Class VI Injection Well Application

Contains proprietary business information.

Attachment 02: Area of Review and Corrective Action Plan
40 CFR 146.84(b)

Aster Project
Madison County, Indiana

17 September 2024

Project Information

Project Name: Aster

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Aster Project Injection Well 1 (AST INJ1) Location:
Madison County, Indiana
Latitude: 40.30026°
Longitude: -85.65565°

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List of Acronyms

°F	degrees Fahrenheit
3D	three-dimensional
AoR	Area of Review
AST ACZ1	Aster Project Above Confining Zone Monitoring Well 1
AST INJ1	Aster Project Injection Well 1
AST OBS1	Aster Project Deep Observation Well 1
AST USDW1	Aster Project USDW Monitoring Well 1
BHFP	bottomhole flowing pressure
BHP	bottomhole pressure
CCS	carbon capture and sequestration
CH_4	methane
CMG	Computer Modeling Group
CO_2	carbon dioxide
EoS	Equation of State
EPA	Environmental Protection Agency
fbsl	feet below sea level
GEM	Generalized Equation Model
GRFS	Gaussian random function simulation
H_2O	Water
IDNR	Indiana Department of Natural Resources
IGWS	Indiana Geological and Water Survey
kv/kh ratio	vertical permeability – horizontal permeability ratio
kh	horizontal permeability
KH	permeability x thickness (injectivity)
kv	vertical permeability
LGR	local grid refinement
mD	millidarcy
mD-ft	millidarcy-feet
MD	measured depth
O&G	oil and gas
PBI	proprietary business information
ppm	parts per million
psi/foot	pounds per square inch per foot
psia	pounds per square inch absolute
UIC	Underground Injection Control
US	United States
USDW	underground source of drinking water

This document describes the method and the geologic and hydrologic information used to delineate the Aster Project Area of Review (AoR). It also addresses the extent to which the Aster Project needs to undertake corrective actions for features within the AoR that may penetrate the confining zone, and, if needed, how such corrective actions will be taken in the future.

Section 1.1 *Model Background* describes the computational model used to delineate the AoR, including a description of the computational modeling, the physical processes modeled, and a description of the conceptual model and numerical implementation. It also describes the AoR and how the AoR will be re-evaluated over time. Section 4 *Corrective Action* describes the Aster Project Corrective Action Plan. This document is intended to demonstrate compliance with 40 CFR 146.84.

1. Computational Modeling Approach (40 CFR 146.84(b)(1))

1.1 Model Background

Computational modeling of carbon dioxide (CO_2) injection into deep geologic formations requires the numerical simulation of complex, coupled hydrologic, chemical, geologic, and thermal processes that include multi-fluid flow and transport, partitioning of CO_2 into the aqueous phase, and chemical interactions with aqueous fluids and minerals. For the Aster Project site (Figure 1), a static geologic model was constructed with available subsurface data from the region, and the static model was then used as the framework for computational modeling. This section will discuss the static model generation and computational modeling results.

1.1.1 Static Model

The Aster Project static model was developed using Rock Flow Dynamics' software, tNavigator, which is a subsurface interpretation and geologic modeling program. Table 1 summarizes the workflow used to generate the static model; the model focuses on the Mt. Simon Sandstone injection zone, the Eau Claire Silt storage zone, and Eau Claire Shale confining zone. The workflow included:

- Interpretation of all publicly available well logs to generate structure and thickness maps,
- Petrophysical analyses of four select wells from the region (Figure 2, Attachment 01: Narrative, 2024),
- Generation of a static model for the total storage zone Mt. Simon Sandstone, Eau Claire Silt, and the Eau Claire Shale confining zone.

