rodger I, La Croix A, Underschultz J & Garnett A (2019*), Transition Zone behaviour test models*, The University of Queensland Surat Deep Aquifer Appraisal Project – Supplementary Detailed Report, The University of Queensland.

Referenced throughout the UQ-SDAAP reports as **Rodger et al. 2019c.**

Publication details

ISBN: 978-1-74272-263-4

Disclaimer

Contents

Figures

1. Executive summary

Dynamic simulations of Carbon dioxide (CO_2) injection were run using models parameterised to represent three different conceptualisations of the Transition Zone stratigraphy based on: Moonie (most sandy and permeable); Meandarra (reference or base case); and Woleebee Creek (least sandy and permeable).

Two additional cases used the most permeable Transition Zone type model (Moonie) with zero capillary pressure (i.e. assuming that the Transition Zone is CO_2 wetting). In one of these cases, the injection well was controlled by wellhead pressure to represent a worst-case scenario (where the pressure in the Blocky Sandstone Reservoir is highest and no capillary effects limit CO_2 vertical migration).

For the models that included capillary pressures, less than 0.45% of the injected CO_2 migrated into the Transition Zone during injection. Post injection, the net flow of CO_2 was initially from the Transition Zone back into the Blocky Sandstone Reservoir, driven by relaxing pressure gradients. Later, upwards CO_2 migration re-occurred in the most permeable model, but at very low rates (ca. 0.5 tonnes/day).

The cases with zero capillary pressure showed more CO_2 was able to enter the Transition Zone. Up to 3.6% of the total CO_2 volume injected had entered the Transition Zone at the end of the 60 year simulation (30 years' injection + 30 years' post-injection). In both these cases, CO_2 was still migrating upwards at the end of the simulation, with a total of 50 tonnes/day entering the Transition Zone by the end of the 60 year simulation period in the high rate case.

Importantly, CO_2 did not migrate beyond the basal 10 m of the Transition Zone in any of the simulations, including those with zero capillary pressure.

These simulations suggest that the Transition Zone acts as an effective vertical barrier, significantly limiting the flow of CO_2 and water. It is therefore unlikely that CO_2 will reach the Ultimate Seal unless an unforeseen high permeability leakage pathway (e.g. a fault or legacy bore) exists in the injection area.

Simulations indicate that the Transition Zone immediately around the injection well could be cooled by up to 15°C in the lowest parts, which may reduce the fracture pressure.

While these models indicate that the Transition Zone is an effective vertical barrier to CO_2 migration, they carry a degree of uncertainty due to being concept driven, with a lack of data at the basin-centre. Uncertainty would be reduced by an appraisal plan that provides additional information on the depositional setting and petrophysical properties (including wettability and capillary pressure) of the Transition Zone.

2. Introduction

The Transition Zone is the lithologically heterogeneous interval between the top of the Blocky Sandstone Reservoir and bottom of the Ultimate Seal. In general, the majority of the Transition Zone appears to be low permeability (<1mD). Some extremely low permeability (or tight) parts of the Transition Zone could act as localised seals, but these are not believed to be thick or laterally continuous enough to be considered as the true seals for commercial-scale CO_2 containment. Other sandier parts have sufficient porosity and permeability to be considered reservoirs, such as the “56 sands” in the Moonie Oil Field or the Lower Evergreen Formation Sandstone intervals on the Roma Shelf (e.g. Borah Creek, Colgoon, Digeridoo, Digger, Kincora, Sandy Creek, Carbean, Newstead, Yarrabend and Yellowbank fields). The overall flow behaviour of the Transition Zone, in any area, is largely dependent on the presence and connectedness of high permeability sandy streaks.

Sector scale static models of three various possible Transition Zone stratigraphic conceptualisations were constructed to capture the range of uncertainty in Transition Zone flow characteristics (see Sector Static Model Report (La Croix et al. 2019e). This document describes how numerical simulations were used to ‘test’ these different Transition Zone conceptualisations in order to assess how much water and CO_2 are likely to flow into (or through) the Transition Zone in each case. These models also make an assessment of the likely temperature reduction in the Transition Zone caused by CO_2 injection (important due to the thermal effects on fracture pressures (see Rodger et al. 2019).

3. Dynamic model set up

Static models of the three Transition Zone conceptualisations were named after wells which were considered to best represent each: Moonie (most sandy and permeable), Meandarra (base case), and Woleebee Creek (least sandy and permeable). These models covered a 10km x 10km area, extending from the top of the Ultimate Seal to the base-Surat Unconformity at the base of the Blocky Sandstone Reservoir (approximately190 m total thickness). They were created on structurally identical 100 x 100 x 55 cell grids, but with properties constrained by the different facies for each conceptualisation (La Croix et al. 2019e)

The Transition Zone consists of three stratigraphic intervals as defined by the sequence stratigraphic framework (La Croix et al. 2019b): an upper, mid, and lower portion (La Croix et al. 2019e). In general, the base of the upper Transition Zone in these models is a 60-80m thick interval approximately 60m above the top of the Blocky Sandstone Reservoir, and directly below the Ultimate Seal.

As the aim of these simulations was to test the Transition Zone only The Blocky Sandstone Reservoir was repopulated as a homogenous volume with an effective porosity of 12.8%, a horizontal permeability (k_h) of 43mD and a vertical permeability (k_v) of 6.5mD (i.e. k_v / k_h is 0.15). This was intended to approximately represent a ‘mid-case’ Blocky Sandstone Reservoir to allow direct comparison of the different Transition Zone types without variations in the Blocky Sandstone Reservoir affecting the results.

Apart from this, the models were set up almost identically to the larger scale sector model used for CO_2 injection modelling at the field-scale. The same fluid model, rock properties (including thermal properties), relative permeability curves and capillary pressure J-functions were used (see Rodger et al. 2019b and Ribeiro et al. 2019a) for details. A large analytic (Carter-Tracy) aquifer was defined as a boundary condition connected to all sides of the Blocky Sandstone Reservoir. Another analytic aquifer was defined on the top of the model to represent a ‘Hutton-like’ formation overlying the seal.

A single 1 km long horizontal well was defined 10 m above the base of the Blocky Sandstone Reservoir, and set up to inject CO_2 at a rate of 0.75 Mtpa for 30 years, then shut in. In theory, the well was also limited by a wellhead pressure of 15 MPa (150 barsa) and a bottomhole pressure limit of 40.5 Mpa (405 barsa), although these pressure were not reached during the simulation, and the well injected at the predefined rate throughout. An alternate case (described below) was run with the well limited by these pressure constraints only.

After testing the effect of the differing Transition Zone types on fluid movement, two additional cases were run using the Moonie-type static model (the model that resulted in the most flow into the Transition Zone). Both had zero capillary pressure throughout, representing CO_2 wet relative permeability cases and thus no membrane seal effects. In these cases, the flow rate of CO_2 through the Transition Zone is limited only by permeability, not by capillary effects.

In the second of these cases, the well was controlled to inject while limited by well-head pressure at 15 MPa. A bottomhole pressure limit at 40.5 Mpa (405 barsa) was also defined, but this limit was not reached. This final case represented a worst case scenario for vertical CO_2 migration, where the pressure around the well would be high during injection (and thus increase viscous flow), but capillary effects would not limit the vertical migration of CO_2.

In all cases, simulations included 30 years of injection and continued for 30 years post-injection.

4. Results

4.1 Meandarra model

Before comparing the results of the five cases, the results from the 'Meandarra' model will be discussed in detail, to highlight and explain some observed behaviour. The Meandarra model represents the mid-case for sandiness in the Transition Zone This is the case considered most likely to occur at the notional injection sites.

4.1.1 Vertical flow of supercritical CO_2

Figure 1 shows the mass flow of supercritical CO_2 from the Blocky Sandstone Reservoir into the lower part of the Transition Zone, and from the mid Transition Zone into the upper Transition Zone for the Meandarra model. CO_2 flow rates into the Transition Zone during injection were relatively steady, at around 10.5 tonnes/day (12 m^3/day at reservoir conditions). For comparison, the CO_2 injection rate was over 2,000 tonnes/day; almost 200 times the flow rate into the Transition Zone. The ratio of the cumulative flow from the Blocky Sandstone Reservoir into the Transition Zone to the cumulative injected CO_2 is shown in Figure 2. Throughout the injection period, only 0.45% of the total injected CO_2 flowed into the Transition Zone, with some flowing back into the reservoir post-injection.

