Attachment 9: Post-injection Site Care and Site Closure Plan
40 CFR 146.93(a)
Vervain Project, McLean County, Illinois
31 January 2023

Navigator CO_2

Project Information

Project Name: Vervain

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List of Acronyms

2D	two-dimensional
3D	three-dimensional
ACZ	above confining zone
AoR	Area of Review
ASTM	American Society for Testing and Materials
BHFP	bottomhole flowing pressure
BHP	bottomhole pressure
CO_2	carbon dioxide
DIC	dissolved inorganic carbon
EPA	Environmental Protection Agency
ERRP	Emergency and Remedial Response Plan
FOT	fall-off test
HGCS	Heartland Greenway Carbon Storage, LLC
kT/Y	kiloton per year
KH	permeability-height product
kv/kh	vertical/horizontal permeability ratio
Mc	magnitude of completeness
MD	measured depth
Mi	mile
MIT	mechanical integrity test
MS	mass spectrometry
NV_ACZ1	Vervain Above Confining Zone Well #1
NV_ACZ2	Vervain Above Confining Zone Well #2
NV_INJ1	Vervain Injection well #1
NV_INJ2	Vervain Injection well #2
NV_MA1	Mahomet Aquifer monitoring well #1
NV_MA2	Mahomet Aquifer monitoring well #2
NV_OBS1	Vervain Deep Observation Well
NRMS	normalized root mean square
PISC	Post Injection Site Care and Site Closure
PNL	pulsed neutron logging
PSI	pounds per square inch
QASP	Quality Assurance and Surveillance Plan
SM	standard methods
TBD	to be determined
TDS	total dissolved solids
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water

This Post-Injection Site Care and Site Closure (PISC) plan describes the activities that Heartland Greenway Carbon Storage, LLC (HGCS) will perform at the Vervain Project Site to meet the requirements of 40 CFR 146.93. HGCS is proposing an alternative timeframe of fifteen (15) years. The position of the subsurface carbon dioxide (CO_2) plume, pressure front, and shallow ground water quality will be monitored for the 15-year PISC period during which CO_2 plume expansion is expected to stabilize and pressure front is expected to decrease quickly based on current computational modeling (Section 4.0).

1. Pre- and Post-Injection Pressure Differential [40 CFR 146.93(a)(2)(i)]

The Area of Review (AoR) is defined by the delta pressure or the increase in pressure necessary to allow fluids to migrate up an open conduit to the lowermost underground source of drinking water (USDW). The delta pressure defining the AoR at the Vervain Project Site is 137 pounds per square inch (psi) (Attachment 2: AoR and Corrective Action Plan, 2023). Computational modeling demonstrates that the maximum delta pressure increase occurs at the injection wells and will be 550 psi at the end of the injection period. After CO_2 injection is stopped, the injection zone pressure will rapidly decline to below the delta pressure after approximately nine years (Section 4.2). Additional information on the projected post-injection pressure declines and differentials is presented in the AoR and Corrective Action Plan (Attachment 2: AoR and Corrective Action Plan, 2023).

2. Predicted Position of the CO_2 Plume and Associated Pressure Front at Site Closure [40 CFR 146.93(a)(2)(ii)]

Figure 1 shows the predicted pressure front at the end of injection operations (i.e., AoR) and the extent of the CO_2 plume 50 years after injection has stopped. This figure, thus, represents the maximum extent of the pressure front and maximum extent of the CO_2 plume and is based on the AoR delineation modeling results submitted pursuant to 40 CFR 146.84. Sensitive, Confidential, or Privileged Information [redacted]