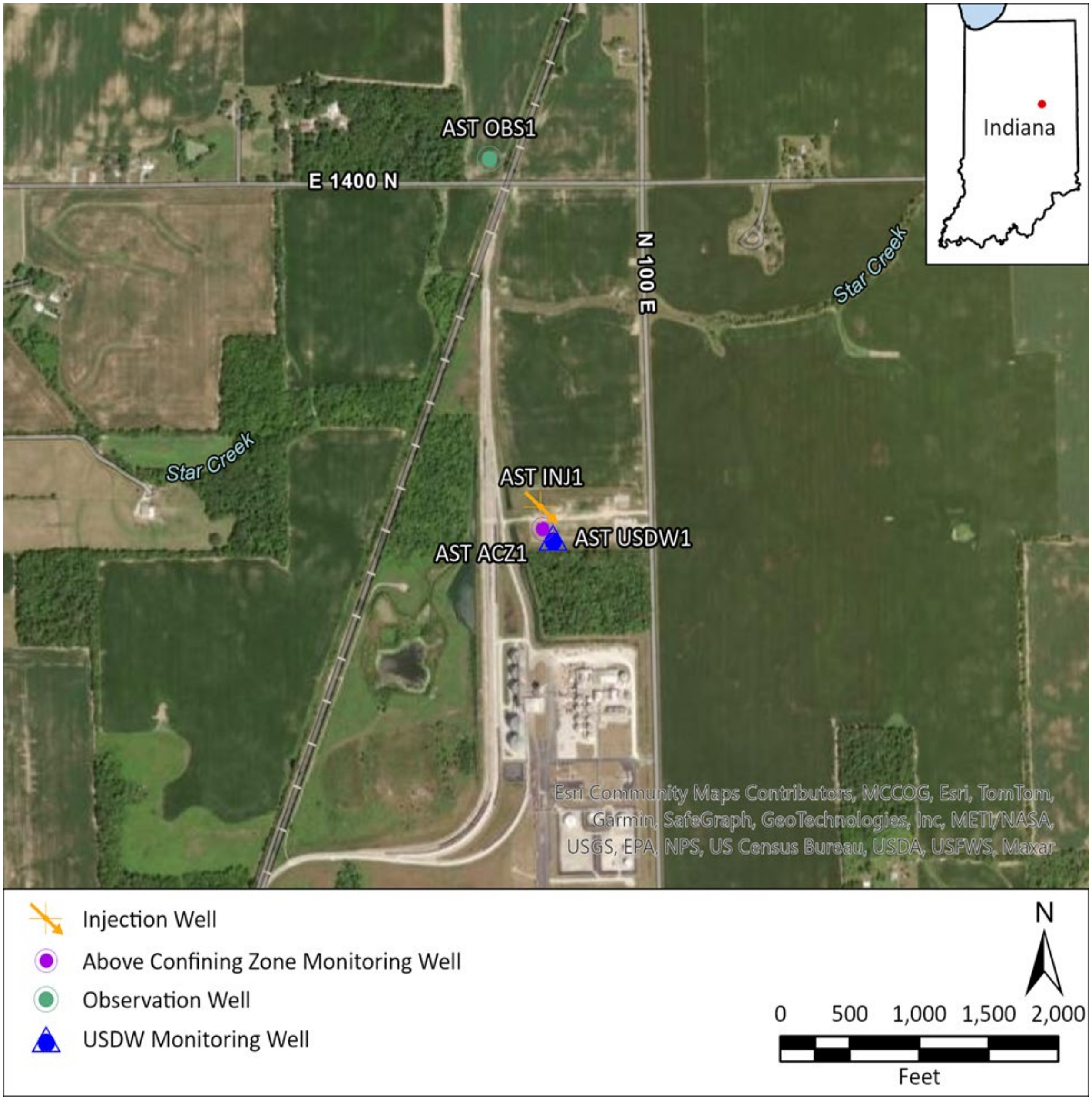

Figure 1: Aster Project well locations are shown. AST INJ1, Aster Project Above Confining Zone Well 1 (AST ACZ1), Aster Deep Observation Well 1 (AST OBS1), and Aster Project underground source of drinking water (USDW) Monitoring Well 1 (AST USDW1). Map adapted from Esri.

Table 1: Summary of static and computational modeling steps.

Modeling Step	Input Data	Information
Geologic interpretation for formation surfaces and thicknesses.	Well logs.	Regional geologic structure and thickness.
Static model injection and confining zone details.	Core, well log, and additional subsurface data were downloaded from public data sources. Petrophysical properties were derived (Attachment 01: Narrative, 2024).	Static model that represents subsurface porosity and permeability of the Davis Formation, Eau Claire Shale, Eau Claire Silt, and Mt. Simon Sandstone.
Prediction of CO_2 plume and pressure front development.	General injection zone information obtained from BP Lima, and the IBDP (Illinois Basin–Decatur Project dataset, 2022) wells.	Computational modeling to predict the maximum sustainable CO_2 injection rate, CO_2 plume footprint, and the pressure front area.

[redacted]

Figure 3 and Figure 4 display horizontal and vertical perspectives of the static model grid. Table 2 summarizes the model layering, horizon type, and dimensions. The proportional static model layers in the Eau Claire Shale, the Eau Claire Silt, the Upper Mt. Simon Sandstone, the Mt. Simon B-cap, and the Lower Mt. Simon Sandstone are relatively thin and were defined to capture vertical well log variability in the injection, storage, and confining zones that are used in the computational model. For instance, the vertical grid sizes used in both the Lower and Upper Mt. Simon Sandstone were approximately three feet. The formations above the Davis Formation use one layer per zone, as the CO_2 is not predicted to penetrate the Eau Claire Shale confining zone (Table 2).

The Tartan pattern consists of the model grid cells that are 400 feet × 400 feet close to the injection well to capture near-wellbore heterogeneities in the injection, storage, and confining zones; the cell size increases to 2,400 feet x 2,400 feet away from the injection well (Figure 3). The entire static model volume contains approximately 5.4 million active cells and covers an area of 640 square miles (Figure 3, Figure 4, and Table 2). The static model cell size captures subsurface geologic variations and maintains a manageable cell count for the computational model.

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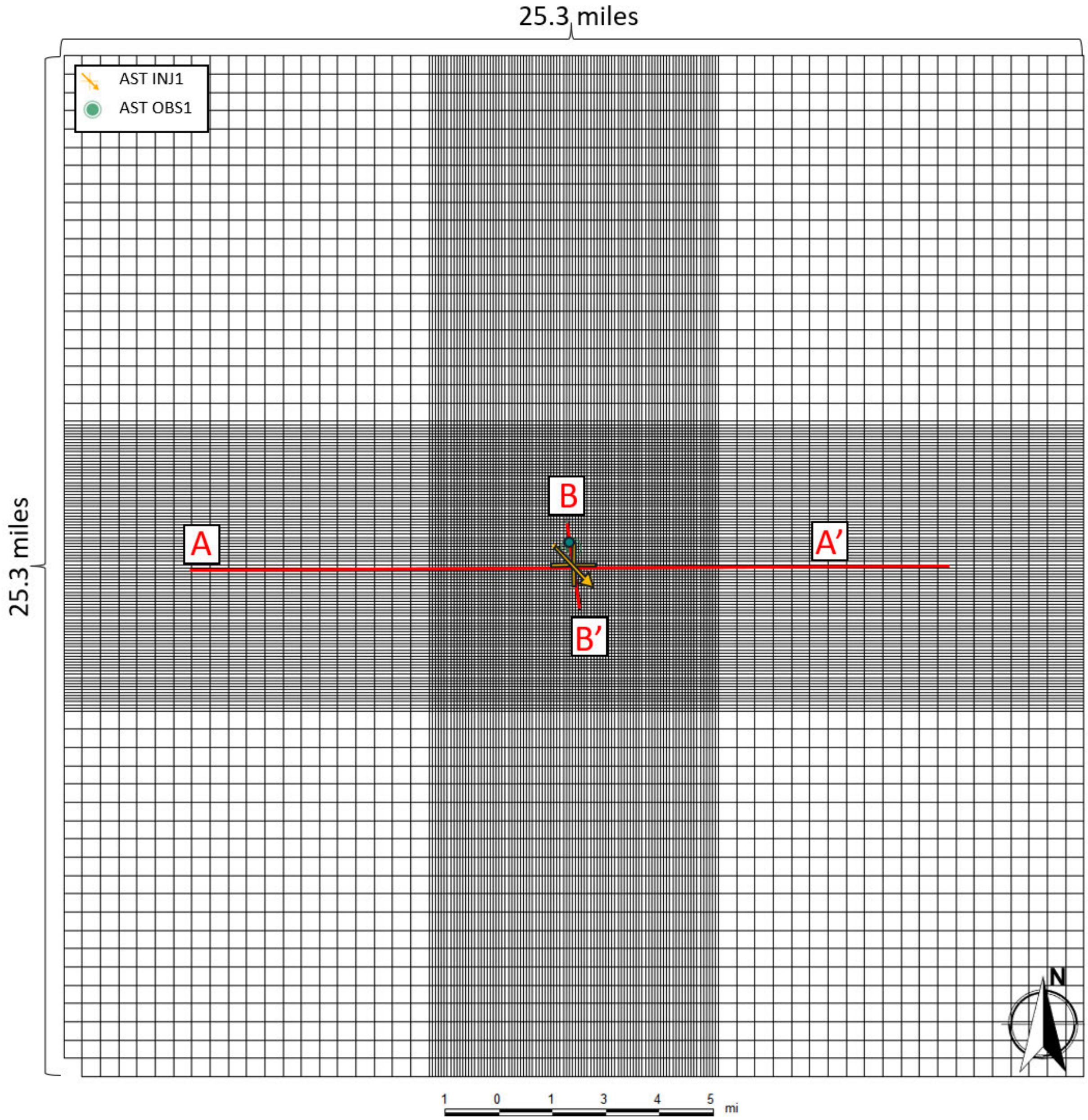

Figure 3: Map view of the static model area tartan grid showing horizontal grid size. Smaller cells (400 x 400 feet) were used around AST INJ1 and AST OBS1. Cross section A-A' is shown in Figure 4 and cross section B-B' is shown in Figure 5, Figure 18, Figure 19, Figure 20, Figure 25, Figure 28, Figure 29, Figure 35, Figure 36, Figure 37, and Figure 38.