The CO_2 did not enter the Transition Zone uniformly. It instead migrated into parts that have lower capillary pressures – likely also to be those with higher permeability. This uneven migration of CO_2 can be seen in the cross-section in Figure 3.

While some supercritical CO_2 did move into the Lower Transition Zone, it remained in the very bottom 8 m. The saturation of CO_2 in the column of cells where CO_2 migrated furthest through the Transition Zone is shown in Figure 4. No CO_2 flowed into the upper Transition Zone at any point in the Meandarra model (or, in fact, in any of the simulations).

Figure 1 *Mass flow rates of CO_2 from the Blocky Sandstone Reservoir into the Transition Zone. Positive values indicate upwards flow, negative values are downwards flow. For comparison, well injection rate was >2,000 tonnes/day. Coloured background indicates periods discussed in text.*

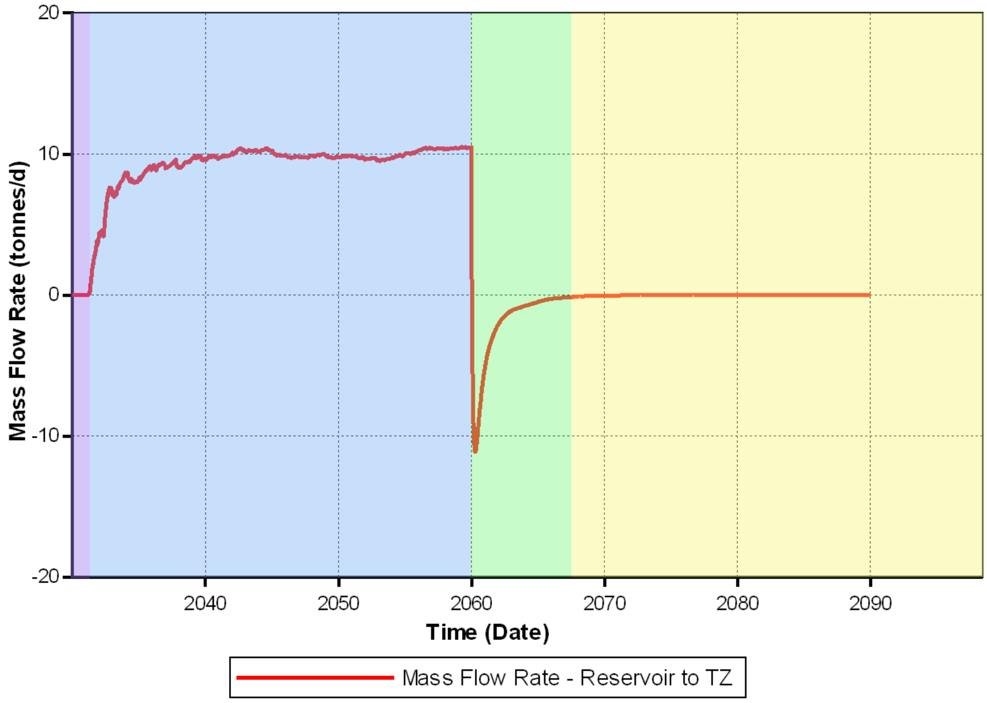


Figure 2 *Ratio of cumulative flow of CO_2 into Transition Zone to cumulative injected CO_2.*

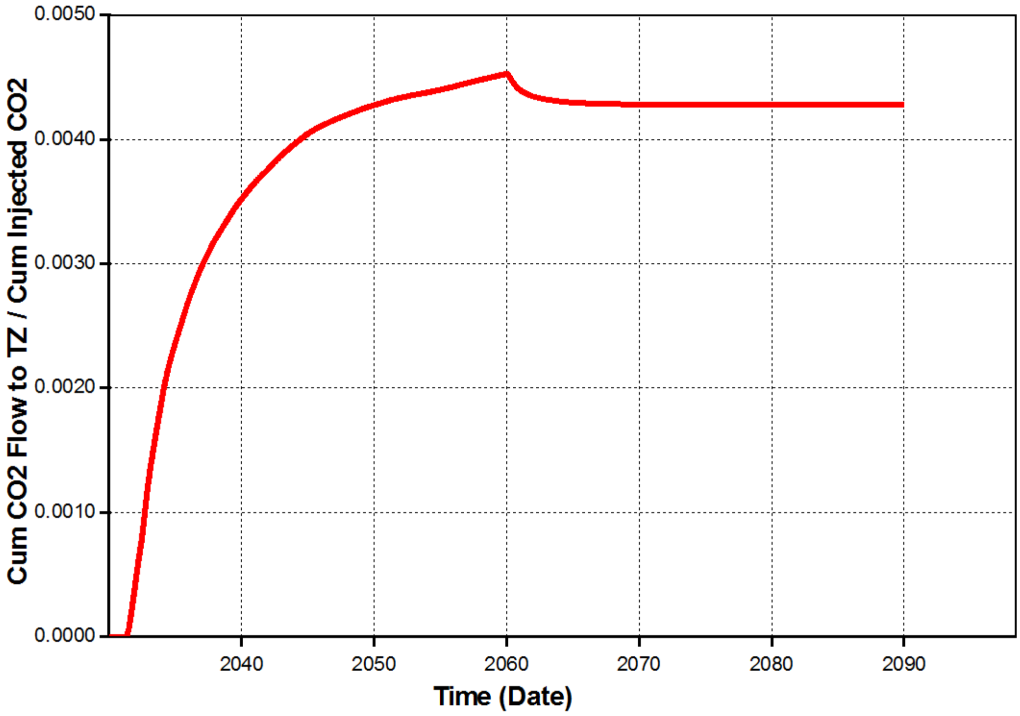


Figure 3 Saturation of supercritical CO_2 at the end of 30 years of injection for the Meandarra model. Horizontal well is in centre of model, running perpendicular to page. Red indicates higher CO_2 saturation. The boundary between the Transition Zone and Blocky Sandstone Reservoir is relatively clear across most of the model as the boundary between high CO_2 saturation below (orange) and low CO_2 saturation above (blue). In some more permeable areas near the centre of the model, capillary pressures are overcome and supercritical CO_2 is able to enter the Transition Zone (green patches higher in model).

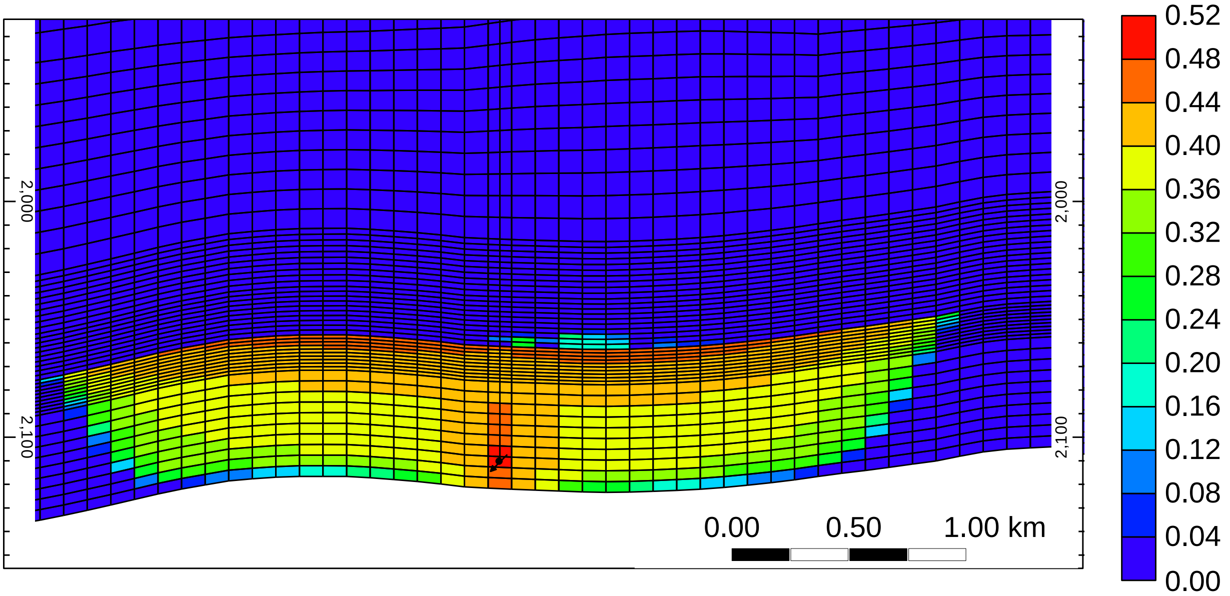


Figure 4 Vertical profiles of $scCO_2$ saturation in the column of cells where CO_2 migrated furthest vertically in the Meandarra model (approximately 300m from the well completion). Shown at end of 30 year injection period (red) and 30 years after injection stops (green). Note that CO_2 saturation actually decreases in the Transition Zone after injection stops.

