AOR DELINEATION

CTV IV

Computational Modeling Results

1. Predictions of System Behavior

Figure 1 and **Figure 2** show the computational modeling results and development of the CO_2 plume at different time steps. The boundaries of the CO_2 plume have been defined with a 0.01 CO_2 global mole fraction cutoff.

[redacted] The majority of the CO_2 injectate [redacted] at the end of the simulation with the remaining portion of the CO_2 [redacted] **Figure 3** shows the cumulative storage for each of the mechanisms.

2. Model Calibration and Validation

Model inputs were compared against publicly available reports and presentations by Lawrence Berkley National Laboratory (LBNL) and the West Coast Regional Carbon Sequestration Partnership (WESTCARB) investigating the CCS potential of the area (Foxall, et. al., 2017; Doughty and Oldenburg, 2011; Beyer et. al., 2013). The results of CTV's simulation compare favorably against the previous work by LBNL regarding storage capacity and CO_2 plume size.

CO_2 Injectate Effect on Plume and AoR Modeling Results

The compositional simulation model developed in CMG GEM software was run for the two simplified injectate compositions discussed in Section 7.2 in Attachment A, and their results were also compared against a 100% CO_2 injectate case. The cumulative volume, rate and injection duration for all 3 cases was kept the same.

The upper injection zone CO_2 plume for Injectate 1 and Injectate 2 is consistent with the plume outline for 100% CO_2 injectate (**Figure 4**), with negligible difference between the 3 cases. The CO_2 plume outline was defined by a 0.01 global CO_2 mole fraction for all 3 cases. The 100 year post end of injection plumes for the 3 cases are shown below in **Figure 4.** The wells that fall within the CO_2 plume are the same for all 3 cases. Similarly, the lower injection zone CO_2 plume for Injectate 1 and Injectate 2 is consistent with the plume outline for 100% CO_2 injectate (**Figure 4**), and the plume outline was defined by a 0.03 global CO_2 mole fraction for all 3 cases. The 100 year post end of injection plumes for the 3 cases are shown below in **Figure 4.** The wells that fall within the CO_2 plume are the same for all 3 cases.

Similarly, the AoR was delineated using critical pressure (see Section 3) for the 3 cases and was found to be consistent. **Figure 4** shows the upper injection zone and lower injection AoR boundary for the 3 cases. Additionally, the average pore volume pressure within the approximate AoR boundary was plotted for the 3 cases and was found to be very close with a maximum difference of ~6 psi seen between the cases for upper injection zone and ~2 psi for the lower injection zone, as shown in **Figure 5**. Multiple scenarios were also run to test the effect of mixing Injectate 1 and Injectates 2 in different ratios on the AoR boundary and plume shapes. As expected, since the resulting mixed injectates were still high purity CO_2 streams with impurity concentrations in-between those of Injectates 1 and 2, the AoR boundaries and plume shapes for these scenarios were within the envelope represented by the end point compositions.

In summary, there is minimal effect of the minor components on the CO_2 plume shape and the AoR boundary, for the proposed injectate compositions. As such, CTV's plume and AoR modeling for corrective action assessment is adequate for the expected injectate composition ranges. CTV will confirm that the properties of the injectate are consistent with the model inputs at pre-operational injectate sampling and will do so for any additional sources. In addition, the AoR will be reviewed as per Section 6 Reevaluation Schedule and Criteria.

Sensitivity Cases

In addition, scenarios listed in the **Table 1** were run to test the effect of varying major model inputs on the CO_2 plume and AoR extent. These scenarios and the comparison against previous work in the area provides us with confidence in the CO_2 plume extent and AoR, and that the corrective action well review and potential impact to the USDW has been appropriately evaluated.

3. AoR Delineation

The AoR delineation was based on the methods of Thornhill et al. (1982), which is referenced in the EPA AoR and Corrective Action Guidance (Critical pressure calculation and results details are also discussed in **Appendix 7**). Based on pressure data available in the Upper and Lower Injection Zone formations in the region (**Figure 7**), it appears that both formations are under-pressured. Graph and data table showing this are shown in **Figure 6**. This is likely due to historic withdrawal from regional gas field operations in the area and limited recharge.