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1.1.2 Computational Model

The fluid flow model used for this application was developed by Computer Modelling Group (CMG) of Calgary, Alberta and is called the Generalized Equation Model (GEM), which is a commercial simulator. GEM was initially developed by CMG for modeling hydrocarbon reservoirs, but is also well-documented for carbon storage, and it is listed in the US EPA document, "Rules and Tools Crosswalk: A Compendium of Computational Tools to Support Geologic Carbon Storage Environmentally Protective UIC Class VI Permitting" (Lackey et al., 2022).

This simulation software was selected because it has many advanced features for carbon sequestration modeling, including relative permeability hysteresis, CO_2 solubility in water, water vaporization, geochemistry, mineralization, thermal, and geomechanics. For this application, an equation of state (EoS) was developed with three components:

- CO_2,
- methane (CH_4), and
- water (H_2O).

Since the computational model was originally designed for hydrocarbon reservoirs, it requires a trace hydrocarbon component (CH_4); this trace amount does not affect the simulation results in any significant way. The following CO_2 trapping mechanisms have been modeled:

- Structural or free gas,
- Residual trapped gas,
- CO_2 dissolved in H_2O,
- Aqueous ions, and
- Mineralization.

The model uses well established, discretized, fluid flow equations and an adaptive-implicit method for solving the resulting sparse matrix (Nghiem and Li, 1989; Collins et al., 1992).

The model uses a cubic EoS with Peng-Robinson (PR) coefficients, and viscosity modeling utilizes either the Jossi-Stiel-Thodos or Pedersen correlations.

Key assumptions of the EoS include:

- Eccentricity of molecules,
- Use of random mixing rules,
- Binary interaction parameter,
- Minimum Gibbs energy as an equilibrium criterion,

- Fugacity as a function of measurable properties, and
- Volume translation is used to improve density prediction.

Table 4 describes the processes used in the computational model for this application and includes:

- Convective and dispersive flow,
- Relative permeability hysteresis,
- Gas solubility in aqueous phase,
- H_2O evaporation
- Aqueous ions, and
- Mineralization.

All these processes were included in the computational model, and no additional mechanisms are anticipated. The integrity of the confining zone was evaluated with geomechanical modeling (Attachment 01: Narrative, 2024). Well log data from the BP Lima well was used as an input to the geomechanical model in order to complete an initial assessment of confining zone integrity. The geomechanical modeling will be updated when data from the injection and monitoring wells have been acquired.

Table 4: Processes captured in the computational modeling.

Computational Modeling Processes	Description
Convective flow	Movement of CO_2 through the pore space during the injection period.
Dispersive flow	Result of gravity segregation and increasing CO_2 solubility in water.
Relative permeability hysteresis	Trapping of CO_2 in pore spaces because of imbibition (increase in wetting phase saturation), which occurs during gravity segregation.
CO_2 solubility	Modeled by a modified form of Henry's law.
H_2O vaporization	Can occur around the wellbore because of high gas velocities and can lead to salt precipitation.
Mineralization	Long-term trapping mechanism that occurs over thousands of years.

As the computational model uses the static model as input, it covers the same area as the static model but is focused on the injection and confining zone (Figure 3 and Figure 4).

1.1.2.1. Thermal Modeling

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1.1.2.2. Salt Precipitation

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1.2 Site Geology and Hydrology

All information regarding the site geology and hydrology are provided in the Project Narrative (Attachment 01: Narrative, 2024). This includes the associated figures such as geologic maps, hydrologic maps, cross sections, and local stratigraphic columns.

1.3 Model Domain

The static and computational model domain information has been summarized in Table 5. The coordinate system is NAD 83 UTM Zone 16N (feet), and the static model contains over 5,000 feet of rock thickness within the 640 square mile model area.

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1.3.1 Model Grid Sensitivities

[redacted]

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1.4 Porosity and Permeability

1.4.1 Petrophysical Modeling

The Project Narrative includes a discussion of the wells in the region that provide important porosity and permeability data for the Aster Project as well as the petrophysical analysis that was completed on these wells (Attachment 01: Narrative, 2024).

The Aster Project static model statistically represents available subsurface data and honors the conceptual understanding of regional and local geology. Cell height plays a significant role in upscaling porosity and permeability logs and must balance the goals of capturing vertical heterogeneity while maintaining a manageable cell-count and computing time (Table 2). The proportional vertical layering used for the Aster Project static model captures variability observed in core data from multiple wells and honors thin intervals in the injection zone that may represent significant permeability streaks (Table 2). The permeability was calculated from the transforms presented in the Project Narrative (Attachment 01: Narrative, 2024). Average effective porosity and permeability values predicted for AST INJ1 well are reported in Table 6.

[redacted]

During the generation of the static model, statistical analyses were used to identify and correct any potential errors with the data distribution. Presently, the Aster Project static model statistically represents the subsurface with the available input data. However, uncertainty will be reduced once site specific data are acquired during the Pre-operational Testing Program (Attachment 05: Pre-operational Testing Program, 2024).

Geophysical logs, core, well test data, and three-dimensional (3D) surface seismic surveys will be collected during the pre-operational phase of the project. Wireline logs run in AST INJ1 and Aster Project Deep Observation Well 1 (AST OBS1) will be used to calibrate 3D surface seismic data and produce inversion products such as porosity and lithology cubes for the area of the surface seismic survey. The logs can also be used to generate a discrete facies log, which can be combined with the lithology cube to provide insight regarding the local depositional setting. The static model will be updated with this newly acquired data and used in the computational modeling discussed in Section 4.5 Re-evaluation Schedule and Criteria.

The conclusions of the geologic, petrophysical, and statistical analyses include:

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1.5 Constitutive Relationships and Other Rock Properties

Relative permeability curves and the capillary pressure curve describe and predict flow through the pores of the injection formation. A generalized gas-liquid relative permeability curve was used in the model (Figure 23). Laboratory curves are not currently available, but the curves used are consistent with published curves in the literature and include gas relative permeability hysteresis which is used to model residual gas trapping. Calculation of the imbibition gas relative permeability curve is described below, from the GEM user's manual:

"For a non-wetting phase (gas) consider a typical drainage process (increasing gas saturation) reaching a maximum gas saturation, S_{gh}, followed by an imbibition process (decreasing gas saturation) leading to a trapped gas saturation, S_{grh}."