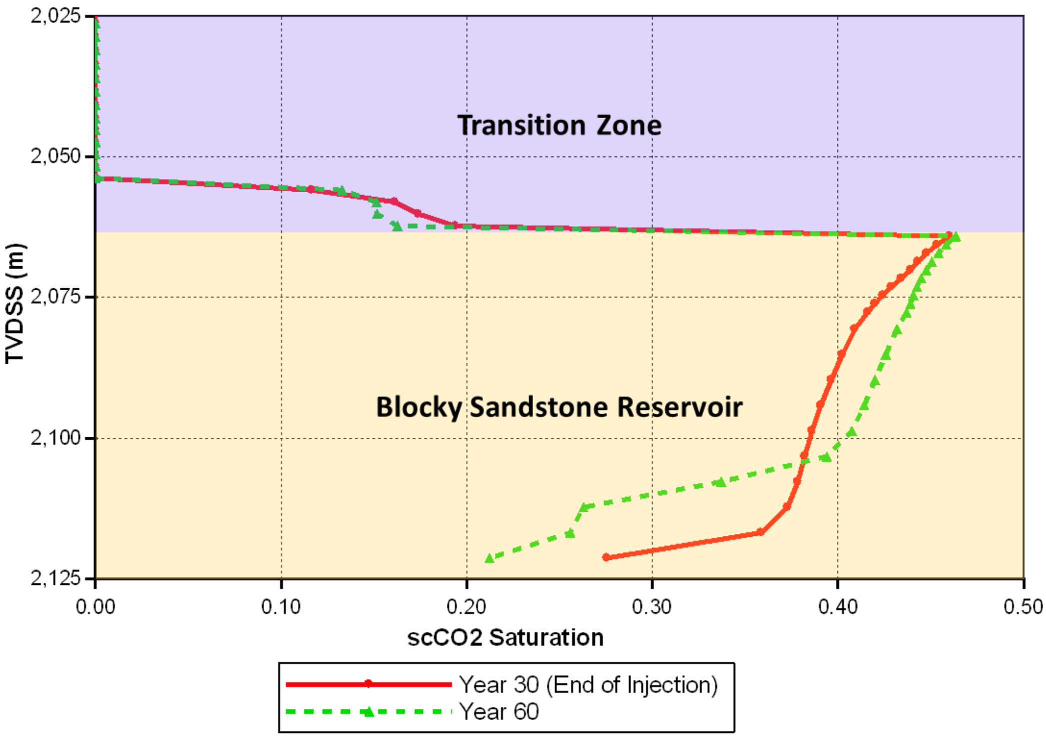


Figure 1 has been coloured to highlight four periods which occur during and after injection. The first period (purple in Figure 1) occurs after injection has started, but before CO_2 has migrated from the well completion to the boundary between the Blocky Sandstone Reservoir and Transition Zone. During this period, no CO_2 flows into the Transition Zone. Water does flow vertically due to the increased pressure in the Blocky Sandstone Reservoir (see Figure 4 and Section 4.1.2).

The second period (blue in Figure 1) starts when CO_2 reaches the Transition Zone, and continues until the well is shut in. Due to the high pressure in the area around the injecting well, it is likely that capillary threshold pressures will be overcome in areas near the well, and CO_2 will begin to move into, and through, the lower parts of the Transition Zone, albeit at low rates relative to the injection rate.

The third period (green in Figure 1) begins after 30 years, when the injection well is shut in. At this point, the pressure around the well drops as fluids (water and supercritical CO_2) move due to the pressure gradient around the well. As the horizontal permeability of the Blocky Sandstone Reservoir (43 mD) is much higher than the vertical permeability in the Transition Zone (typically <<0.1mD), the pressure in the Blocky Sandstone Reservoir quickly reduces due to horizontal flow, while parts of the Transition Zone remain over-pressured (see Figure 7). Buoyancy acts on the supercritical CO_2 during this period, but the overall flow in the Meandarra model is dominated by the pressure gradient, which causes downwards flow of both water and CO_2 back into the Blocky Sandstone Reservoir. The CO_2 in the Blocky Sandstone Reservoir further from the well remains trapped in the Blocky Sandstone Reservoir by the Transition Zone, which is acting as a membrane seal. These effects will be discussed in more detail in relation to the results from the simulations for models with zero capillary pressure. The rate of downwards flow decreases as the Blocky Sandstone Reservoir and Transition Zone move closer to hydrostatic equilibrium.

The final period (yellow in Figure 1) is not as well defined as the previous three periods, but instead represents the period post-injection when the reservoir and Transition Zone have very nearly returned to hydrostatic equilibrium. During this period, depending on capillary pressures, CO_2 may be able to move upwards into the Transition Zone driven by buoyancy forces. In the Meandarra model, this effect was minimal with no net flow of CO_2 into the Transition Zone in the 30 years post-injection. However, other models did indicate net upwards flow of CO_2 when buoyancy forces become dominant in the longer term (see sections 4.2.1 and 4.2.2).

4.1.2 Vertical flow of water

Figure 5 shows the flow of water from the Blocky Sandstone Reservoir into the lower Transition Zone for the Meandarra model. Water began to move from the Blocky Sandstone Reservoir into the Transition Zone almost as soon as injection started. The rate declined gradually, before levelling out at approximately 120 m^3/day. When injection stopped, water began to flow back into the Blocky Sandstone Reservoir from the Transition Zone, although the change in the direction of net flow was not as abrupt as for supercritical CO_2. This is be because all of the CO_2 in the Transition Zone was in the area immediately around the well, and was therefore affected more quickly by the well being shut in. In areas further from the well, water could continue to flow from the Blocky Sandstone Reservoir into the Transition Zone for a period after injection stops. The net rate of water flow back into the Blocky Sandstone Reservoir peaked, then declined as the Blocky Sandstone Reservoir and Transition Zone moved towards hydrostatic equilibrium.

The flow rate of water from the lower Transition Zone into the upper Transition Zone was very low throughout the simulation, and is therefore shown on a separate plot in Figure 6.

Figure 5 Flow rates of water (volumetric, reservoir conditions) from the Blocky Sandstone Reservoir to the Transition Zone. Positive values indicate flow upwards, negative values are flow downwards.