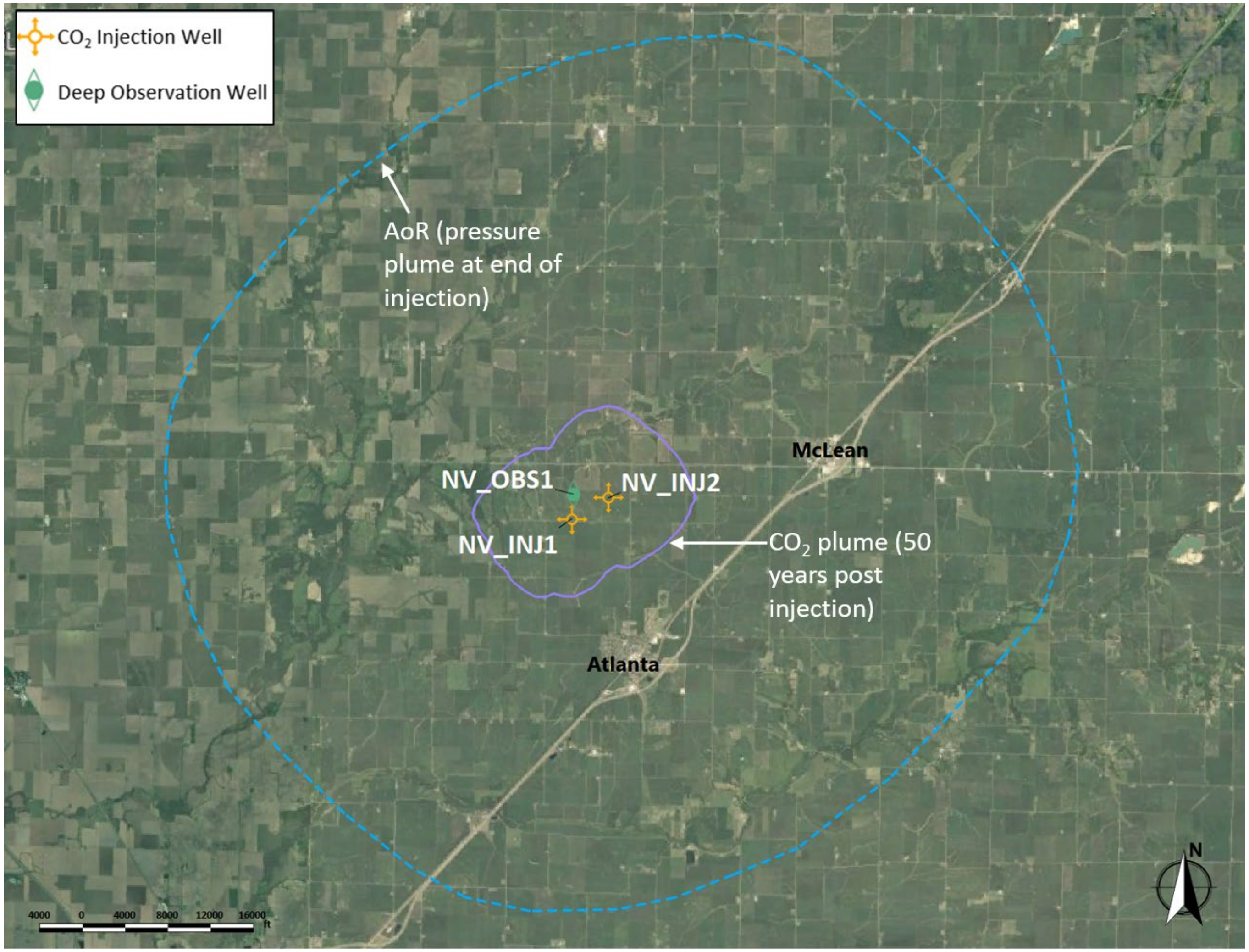

Figure 1: Map of the project AoR, as predicted by the 137-psi delta pressure at the end of the operational phase of the project. The outline of the CO_2 plume at 50 years post-injection is also shown. NV_INJ1 and NV_INJ2 are injection wells and NV_OBS is the deep observation well.

3. Post-Injection Monitoring Plan [40 CFR 146.93(b)(1)]

The PISC monitoring plan for the Vervain Project Site includes shallow groundwater monitoring, above confining zone (ACZ) monitoring, injection zone monitoring, and geophysical monitoring to meet the post injection monitoring requirements of 40 CFR 146.93(b)(1). The results of PISC monitoring will be submitted annually, within thirty days of the conclusion of the activities or receipt of processed data, whichever is later, as described under "Schedule for Submitting Post-Injection Monitoring Results," following.

A Quality Assurance and Surveillance Plan (QASP) for all testing and monitoring activities during the injection and post injection phases is provided (Attachment 11: QASP, 2023).