For the purpose of calculating the critical pressure and delineating the AoR for the project area, the aquifers are considered to be under-pressured by 128 psi for the Upper injection zone and 37 psi for the lower injection zone. Also the following equations were used to calculate critical pressure across the model domain:

$$P_{i,f} = P_u + \rho_i g(Z_u - Z_i) \qquad \text{– Eq (1)}$$

$$\Delta P_{i,f} = P_u + \rho_i g(Z_u - Z_i) - P_i \qquad \text{– Eq (2)}$$

Where,

$\Delta P_{i,f}$	-	the admissible overpressure in an under-pressured aquifer before fluid in the injection zone would flow into the USDW through a hypothetical open conduit
P_u	-	the initial pressure in the USDW. Assumed to be hydrostatic.
P_i	-	the initial pressure in the injection zone. The upper injection zone is assumed to be 128psi below hydrostatic pressure across the model domain, and the lower injection zone is assumed to be 37psi below hydrostatic.
g	-	acceleration due to gravity, 9.81m/s^2
Z_u	-	Elevation of the base of the USDW
Z_i	-	Elevation of the injection zone
ρ_i	-	Density of the brine in injection zone

An average TDS of 13,889 ppm was used for the upper injection zone and 14,415 ppm was used for the Lower injection zones based on test data. An average TDS of 6,930 ppm was assumed for the USDW based on Salinity calculations in the project area. Injection zone and USDW depths were based on the model grid and USDW mapping in the project area. Density and density gradients were calculated as a function of temperature and salinity using standard methods (McCutcheon et. al. 1993). Using these, the critical pressure was calculated at each grid point in the Petrel model using **Equations 1 & 2**, and combined with the pressure outputs from the plume simulation to delineate an AoR boundary at different timesteps. The final AoR boundary was determined by combining the outermost extent of the threshold pressure for the Upper Injection zone (seen at [redacted] years of injection) and the Lower Injection zone (seen at [redacted] years of injection). **Figure 8** shows the AoR extent, CO_2 plume extent, injector locations and proposed monitoring well locations. Details on the monitoring wells are discussed in further detail in Attachment C (Testing and Monitoring Plan).

TABLES

Table 1. Simulation sensitivity scenarios

Scenario	CO_2 plume and AoR impact
Porosity: 10% reduction from base case	Minimal Impact
Porosity: 10% increase from base case	Minimal Impact
Permeability: 10% reduction from base case	Minimal Impact
Permeability: 10% increase from base case	Minimal Impact
Upper Injection Zone Local Grid Refinement: the refined grid size to 100 feet x 100 feet around each injector within 52 acres	Minimal Impact
Lower Injection Zone Local Grid Refinement: the refined grid size to 100 feet x 100 feet around each injector within 52 acres	Minimal Impact

FIGURES

[redacted]

Figure 1. (A) Upper Injection Zone plume development through time: 1-year, 5-year, 10-year, 20-year, 23-year (end of injection), 77-year, and 100-year post injection. (B) Lower Injection Zone plume development through time: 1-year, 5-year, 10-year, 20-year, 25-year (end of injection), 75-year, and 100-year post injection.

[redacted]

Figure 2 Cross-sections showing plume development at various time steps through the project