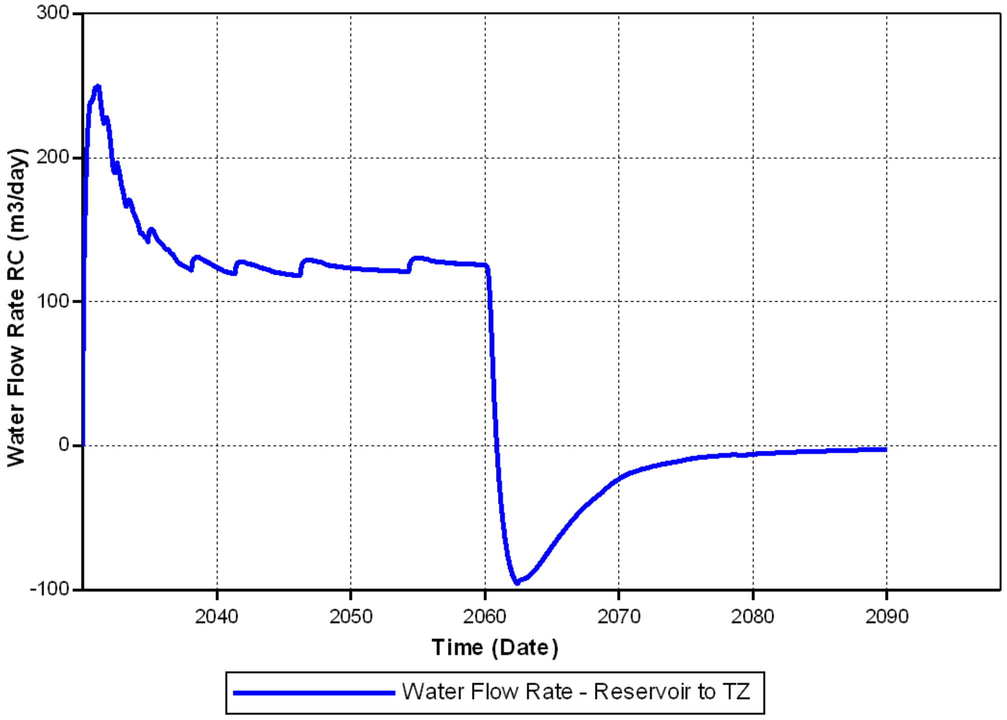
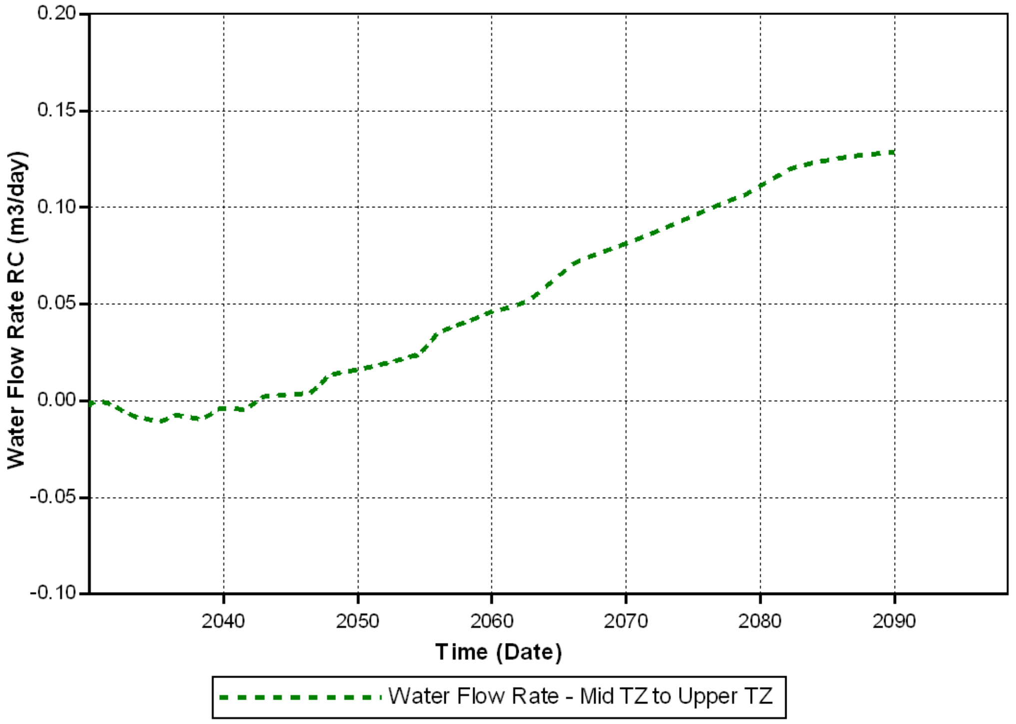


*Figure 6 Flow rate of water (volumetric, reservoir conditions) from the Mid Transition Zone to the Upper Transition Zone (approximately 60m below the Ultimate Seal). Positive values indicate flow upwards, negative values are flow downwards. Flow into the Upper Transition Zone is **very** low, but slowly increases throughout the simulation, to a maximum of 0.13 m^3/day.*



4.1.3 Pressure and temperature

Vertical pressure and temperature profiles for a column of cells in the centre of the model (for a column that includes the well completion) are shown in Figure 7 and Figure 8 respectively.

These profiles indicate that cooling extended much further through the Transition Zone (in this case) than any pressure response, but only in the area immediately around the injection well. In fact, the cooling of the Transition Zone led to an apparent pressure reduction approximately 30m above the top of the Blocky Sandstone Reservoir. This may seem counter-intuitive, but can be explained by considering the effect of a low permeability 'flow boundary'.

When fluids are pushed vertically through the Transition Zone during injection, the flow rate can be limited (and nearly stopped altogether) by the low vertical permeability parts of the zone. Temperature (heat) can still be transferred across such a low permeability barrier by conduction, even if no fluid is flowing. In the Meandarra model, low permeability cells in the Transition Zone limit the flow of fluids (and thus transmission of pressure), but the overlying cells are still cooled due to the low temperatures occurring around the well. As these cells are cooled, the pressure decreases due to thermal contraction of the fluids and rock matrix thus causing a pressure decline if permeability is sufficiently low to not allow ingress of fluid at the same rate as the cooling effect.

It is also important to note that the cooling of the Transition Zone around the well continued after injection stopped, and thus the effect is seen much higher in the Transition Zone than any pressure or CO_2 saturation changes.

Figure 7 Pressure profile for a column of cells in the centre of the Meandarra model at end of 30 years injection (red) and 30 years after injection stops (blue).Note that part of Transition Zone remains slightly over-pressured in year 60, while Blocky Sandstone Reservoir has returned to near hydrostatic pressure (black). The slight decrease in pressure between approximately 2000m and 2030m TVDSS appears to be due to reduced temperature and thermal contraction (see Figure 8).

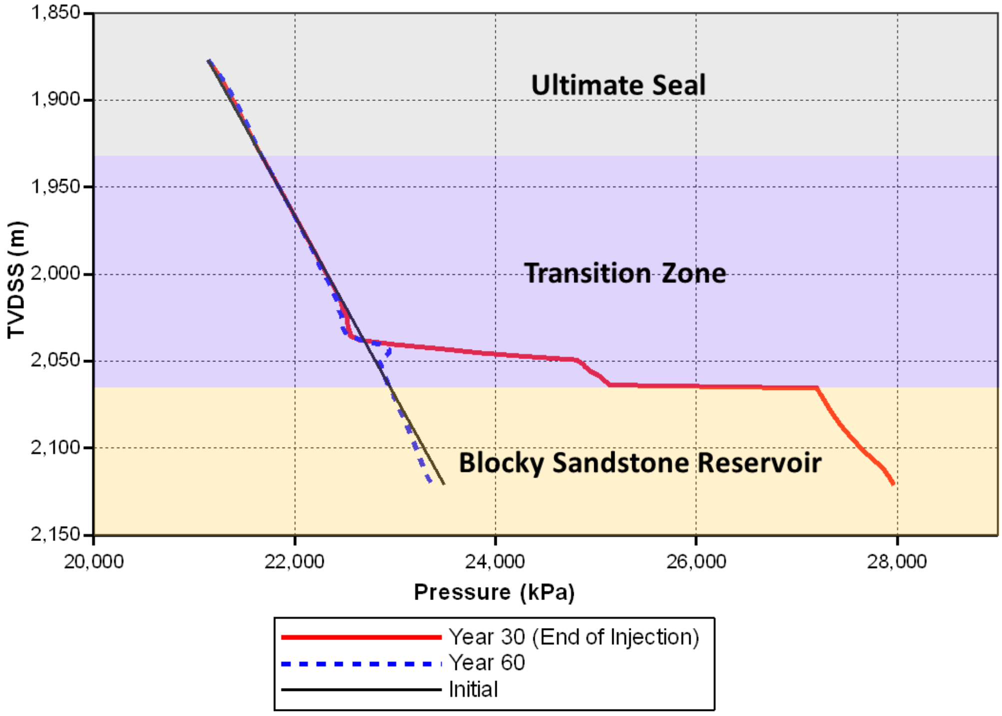
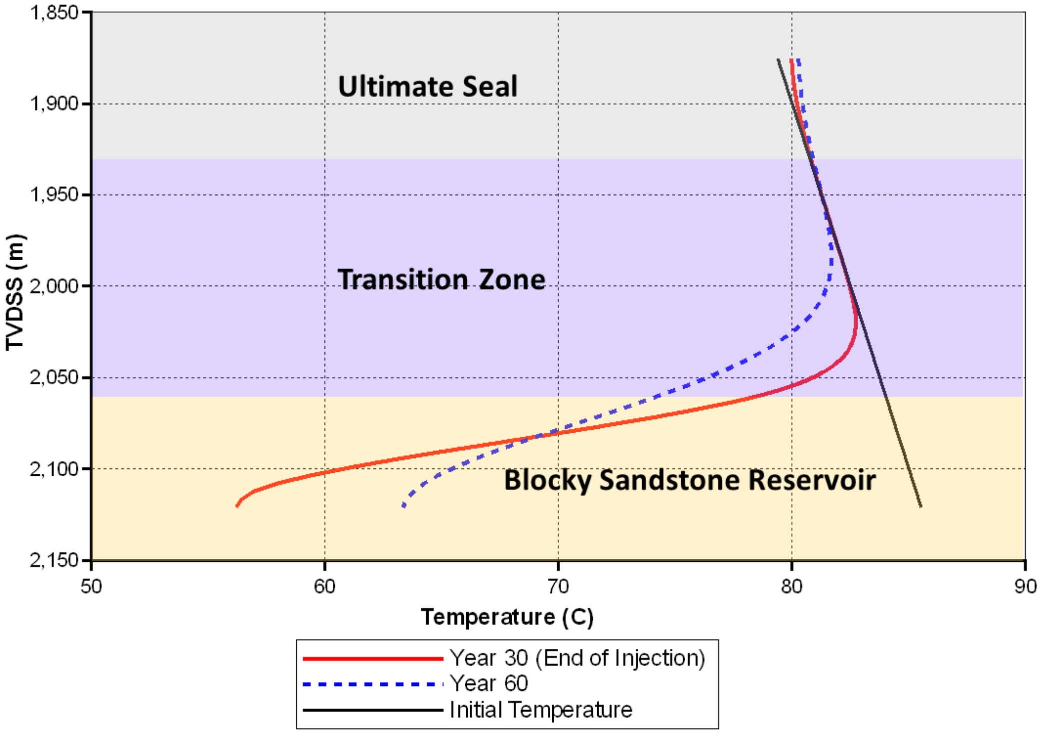