The gas relative permeability on the drainage to imbibition scanning curve for a given value of the gas saturation, S_g, is given by:

$$k_{rg}(S_g) = k_{rg}^{drn}(S_{gf}) \quad (1)$$

where the free gas saturation S_{gf} is calculated from the following relationship:

$$S_{gf} = S_{gcrit} + \frac{(S_g - S_{grh})(S_{gh} - S_{gcrit})}{(S_{gh} - S_{grh})} \quad (2)$$

(S_{gh} is the maximum gas saturation, S_{grh} is the reversal saturation)

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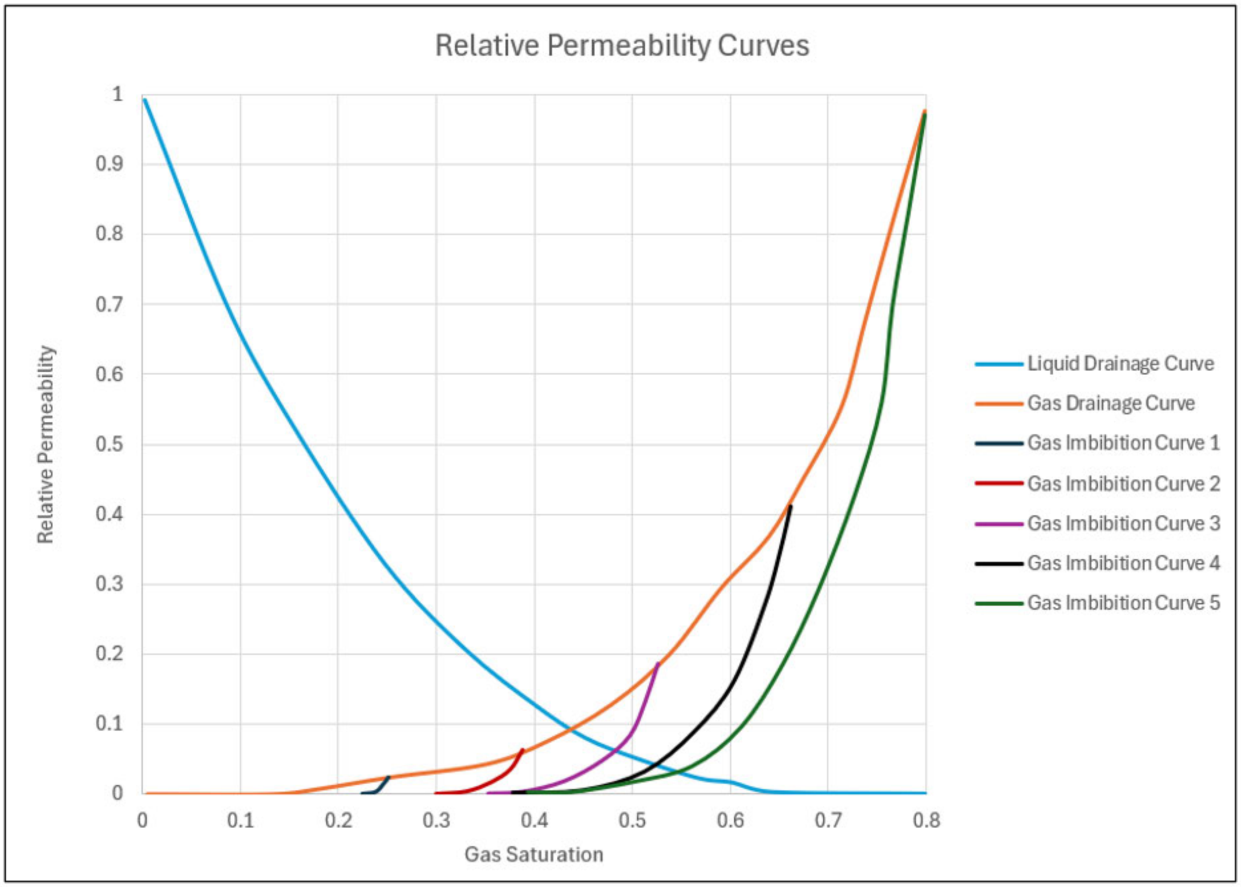

Figure 23: Gas-liquid relative permeability curves used in model. The blue curve is the liquid relative permeability curve, and the orange curve is the drainage gas relative permeability curve. The other curves are imbibition gas relative permeability curves and are used to model residual gas trapping.

1.6 Boundary Conditions

In the computational model, an aquifer function (Carter-Tracey) was applied to the grid boundary (side). The top and bottom of the grid are considered no-flow boundaries (Neumann). The formation was allowed to "leak" (i.e., accept fluids from the grid). This approach was used to simulate the pressure response of an infinite-acting aquifer and is considered preferable to using large pore volumes on edge grid blocks.

1.6.1 Initial Conditions

Initial conditions for the model are given in Table 8. These initial conditions include datum, pressure, temperature, and salinity.

[redacted]

1.6.2 Operational Information

Details of the proposed Aster Project injection operations are presented in Table 9 including coordinates, depths, wellbore diameter in inches, and planned injection periods.

[redacted]

1.6.3 Fracture Pressure and Fracture Gradient

Calculated fracture gradient and maximum injection pressure values are reported in Table 10. The fracture gradient was calculated by mapping total closure stress (TCS) across the region. (Attachment 01: Narrative, 2024). A step-rate test will be performed in the Mt. Simon Sandstone to determine the fracture gradient at the project site as part of the Pre-operational Testing Program (Attachment 05: Pre-operational Testing Program, 2024). The project specific fracture gradient will be updated in the computational model once it is available.

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2. Computational Modeling Results

2.1 Predictions of System Behavior

The following figures have been created for the base case to present the predicted behavior of the [redacted]

[redacted]

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When the first well is drilled for the project, the data gathered as part of the Pre-operational Formation Testing Program will be used to refine these parameters, and the project models will be updated (Attachment 05: Pre-operational Testing Program, 2024). Data collected during the pre-operational or injection phases of the project will be used to confirm the AoR or re-evaluate it, as necessary.