Table 1 summarizes the monitoring activities of the PISC phase of the Vervain Project. Bottomhole pressure (BHP) will be monitored continuously within the injection zone in the Injection Wells (NV_INJ1, NV_INJ2) and Deep Observation Well (NV_OBS1) until it becomes less than the delta pressure of 137 psi (Attachment 2: AoR and Corrective Action Plan, 2023). Once BHP is less than the delta pressure of 137 psi, annual static gradient surveys will be collected from NV_INJ1 and NV_INJ2, and pressure monitoring will cease in NV_OBS1. The pressure within the injection zone is expected to begin to dissipate once CO_2 injection ceases and based on computation modeling the delta pressure will be less than 137 psi within 9 years (Section 4.0). The injection zone pressure measurements will be used to verify and calibrate the computational modeling results during the PISC period. Wellhead pressures will be monitored continuously.

Fluid samples will be taken from the ACZ monitoring zone annually for geochemical analysis to verify CO_2 containment. Fluid samples will be obtained for geochemical analysis of shallow groundwater monitoring wells, including the Mahomet Aquifer wells, will be obtained annually during the PISC phase.

Passive seismic monitoring will continue during the initial months of the PISC and will be phased out as pressure, and frequency of detectable events, decrease. This will be evaluated during the initial months of the PISC phase. The Underground Injection Control (UIC) Program Director will be consulted prior to ending any monitoring activities during the PISC phase of the project.

Two time-lapse three-dimensional (3D) surface seismic surveys will be acquired during the PISC phase of the project. The first survey will be acquired in the first (1^{st}) year of the PISC period, and the second survey will be acquired in the thirteenth (13^{th}) year of the PISC period. The objectives of the two 3D seismic surveys include:

- Verification of CO_2 containment in the injection zone,
- Demonstration of post-injection CO_2 plume stability,
- Input to calibration and verification of computational modeling.

Table 1: Summary of proposed testing and monitoring activities to take place during the PISC phase of the project

Monitoring Activity	PISC Frequency*	Location	Depth Range (MD feet) ***
Fluid Monitoring			
Fluid Sampling	Annual (Q2 of each year)	Shallow wells TBD NV_MA1, NV_MA2, NV_ACZ1, NV_ACZ2	Sensitive, Confidential, or Privileged Information [redacted]
Pressure Monitoring			
Downhole Pressure	Continuous **	NV_INJ1**, NV_INJ2**, NV_OBS1**, NV_ACZ1, NV_ACZ2	
Wellhead Pressure	Continuous	NV_INJ1**, NV_INJ2**, NV_OBS1**, NV_ACZ1, NV_ACZ2	
Mechanical Integrity Tests			
MIT (External): Temperature Logging	Every 5 years	NV_INJ1, NV_INJ2, NV_OBS1	
Plume Verification Monitoring			
Pulsed Neutron Logging (PNL)	Year 1, Year 3, Year 5, Year 7, Year 9, Year 15	NV_INJ1, NV_INJ2, NV_OBS1	
Passive Seismic Monitoring	Continuous	Minimum 5 Stations	
Time-lapse 3D Surface Seismic Data	Q1 Year 0 Q1 Year 13	Area sufficient to image modeled CO_2 plume extent	

*Minimum frequency listed in table.

**Pressure is to be monitored continuously in deep wells until the BHP change in NV_INJ1 and NV_INJ2 is below the delta pressure. After BHP is below delta pressure, annual static gradient surveys will be collected from NV_INJ1 and NV_INJ2, and BHP pressure monitoring will cease in NV_OBS1 and NV_ACZ1 and NV_ACZ2.

***To be confirmed after well is drilled.

Surface access to the wells for testing will be negotiated as part of the landowner leases for the project.

3.1 Monitoring Above the Confining Zone

The monitoring plan for the Vervain PISC phase is designed to be adaptive and responsive to changes in project risks. No changes will be made to the PISC monitoring plan without informing the UIC Program Director (40 CFR 146.93 (a)(3)).