Figure 8 Temperature profile for a column of cells in the centre of the Meandarra model at end of 30 years injection (red) and 30 years after injection stops (blue). The apparent ~1°C increase in temperature at the top of the model is due to a minor issue with the thermal boundary condition used, but is considered unlikely to significantly impact the findings in these models.



4.1.4 Meandarra behaviour –summary

The Meandarra model represents the Transition Zone 'type' considered most likely to occur in the notional injection areas (see La Croix et al. 2019e). The results of the numerical simulations for this study indicate that in this case, vertical CO_2 migration is likely to be limited to the lowest 8 m of the Transition Zone, due to a combination of low permeability and high capillary pressures. While some slightly higher permeability parts of the Transition Zone did allow flow of CO_2, these parts are not well-connected throughout the Transition Zone. At the end of injection, less than 0.5% of the total injected CO_2 had migrated into the Transition Zone.

The generally low permeability in the Transition Zone, and the lack of connectivity between the higher permeability parts, also limited water flow, and very little pressure build up was seen anywhere above the lowest 30m of the Transition Zone.

Thermal effects occur further through the Transition Zone, with the region up to 75m above the top of the Blocky Sandstone Reservoir cooled by 1°C at the end of the simulations, but only in the immediate vicinity of the injection well.

4.2 Model comparisons

4.2.1 Transition zone types

The flow of supercritical CO_2 from the Blocky Sandstone Reservoir into the Transition Zone for three Transition Zone 'type' models are shown in Figure 9. The CO_2 saturation in the column of cells in each model where CO_2 had migrated furthest through the Transition Zone during injection are shown in Figure 10.

Figure 9 *Mass flow rates (tonnes/day) over time of CO_2 from the Blocky Sandstone Reservoir to the Transition Zone for the three Transition Zone models. No CO_2 flowed into the Upper Transition Zone at any point in any of these simulations. The Moonie (blue dashed) line is positive (at approximately 0.5 tonnes/day) after 2068.*

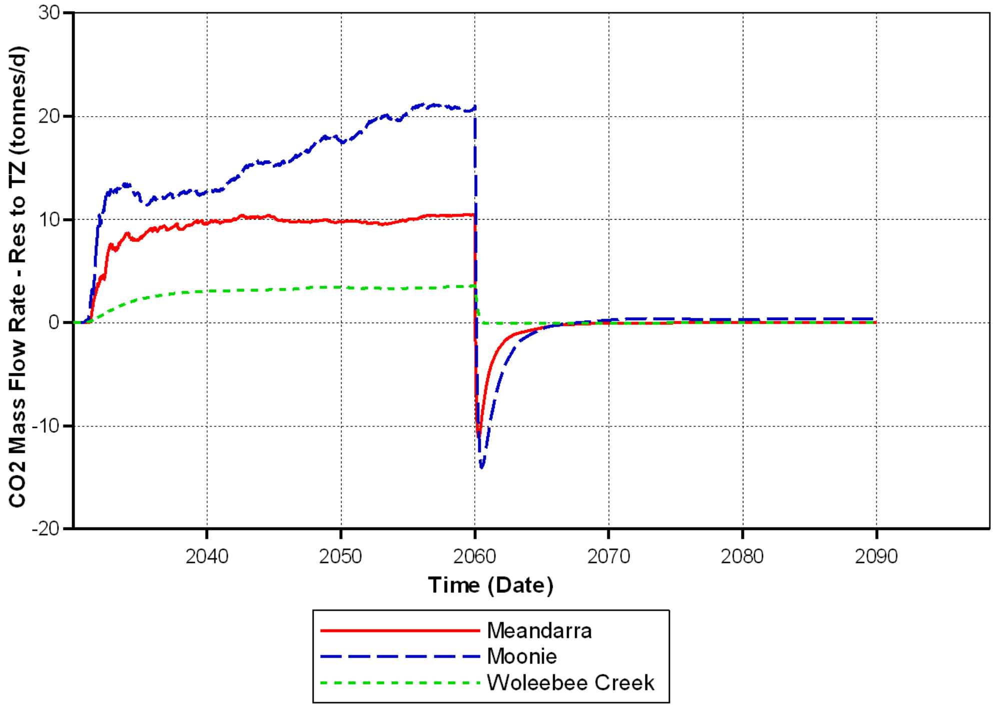
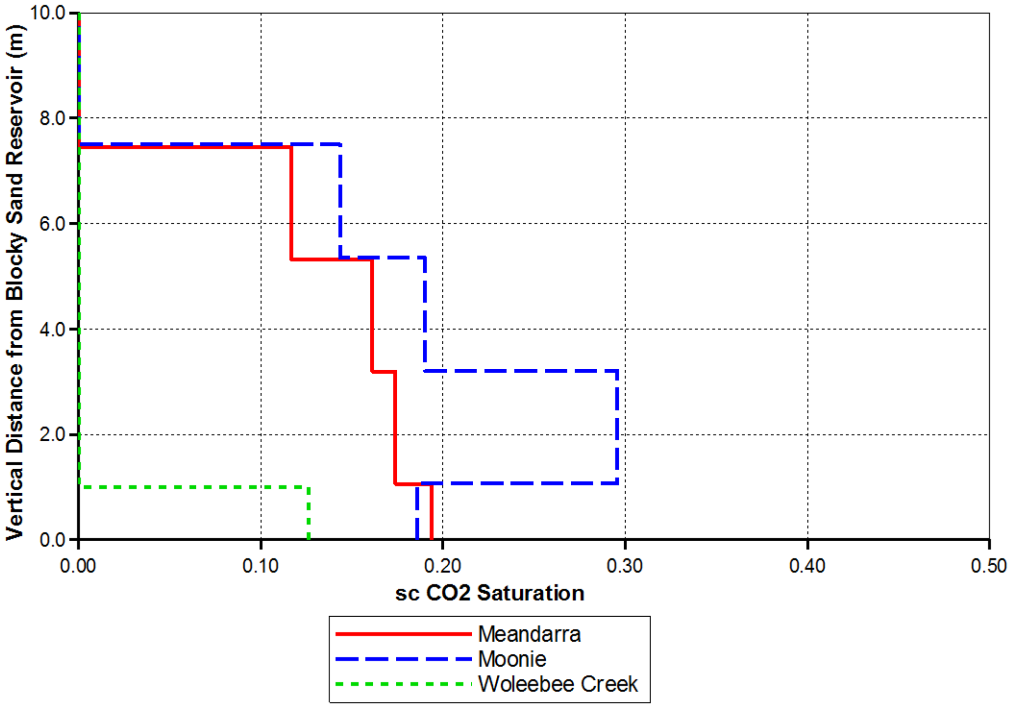


Figure 10 *Saturation of supercritical CO_2 in the lowest part of the Transition Zone after 30 years injection. The plot shows saturation for the column of cells where CO_2 was identified to have migrated furthest through the model in each case. These are shown relative to the distance to the top of the Blocky Sandstone Reservoir, rather than TVD (shown for Meandarra in Figure 4). For reference, the base of the Ultimate Seal is approximately 100 m above the top of this plot.*



While the rate of supercritical CO_2 flow into the Transition Zone in the more permeable (Moonie) model was almost twice that of the Meandarra model during injection, CO_2 did not migrate any further vertically through the model. The CO_2 that managed to enter the Transition Zone remained in the lowest 8 m, as it did in the Meandarra model. In the less permeable (Woleebee Creek) model, less CO_2 was able to enter the Transition Zone, and the CO_2 that did, remained in the lowest 1 m of the Transition Zone.