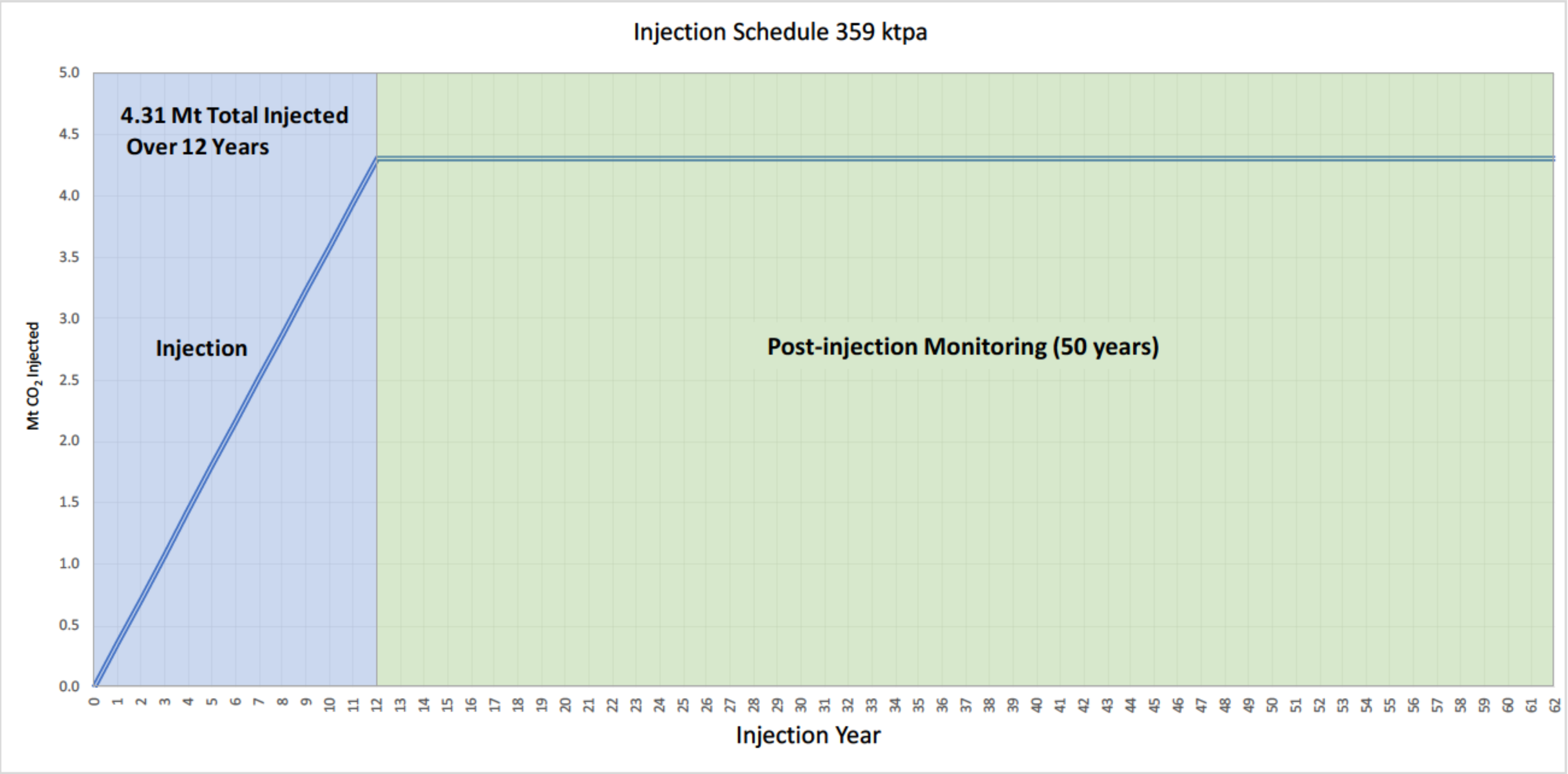

Figure 24: CO_2 injection schedule highlighting injection and post-injection monitoring intervals in years.

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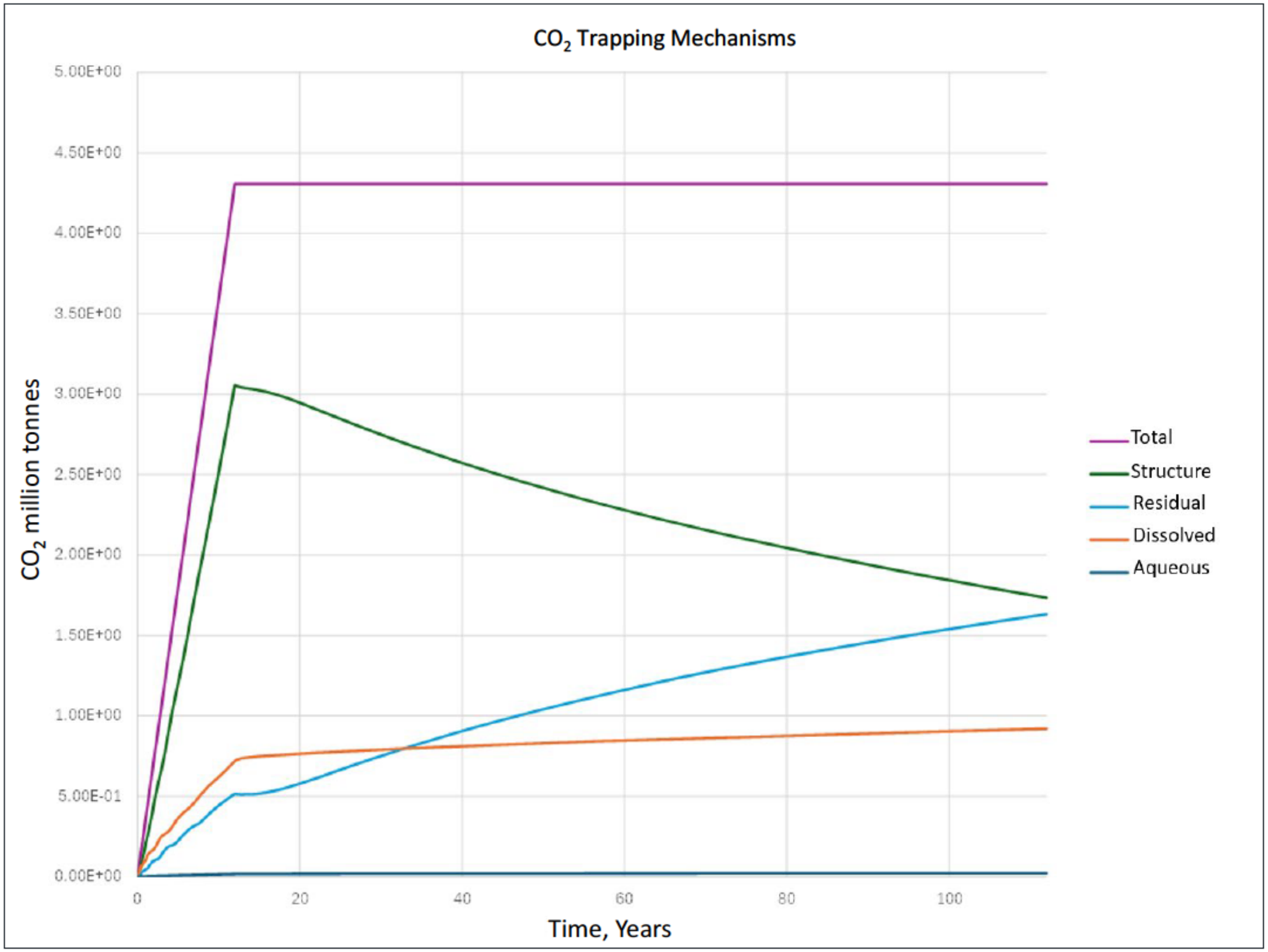

Figure 33: Graph of the relationship and evolution of CO_2 trapping mechanisms over time at the Aster Project.