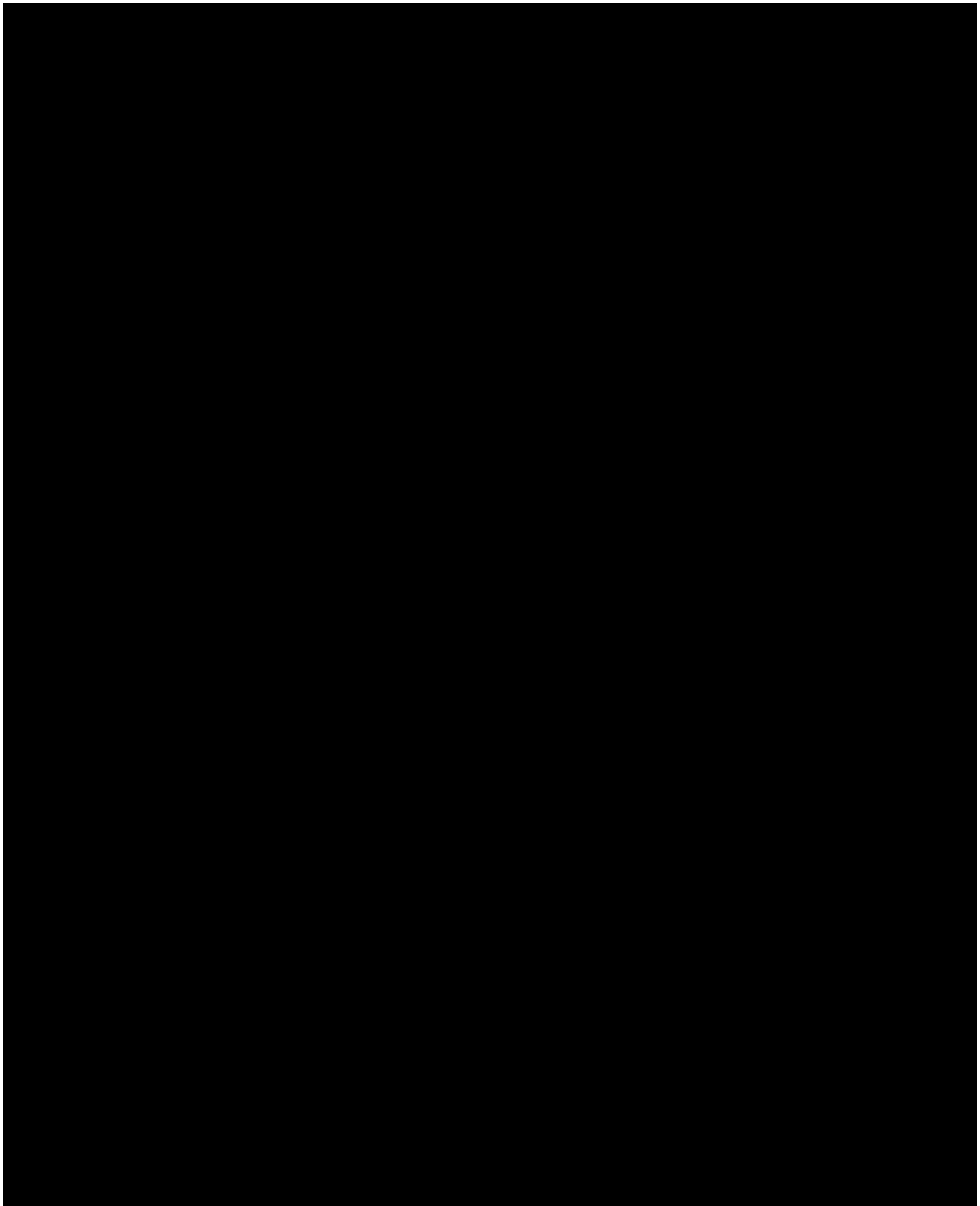

Figure 3 CO_2 storage mechanisms in the reservoir.

[redacted]

Figure 4. AoR boundaries and CO_2 plume outlines for Injectate 1 (Light Blue), Injectate 2 (Pink) and 100% CO2 Cases (Dark Blue). Larger Red outline is the model boundary. Minimal difference in AoR boundaries between the 3 cases with the boundaries overlying each other for the most part.

[redacted]

Figure 5. Average reservoir pressure within approximate AoR for Injectate 1, Injectate 2 and 100% CO_2 cases. 100% CO_2 case and Injectate 2 case pressure trends plot almost on top of each other.

[redacted]

Figure 6. Upper Injection Zone pressure profile and data and Lower Injection Zone pressure profile and data.

[redacted]

Figure 7. Map showing location of wells with pressure data for the Upper and Lower Injection Zones.

[redacted]

Figure 8. Map showing the location of injection and monitoring wells.