One important difference between these models is in the behaviour that occurs post-injection. For the Moonie model the net flow of CO_2 became upwards into the Transition Zone after 2068 (i.e. eight years after injection stopped), although the net rate was less than 0.5 tonnes/day. This effect is likely due to the higher permeability in the Transition Zone in this case, which allowed the pressure in the Transition Zone to move more quickly towards hydrostatic equilibrium (and thus more quickly reduced the force driving fluids back into the reservoir). This means buoyancy forces became dominant and CO_2 moved upwards. The rate of the vertical CO_2 flow would also be dependent on capillary effects, which will be discussed in more detail in 4.2.2.

The simulated water flow into the Transition Zone (Figure 11), and into the Upper Transition Zone (Figure 12) was also different for the different Transition Zone types.

Figure 11 Water flow rates over time (volumetric, reservoir conditions) from the Blocky Sandstone Reservoir to the Transition Zone for the three Transition Zone types.

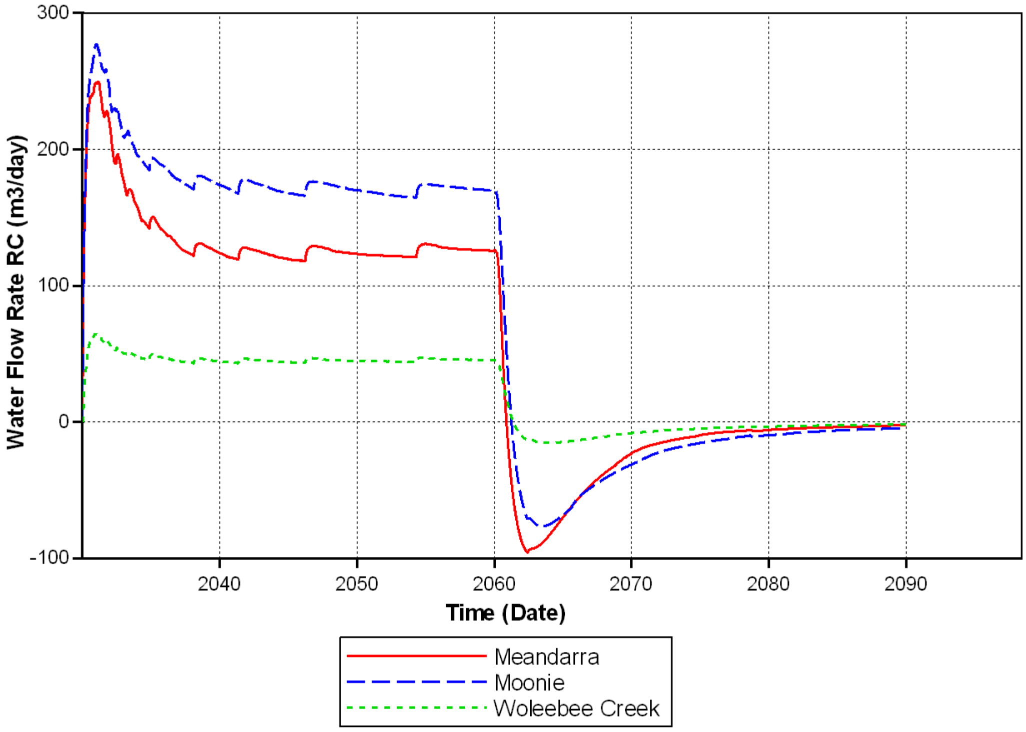


Figure 12 Water flow rates over time (volumetric, reservoir conditions) into the Upper Transition Zone (approximately 60m above the Blocky Sandstone Reservoir) for the three Transition Zone types. Note y axis scale is different from Figure 11 Water flow rates over time (volumetric, reservoir conditions) from the Blocky Sandstone Reservoir to the Transition Zone for the three Transition Zone types..

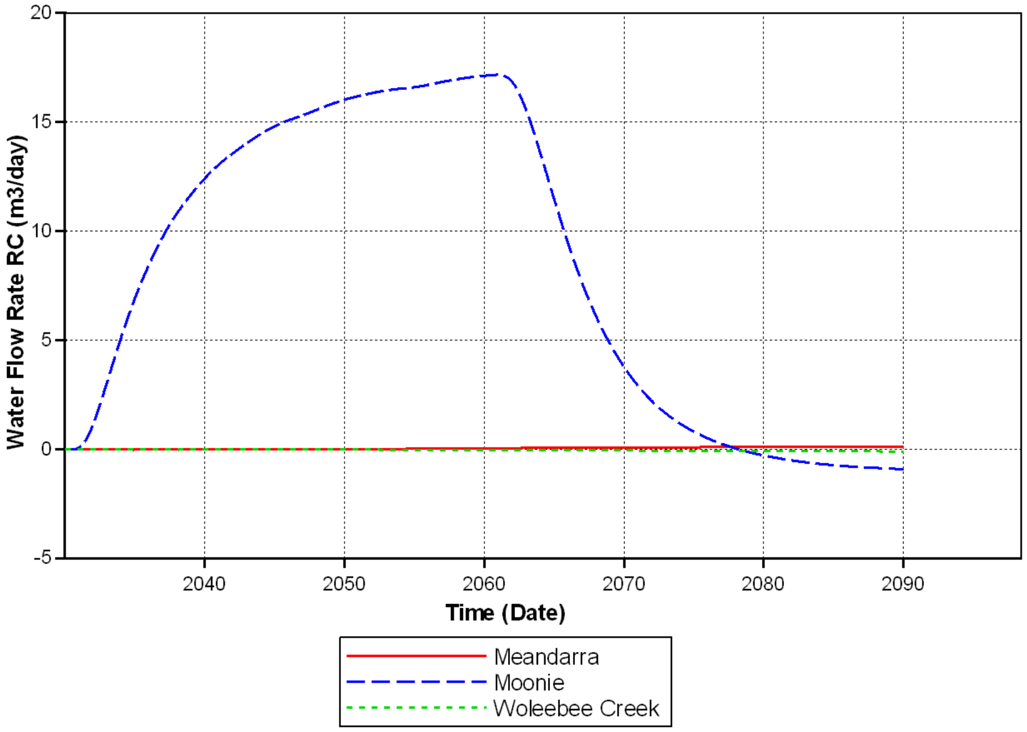
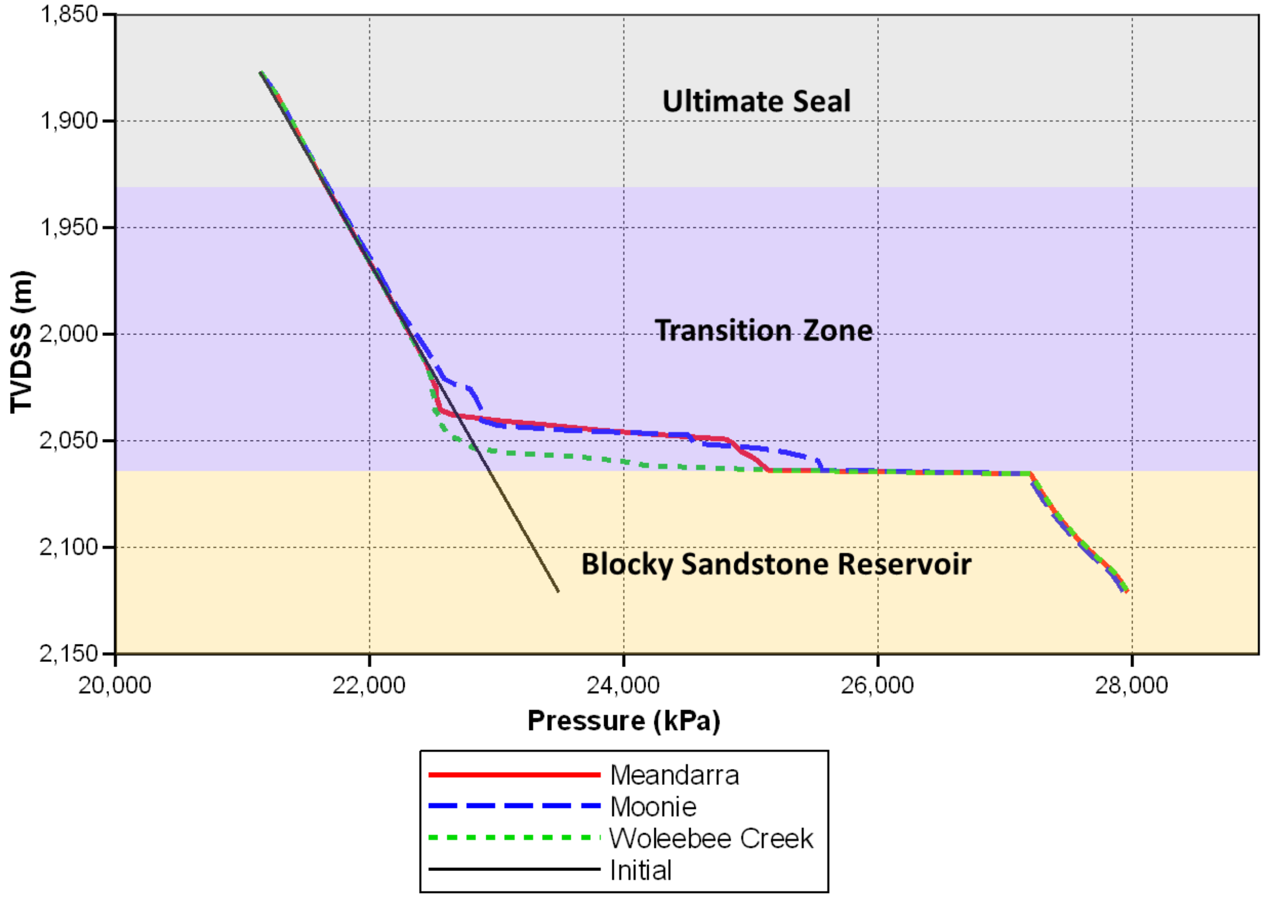