Figure 33 and Table 12 show the proportion of the mass of injected CO_2 trapped by the five mechanisms in the first 100 years after injection ceases. Structural trapping as free gas, dissolution, and residual gas trapping are the dominant trapping mechanisms 100 years post-injection at the Aster Project site.

[redacted]

Initially, a large percentage of the CO_2 is structurally trapped. As the fluids gravity segregate, the amount of residual (immobile) gas increases. Dissolution of CO_2 into brine also begins at a slow rate. Dissociation of dissolved CO_2 into aqueous ions also occurs but only accounts for a small percentage of the trapping. Mineralization is a slow process that generally takes hundreds or thousands of years to become a significant trapping mechanism.

2.2 Model Calibration and Validation

2.2.1 Model Calibration

History matching was not performed as there is no current injection data available. The model was constructed using available reference information from the BP Lima, IBDP, and the CarbonSAFE Illinois project, which includes well test results that allow for the calibration of the computational model for various parameters including permeability in both the horizontal and vertical directions (INEOS Nitriles, 2016; Attachment 01: Narrative, 2024).

2.2.2 Uncertainty and Sensitivity Analysis – Static Model

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2.2.3 *Uncertainty and Sensitivity Analysis -- Dynamic Modeling*

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[redacted]

3. AoR Delineation

3.1 Critical Pressure Calculations

To delineate the pressure plume radius, a minimum (or critical) delta pressure was calculated. The delta pressure is the increase in pressure necessary to overcome the hydrostatic head of the injection zone fluid and would allow fluids to migrate up an open conduit to the lowermost USDW in the unlikely event that a conduit exists. The formula for calculating the delta pressure is given below (source: Underground Injection Control (UIC) Program Class VI Well Area of Review and Corrective Action Evaluation Guidance). Table 17 summarizes the input parameters used for the delta pressure calculation.

$$\Delta P_{if} = P_u + \rho_i * (z_u - z_i) - P \quad (4)$$

Where:
ΔP_{if} = delta pressure,
P_u = initial pressure of the lowermost USDW,
ρ_i = fluid density of the injection zone,
g = acceleration due to gravity,
z_u = elevation of the lowermost USDW,
z_i = elevation of the injection zone, and
P = initial pressure of the injection zone.

[redacted]

Substituting appropriate values into the equation, a minimum delta pressure was calculated to be [redacted] psi.

3.2 AoR Delineation

[redacted]

Through the Pre-operational Testing Program, uncertainties around the injection zone parameters will be addressed, and the static and computational models will be updated with the new data (Attachment 05: Pre-operational Testing Program, 2024).

The new computational model will be used to re-evaluate the CO_2 plume and pressure front, and the AoR will be revised if necessary. AST OBS1 will be used to monitor changes in injection zone pressure and aqueous geochemistry at a distance from AST INJ1 (Attachment 06: Testing and Monitoring, 2024). The computational model will be updated to match the observed data over the life of the project. If the injection zone does not perform as predicted, the AoR will be re-assessed if necessary.

4. Corrective Action

US EPA Class VI regulations require the identification of all confining zone penetrations within the AoR because these wells could become a preferential pathway for leakage of CO_2 and/or formation fluids out of the injection zone. Corrective actions may be required for existing confining zone penetrations, if present, to prevent endangerment to a USDW; no such penetrations are known to exist within the Aster Project AoR. The following sections discuss the findings of an evaluation of the Aster Project site that was performed to:

- Identify existing penetrations within the vicinity of the AoR,
- Determine if any penetrations extend below the primary confining zone, thereby presenting a risk of leakage that may require corrective actions,
- Identify corrective actions and define the approach that will be taken to prevent leakage that could endanger a USDW.

4.1 Tabulation of Wells Within the AoR

The area well data was examined and collected from commercially available subscription services and public sources that include the Indiana Department of Natural Resources (IDNR).

4.1.1 Oil and Gas Wells

There are 22 oil and gas (O&G) wells within the Aster Project AoR boundary (Table 18; Figure 43). A review of proprietary and public well data sources indicate that in the AoR all wells are dry or abandoned and all have total depths (TD) above the confining layer; therefore, no corrective action is necessary. Per 40 CFR 146.82(a)(4) and 146.84(c)(2), the detailed site evaluation determined that no wells penetrate the injection or confining zone within the AoR.

Table 18 lists all O&G wells identified within the AoR boundary, and a separate spreadsheet has been uploaded to the Geologic Sequestration Data Tool (GSDT) with additional information as requested under 40 CFR 146.82(a)(4) and 146.84(c)(2). The wells within the AoR boundary are abandoned and with TDs at least 1000 feet above the top of the Eau Claire Shale confining zone. Due to the age of the wells, the casing sizing and construction is unknown.

Table 18: O&G wells within project AoR [1]. Per 40 CFR 146.82(a)(4) and 146.84(c)(2), no wells identified penetrate the injection or confining zone (IGWS; S&P Global) .