Figure 11 shows that, during injection, more water flowed into the Transition Zone from the Blocky Sandstone Reservoir in the Moonie model, with less flow in the Woleebee Creek model. This behaviour was expected due to the generally higher permeability in the Moonie type Transition Zone, and lower permeability in the Woleebee Creek type Transition Zone.

The flow of water post-injection is more interesting. All three Transition Zone types had water flow back into the Blocky Sandstone Reservoir from the Transition Zone when injection stopped (as discussed in Section 4.1.2), but the peak flow rate back into the Blocky Sandstone Reservoir was less for the Moonie model than for the Meandarra model, despite the higher permeability Transition Zone in the Moonie model. This result can be explained by considering the flow higher in the Transition Zone. Figure 12 shows that the flow of water into the Upper Transition Zone (approx. 60m above the Blocky Sandstone Reservoir) was almost zero for the Meandarra and Woleebee Creek models. This is due to layers of the model that have particularly low permeability, coinciding with the muddiest parts of the sequence (La Croix et al. 2019b). This lower permeability part of the Transition Zone significantly limited flow in these models, almost acting as a no-flow boundary. The Moonie model does have these lower permeability layers, but they have some slightly more permeable parts that allowed water to flow through at rates of up to 17.5 m^3/day, as seen in Figure 12. This flow of water upwards provided an alternate mechanism for pressure to be 'released' from the lower parts of the Transition Zone after injection in the Moonie model, and thus reduced the flow of water back into the Blocky Sandstone Reservoir. This effect was much less significant in the other two models.

The effect of the different Transition Zone types can also be seen in the vertical pressure profiles at the end of injection, as shown in Figure 13.

Figure 13 Pressure profile for a single column of cells in the centre of the models at end of 30 years injection. Note the higher pressures in the Moonie model at around 2025m TVDSS.



The profiles in Figure 13 show that the pressure increase in the Woleebee Creek model was limited to the lowest 10m of the Transition Zone, while pressure increases were seen almost all the way through the Moonie model. The temperature profiles at the end of injection were almost identical for all three models.

4.2.2 Zero capillary pressure and high injection rate cases

The Moonie model was modified to have zero capillary pressure (representing a scenario where CO_2 was the wetting phase), and then to have the injection well controlled by a maximum wellhead pressure (and thus injecting at higher rate/pressure). The Moonie model was chosen for these tests as the 'worst case' Transition Zone type for vertical CO_2 migration (Figure 9). In the other cases the Transition Zone appeared to be acting as a hydraulic barrier so would prevent CO_2 migration even if the capillary pressures were zero and the Transition Zone did not act as a membrane seal.

The mass flow rate of CO_2 into the Transition Zone for both zero-capillary pressure cases are shown in Figure 14 alongside the original Moonie model results (as previously shown in Figure 9). The ratio of the cumulative flow from the Blocky Sandstone Reservoir into the Transition Zone to the cumulative injected CO_2 is shown in Figure 15.

Figure 14 *Mass flow rates over time (tonnes/day) of CO_2 from the Blocky Sandstone Reservoir to the Transition Zone for the original Moonie Transition Zone model, for the same model with zero capillary pressure, and with zero capillary pressure and high injection rate. No CO_2 flowed into the Upper Transition Zone at any point in any of these simulations.*

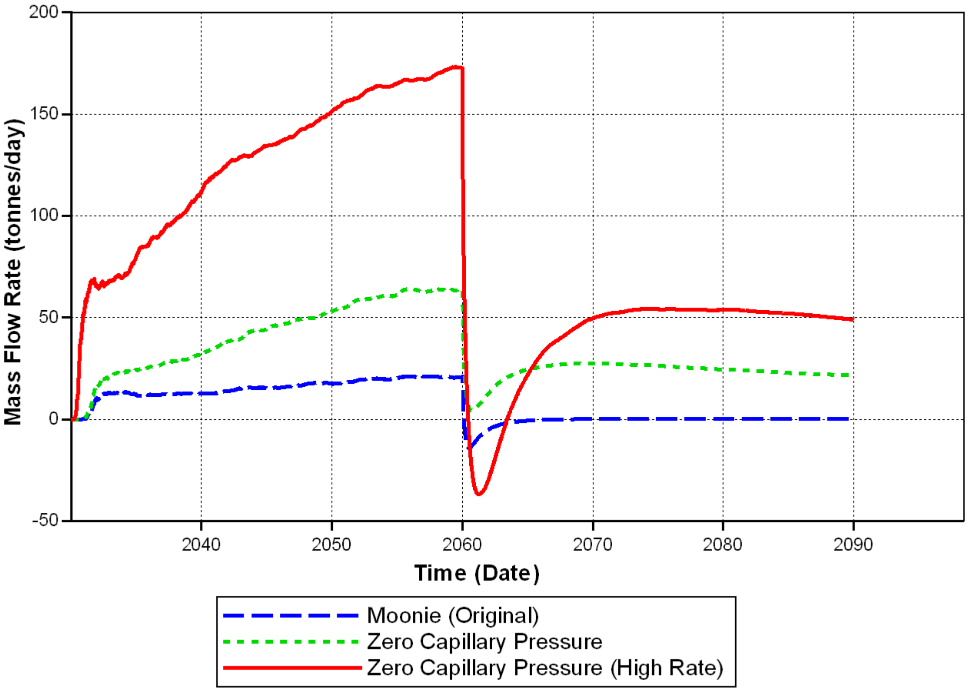
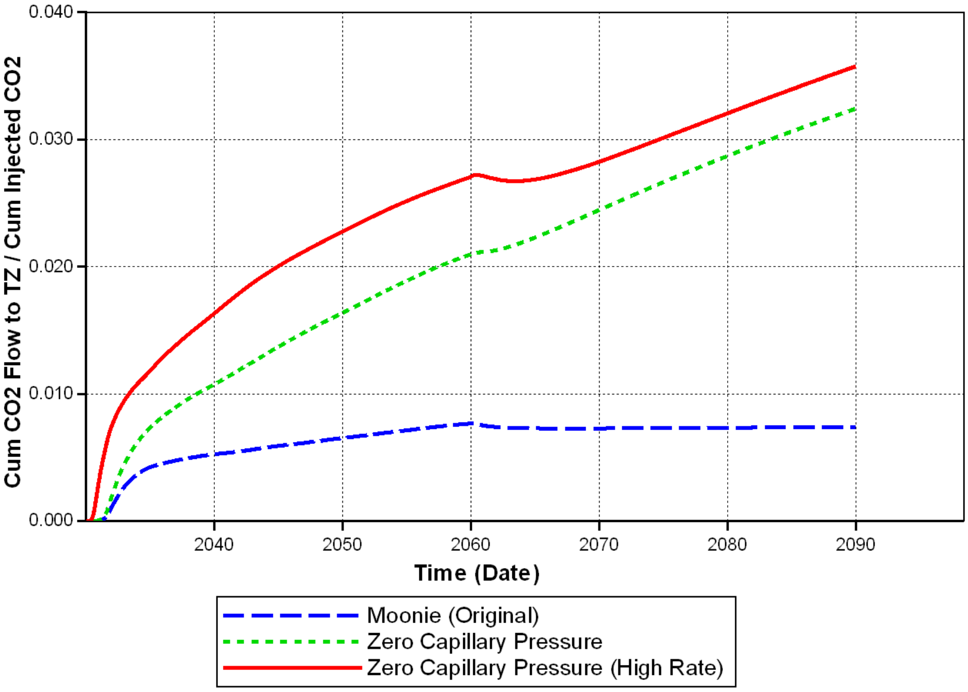


Figure 15 *Ratio of cumulative flow of CO_2 into the Transition Zone to cumulative injected CO_2 for the three models. The equivalent plot for the Meandarra type Transition Zone is shown in Figure 2. The maximum value in the Meandarra model was 0.0045 (i.e. almost an order or magnitude less than the two models with zero capillary pressure).*

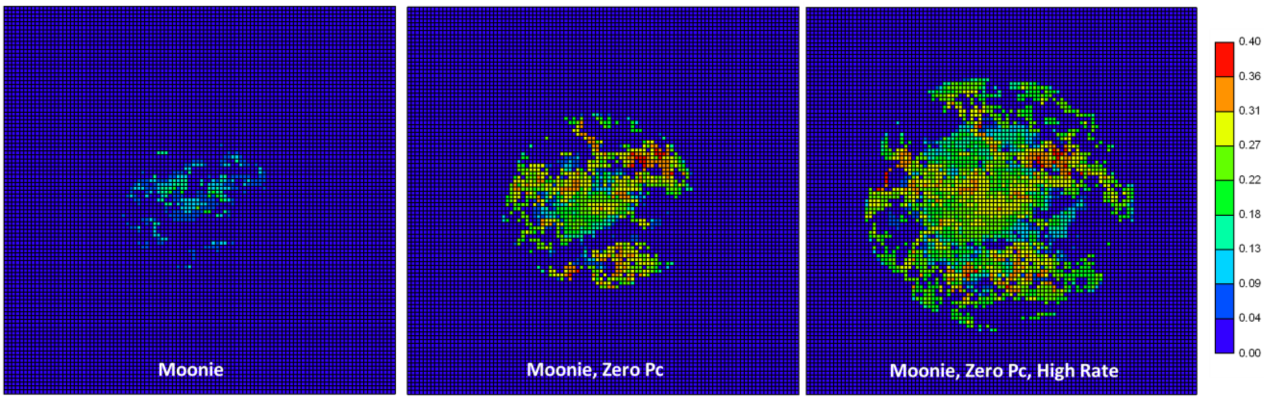


As expected, more CO_2 was able to enter the Transition Zone in the cases where zero capillary pressure was defined for the model. For the high injection rate case, CO_2 flowed into the Transition Zone at a maximum rate of approximately 175 tonnes/day (~64,000 tonnes/year). While this could be considered a significant mass of CO_2, it represents a small fraction of the injected CO_2. In fact, throughout the simulation period, including the 30 years post-injection, only around 3.6% of the injected CO_2 migrated into the Transition Zone for the high rate case (Figure 15).

Importantly, in both the cases with zero capillary pressure, CO_2 continued to migrate vertically into the Transition Zone at significant rates (tens of tonnes/day) after injection stopped. This did not occur in the model that included capillary pressure as the buoyancy forces were not sufficient to overcome the capillary pressures for most of the Transition Zone. The rate of CO_2 vertical migration post-injection was higher for the high injection rate case due to the more extensive CO_2 plume area (and thus larger area where CO_2 flow can occur). In both cases the rate of CO_2 upwards migration appears to decrease over time.

While more CO_2 entered the Transition Zone in these cases, it did not actually migrate much further through the Transition Zone vertically, and no CO_2 migrated beyond the lowest five layers (10m) of the Transition Zone in the 60 year simulation period. Instead, the extra CO_2 which migrated into the Transition Zone was spread across a larger lateral extent of the basal layers. In the model with capillary pressures defined, CO_2 could only enter a very small number of cells in the lowest layer of the Transition Zone, and only while pressures were high during injection. In the cases with zero capillary pressure the CO_2 was able to enter most of the cells overlying the plume. Some cells with extremely low permeability did limit CO_2 migration, particularly post injection when buoyancy was the dominant driver of migration. This can be seen in Figure 16, which shows the saturation of supercritical CO_2 in the lowest layer of the Transition Zone at the end of the 60 year simulation period. Since the three models have identical permeability fields, the highest CO_2 saturations occur in the same parts of the models.

Figure 16 Saturation of CO_2 in the lowest layer of the Transition Zone at the end of the 60 year simulation (30 years injection + 30 years' post-injection) for the three Moonie models. The higher saturations (orange/red) in the zero capillary pressure case (middle) can also be seen in the high rate case (right) as all models have the same permeability field. These were also the areas where CO_2 was able to enter the Transition Zone in the original model (left).



5. Conclusions

Uncertainty exists about the character of the Blocky Sandstone Reservoir, Transition Zone, and Ultimate Seal in at the Surat Basin-centre where notional injection sites have been selected. This is largely due to the lack of well, core and seismic data. To capture the full range of uncertainty, sector-scale static geological models were created for three stratigraphic conceptualisations of the Transition Zone, which could possibly occur within the area.

Dynamic simulations indicate that, in any of these cases, the Transition Zone acts as an effective barrier, limiting vertical migration of CO_2. It seems that, even for the sandiest and most permeable Transition Zone types, the Transition Zone is likely to have such low permeability that any flow (of CO_2 or water) through it will be limited. Even in a worst-case scenario, which combined the most permeable and most sandy Transition Zone type, zero capillary pressure and high injection rates, only 3.6% of the injected CO_2 entered the Transition Zone in the 30 year injection period and 30 years post injection. Even in this worst case, the CO_2 did not migrate beyond the lowest 10m of the Transition Zone during the simulation period.

In all cases, the lowest part of the Transition Zone was cooled by up to 15°C during the simulation, which caused an apparent reduction in pressure in parts of the Transition Zone where the permeability was low and fluid flow was near zero.

These models indicate that the Transition Zone is an effective barrier to vertical CO_2 migration. However, future efforts should focus on reducing uncertainty in model parameters through an appraisal plan that can provide additional information on the depositional setting and petrophysical properties (including wettabilty and capillary pressure) of the Transition Zone. This would most reasonably be achieved by drilling a well to the base-Surat unconformity, and collecting core.

6. References

La Croix A, Wang J, Gonzalez S, He J, Underschultz J & Garnett A (2019), *Sequence stratigraphy of the Precipice Sandstone and Evergreen Formation in the Surat Basin*, The University of Queensland Surat Deep Aquifer Appraisal Project – Supplementary Detailed Report, The University of Queensland.

La Croix A, Harfoush A, Rodger I & Underschultz J (2019), *Sector-scale static reservoir modelling of the basin-centre in the Surat Basin*, The University of Queensland Surat Deep Aquifer Appraisal Project – Supplementary Detailed Report, The University of Queensland.

Ribeiro A, Rodger I & Underschultz J (2019), *Fluid model*, The University of Queensland Surat Deep Aquifer Appraisal Project – Supplementary Detailed Report, The University of Queensland.

Rodger I, Altaf I, Underschultz J & Garnett A (2019*), Pressure constraints on injection*, The University of Queensland Surat Deep Aquifer Appraisal Project – Supplementary Detailed Report, The University of Queensland.

Rodger I, Sedaghat M & Underschultz J (2019*), Multiphase behaviour – relative permeability and capillary pressures*, The University of Queensland Surat Deep Aquifer Appraisal Project – Supplementary Detailed Report, The University of Queensland.

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

CREATE CHANGE