UWI10	IGS ID	Well Name	Completion Date	Hole Direction	Well Type	Well Status (IGS)	Well TD (MD, feet) [2]	Deepest Formation	Casing Minimum Size (in)	LatWGS84	LonWGS84
1309578766	143184	WALKER #2	1/1/1895	VERTICAL	GAS	Prsmd Plggd	1033	Trenton	Unknown	40.30324	-85.64196
1309578764	143182	ALLMAN	1/1/1895	VERTICAL	GAS	Prsmd Plggd	1024	Trenton	Unknown	40.30625	-85.65277
1309578768	143187	FRAZIER #2	1/1/1896	VERTICAL	GAS	Prsmd Plggd	1028	Trenton	Unknown	40.30193	-85.65300
1309578741	143190	MCMAHAN #2	1/1/1899	VERTICAL	DRY	Prsmd Plggd	1022	Trenton	Unknown	40.29960	-85.66934
1309578742	143191	MCMAHAN #3	1/1/1899	VERTICAL	GAS	Prsmd Plggd	1024	Trenton	Unknown	40.29952	-85.66247
1309578743	143192	MCMAHAN #4	1/1/1899	VERTICAL	GAS	Prsmd Plggd	1011	Trenton	Unknown	40.30177	-85.66260
1309578744	143193	VINSON	1/1/1897	VERTICAL	DRY	Prsmd Plggd	995	Trenton	Unknown	40.30365	-85.66886
1309578769	143188	FRAZIER #1	1/1/1896	VERTICAL	GAS	Prsmd Plggd	1031	Trenton	Unknown	40.29716	-85.65295
1309567660	143186	FRAZIER	1/1/1907	VERTICAL	DRY	Prsmd Plggd	1385 [3]	Glenwood	Unknown	40.29428	-85.66562
1309578740	143189	MCMAHAN #1	1/1/1899	VERTICAL	GAS	Prsmd Plggd	1023	Trenton	Unknown	40.29599	-85.66930
1309578767	143185	FRAZIER	1/1/1900	VERTICAL	DRY	Prsmd Plggd	1028	Trenton	Unknown	40.29307	-85.66224
1309578746	143196	HERITAGE	1/1/1898	VERTICAL	GAS	Prsmd Plggd	1035	Trenton	Unknown	40.29211	-85.65296
1309578745	143195	EDWARDS	1/1/1897	VERTICAL	GAS	Prsmd Plggd	1032	Trenton	Unknown	40.28491	-85.65332

UWI10	IGS ID	Well Name	Completion Date	Hole Direction	Well Type	Well Status (IGS)	Well TD (MD, feet) [2]	Deepest Formation	Casing Minimum Size (in)	LatWGS84	LonWGS84
1309578749	143199	HUGHES	1/1/1900	VERTICAL	DRY	Prsmd Plggd	1027	Trenton	Unknown	40.29135	-85.66490
1309578750	143200	HUGHES	1/1/1900	VERTICAL	OIL	Prsmd Plggd	1028	Trenton	Unknown	40.29178	-85.66349
1309578748	143198	HERITAGE	1/1/1898	VERTICAL	OIL & GAS	Prsmd Plggd	1027	Trenton	Unknown	40.29212	-85.66178
1309578747	143197	HERITAGE	1/1/1900	VERTICAL	DRY	Prsmd Plggd	1034	Trenton	Unknown	40.28535	-85.65265
1309578756	143206	HUGHES	1/1/1896	VERTICAL	GAS	Prsmd Plggd	1012	Trenton	Unknown	40.29192	-85.64463
1309578755	143205	HUGHES	1/1/1900	VERTICAL	OIL	Prsmd Plggd	1033	Trenton	Unknown	40.28722	-85.65035
1309573398	143673	WARNER	1/1/1900	VERTICAL	GAS	Prsmd Plggd	1025	Trenton	Unknown	40.31370	-85.65754
1309573339	143674	ALLEN	1/1/1900	VERTICAL	GAS	Prsmd Plggd	1037	Trenton	Unknown	40.30653	-85.63882
1309573341	143676	ALLMAN	1/1/1891	VERTICAL	GAS	Prsmd Plggd	1016	Trenton	Unknown	40.31004	-85.65281

[1] Well files that exist for these older wells are very limited in their details.

[2] Depth of well based on midpoint of formation as determined by regional mapping, except where noted.

[3] Depth of well from well record.

[redacted]

4.1.2 Water Wells

A search of the Indiana Water Well Records database found 32 records for water wells located within the Aster Project AoR boundary (Figure 44). IDNR estimated the location for 11 of these water wells based on Township, Range, and Section, as an exact location was not provided in the well records. Water well depths within the AoR range from 48 to 300 fbgl with an average depth of 126.6 fbgl (Indiana DNR, Division of Water). Well construction and location information on the water wells within the AoR boundary can be found in the AsterWaterWellsWithinAoR.csv file uploaded to the GSDT.

[redacted]

4.2 Wells Within the AoR

Details of the O&G and water wells have been provided in the preceding section. The S&P Global Energy Portal, Indiana Geological and Water Survey (IGWS), and IDNR Division of O&G websites were used to compile the data for this section. Per 40 CFR 146.82(a)(4) and 146.84(c)(2), a detailed site evaluation determined that no wells penetrate the injection or confining zone within the AoR boundary. It is believed that all historical wells in the AoR have been captured by the above data sources.

4.2.1 Wells Penetrating the Confining Zone

After extensive review of the publicly available well data, no wells are present in the AoR that penetrate the Eau Claire Shale confining zone. The closest well (Light Norman R #1-17) that penetrates the Eau Claire Shale is a dry abandoned well with a TD of 3,167 fbgl located more than 12 miles from the injection well (Figure 45, IGWS). Based on Vault GSL CCS Holdings LP review, corrective action is not required for the Aster Project at this time.

[redacted]

4.3 Plan for Site Access

Consistent with 40 CFR 146.84(b)(2)(iv), surface access to land parcels within and surrounding the AoR will be negotiated through surface use and pore space lease agreements with area landowners. A list of names and addresses of all owners of record of land within the AoR of the Aster Project can be found in the Aster Project Narrative *Appendix A – List of Landowners Within the AoR* (Attachment 01: Narrative, 2024).

The surface access agreements will permit land access for the project wells in addition to land that may be needed for project activities. Agreements for project activities have been put in place to allow surface access for monitoring such as time-lapse seismic data acquisition as well as periodic groundwater sampling, and for site access in the case that potential future corrective action is required. These agreements will remain in place for the life of the project.

4.4 Corrective Action Schedule

Consistent with 40 CFR 146.84(c), an extensive review of all wells within the AoR has been performed and determined that there are no known wells within the AoR which would require corrective action as discussed in Section 4.2 *Wells Within the AoR*. As such, no corrective action schedule is necessary at this time. If upon re-evaluation of the AoR during the project life it is determined that the AoR has expanded to encompass a well that penetrates the confining zone, the well will be added to the corrective action schedule.

Should corrective action be required:

- Materials for plugging the well(s) will be consistent with those detailed in Attachment 07: Injection Well Plugging Plan (2024).
- These materials will be of appropriate quality and composition to withstand corrosive conditions, pressure, or any additional loading that may impact the well.
- Contingent actions may be required should field conditions necessitate.

The following high-level procedure may be utilized to properly plug and abandon the well.

1. Locate improperly plugged well using appropriate technology and equipment (i.e., metal detector, LIDAR, etc.).
2. If necessary, excavate to locate top of remaining casing.
3. Install new casing head or casing head spool.
4. Rig up service rig, nipple up blow out preventers (BOPs) to the well.
5. Function test BOPs and pressure test all lines.
6. Pick up mill tooth bit and pipe and run in hole.
7. Begin drilling out cement and well fill, circulate cuttings back to surface for inspection and analysis.
8. Annotate changes in circulated materials to confirm tops of each plug.
9. Continue drilling out the well until the bottom of the well is reached.

   a. If unable to reach the bottom, annotate the depth of maximum penetration.
   b. Should the total depth (TD) of the well be unable to be achieved, contingent actions will be necessary to ensure the TD is reached.
      i. These actions may include, but are not limited to changing bit types, bringing in a different rig, or other actions.
   c. Note that the bottom of the well will be reached if possible.
10. After reaching the total depth, circulate out the hole until returns are clean.
11. Trip out of hole with the pipe and bit.
12. Pick up open-ended work string and run in hole to the bottom of penetration.
13. Rig up cement pumping truck.
14. Pump CO_2 resistant cement in appropriately sized balanced plug(s) to ensure that the top of the corrosion resistant cement will be a minimum of 500 feet above the top of the confining zone.
    a. Note that this is the same cement top approach that will be utilized for the plugging of the project wells which penetrate and directly access the confining zone (Attachment 07: Injection Well Plugging Plan, 2024; Attachment 08: Post-injection Site Care and Site Closure, 2024).
15. Allow appropriate time for cement to harden and tag the top of the cement to ensure the top has not moved.
    a. If necessary, pump additional cement to ensure the top of the cement is at least 500 feet above the top of the confining zone.
16. Continue to pump cement using balanced plugs to surface.
17. Rig down cement pumping truck.
18. Nipple down BOPs.
19. Rig down service rig.
20. Cut and cap wellhead below ground. Install marker and bury the cap.

4.5 Re-evaluation Schedule and Criteria

4.5.1 AoR Re-evaluation Cycle

The Aster Project AoR will be updated when site specific data from the project wells and more extensive seismic data are available, and it will be re-evaluated every five years during the injection and post-injection phases of the project. Additionally, any significant changes to the CO_2 stream or an increase in the injection volumes will trigger a re-evaluation of the AoR.

As part of this re-evaluation, monitoring and operational data will be used to assess the performance of the injection well and injection zone as well as to calibrate the computational modeling. The testing and monitoring data will include (but is not limited to) the following:

- Surface pressure and BHP,

- Total mass injected and mass injection rates,
- Mechanical integrity logs,
    - Temperature logs,
    - Pulsed neutron logging,
- Time-lapse surface seismic data,
- Passive seismic monitoring.

In addition to reviewing the testing and monitoring data for AoR re-evaluation on five-year intervals, this data will also be assessed on an annual basis to identify any unexpected changes in behavior. Should the monitoring data show notable deviations from the computational modeling results, the modeling will be re-assessed, and a new AoR will be established. Notable deviations are defined in the following section.

4.5.2 Triggers for AoR Re-evaluations Prior to Next Scheduled Re-evaluation

Table 19 presents a non-exhaustive list of potential parameters that could trigger a re-evaluation of the AoR prior to the next scheduled re-evaluation should notable deviations from anticipated values occur.

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Additional causes for AoR re-evaluation could include the extension of the CO_2 plume or pressure front beyond the initial plume predictions based on results of time-lapse seismic surveys; an exceedance of any operating conditions; or if the data gathered during the pre-operational testing program (Attachment 05: Pre-operational Testing Program, 2024) results in substantial changes to the current models and understanding of the subsurface.

Should any of the events that are detailed above occur, the project team will discuss AoR re-evaluation procedures and timeline with the UIC Program Director to conclude whether the re-evaluation is necessary.

5. References

Attachment 01: Narrative, 2024, Underground Injection Control Class VI Permit Application: Aster Project.

Attachment 05: Pre-operational Testing Program, 2024, Underground Injection Control Class VI Permit Application: Aster Project.

Attachment 06: Testing and Monitoring, 2024, Underground Injection Control Class VI Permit Application: Aster Project.

Attachment 07: Injection Well Plugging Plan, 2024, Underground Injection Control Class VI Permit Application: Aster Project.

Attachment 08: Post-injection Site Care and Site Closure, 2024, Underground Injection Control Class VI Permit Application: Aster Project.

Cleveland-Cliffs Steel Corporation, 2021, Underground Injection Control Permit to Operate Class I Hazardous Well; Ohio Permit UIC 05-09-001-PTO-I, Ohio Permit UIC 05-09-001-PTO-I: Ohio Environmental Protection Agency Division of Drinking and Ground Waters.

Collins, D. A., L. X. Nghiem, Y.-K. Li, and J. E. Grabenstetter, 1992, An Efficient Approach to Adaptive-Implicit Compositional Simulation with an Equation of State: SPE Reservoir Engineering, v. 7, no. 02, p. 259–264, doi:10.2118/15133-PA.

Cruz, F., S. Dang, M. Curtis, and C. Rai, 2023, Effect of Geochemical Reactivity on ScCO2–Brine–Rock Capillary Displacement: Implications for Carbon Geostorage, 21: Energies, v. 16, no. 21, p. 7333, doi:10.3390/en16217333.

Greenberg, S. E., 2021, Illinois Basin-Decatur Project Final Report: An Assessment of Geologic Carbon Sequestration Options in the Illinois Basin: Phase III: United States Department of Energy.

IDNR Water Well Locations., Water well records: Indiana DNR, Division of Water.

IGWS, Indiana Geological & Water Survey (IGWS) Petroleum Data Management System (PADMS) Well Record Tables: https://legacy.igws.indiana.edu/pdms/WellSearch.cfm, Indiana Geological & Water Survey (IGWS).

Illinois Basin–Decatur Project dataset, 2022: EDX.

INEOS Nitriles, 2016, Underground Injection Control Permit to Operate Class I Hazardous Well; Ohio Permit UIC 03-02-005-PTO-I, Ohio Permit UIC 03-02-005-PTO-I: Ohio Environmental Protection Agency Division of Drinking and Ground Waters.

Lackey, G. et al., 2022, Rules and Tools Crosswalk: A Compendium of Computational Tools to Support Geologic Carbon Storage Environmentally Protective UIC Class VI Permitting, DOE/NETL-2022/3731: National Energy Technology Laboratory (NETL), Pittsburgh, PA, Morgantown, WV, and Albany, OR (United States), doi:10.2172/1870412.

Mehnert, E., and P. Weberling, 2014, Groundwater Salinity Within the Mt. Simon Sandstone in Illinois and Indiana, 582: Illinois State Geological Survey, Prairie Research Institute, University of Illinois, Circular, 31 p.

Nghiem, L. X., and Y.-K. Li, 1989, Phase-Equilibrium Calculations for Reservoir Engineering and Compositional Simulation, *in* Second International Forum on Reservoir Simulation, Alpbach, Austria.

S&P Global, S&P Global Energy Portal: <https://my.ihs.com/Energy/Products> (accessed May 5, 2023).

Whittaker, S., and C. Carman, 2022, CarbonSAFE Illinois - Macon County Final Report.