Table 2 presents the ACZ fluid monitoring methods, locations, and frequencies. The ACZ monitoring zone will be in the Ironton-Galesville formations at a depth to be determined through the Pre-Operational Testing Program (Attachment 5: Pre-Op Testing Program, 2023). Formation fluid samples will be collected using a bailer system that maintains the formation pressure for analysis of dissolved inorganic carbon, alkalinity, and pH. Samples for all other analytes will be collected with an open-ended bailer. Prior to sample collection the well will be swabbed to remove stagnant water from the well and ensure representative water is collected from the formation. The fluid swabbed from the well will be monitored for field parameters, such as pH, specific conductance, and temperature, using a calibrated water quality meter. Once these parameters stabilize, it will be an indication that representative formation fluid is in the well at the time the sample is collected.

Further detail on specifications, sample collection methods, analytical techniques, detection limits, and means of storing and transporting fluid samples is provided in the QASP (Attachment 11: QASP, 2023).

Table 2: Monitoring of ground water quality and geochemical changes above the confining zone.

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
Shallow Groundwater	Aqueous geochemistry	Shallow existing wells NV_MA1, NV_MA2	Distributed throughout AoR Adjacent to NV_INJ1, NV_INJ2	Annual (Q2/year)
Ironton-Galesville formations	Aqueous geochemistry	NV_ACZ1, NV_ACZ2	Adjacent to NV_INJ1, NV_INJ2	Annual (Q2/year)

Table 3 identifies the initial groundwater parameters to be monitored and the analytical methods that will be used for the samples in the baseline analysis of the data.

Table 3: Summary of analytical and field parameters for ground water samples

Parameters	Analytical Methods *
Cations: Ca, Fe, K, Mg, Na, Si	EPA 6010B
Cations: Al, Sb, As, Ba, Cd, Cr, Cu, Pb, Mn, Hg, Se, Tl	EPA 200.8, EPA 245.1
Anions: Br, Cl, F, NO_3, and SO_4	EPA 300.0
Alkalinity	SM 2320B
Total Dissolved Solids (TDS)	SM 2540C
Total Organic Carbon (TOC)	SM 5310C
Dissolved Inorganic Carbon (DIC)	SM 5310C
Total and Dissolved CO_2	ASTM D513-06B
Stable Isotopes of δ13C **	Isotope Ratio Mass Spectrometry ***
pH	Field with multi-probe system
Conductivity/Resistivity	Field with multi-probe system
Temperature	Field with multi-probe system

*An equivalent method may be employed with the prior approval of the UIC Program Director.
**Isotope analysis is contingent.
***Gas evolution technique by Atekwana and Krishnamurthy (1998) with modifications made by Hackley et al. (2007)

All sampling and analytical measurements will be performed in accordance with project quality assurance requirements. A qualified laboratory will be selected for the groundwater sampling and analysis. All samples will be tracked using appropriately formatted chain-of-custody forms (Attachment 11: QASP, 2023).

The results of the geochemical will be delivered in the form of lab reports. If an anomalous value in a parameter of the aqueous geochemistry is observed in the ACZ, Mahomet Aquifer, or shallow groundwater monitoring zones, new samples will be obtained from the affected zone to verify accuracy of the measurement. The frequency with which fluid samples are obtained for analysis from that zone may also be increased. Anomalous results obtained in the Ironton-Galesville formations may also trigger fluid monitoring of the St. Peter Sandstone as the lowermost USDW.

If anomalous geochemical values are confirmed in ACZ or lowermost USDW fluid samples, the fluid sampling and analysis frequency for the shallow groundwater monitoring wells will also be increased. Anomalous values may also trigger additional well integrity testing in NV_INJ1, NV_INJ2, and NV_OBS1. A combination of anomalous pressure, geochemical, and well integrity testing results may result in the decision to acquire a time-lapse 3D surface seismic survey before the survey scheduled in Year 13 of the PISC (Table 1).

Table 4 presents information about the methods and frequency of pressure monitoring to be used in the NV_ACZ1 and NV_ACZ2 wells. Further detail and specifications on equipment to be used in the NV_ACZ1 and NV_ACZ2 are provided in the QASP (Attachment 11: QASP, 2023). The pressure data will be stored as time stamped data. An increase in pressure in the ACZ monitoring zone is considered the most probable first indication that migration of fluids above the confining zone has occurred. An increase in pressure greater than 2% above baseline values will trigger additional monitoring and inspection to evaluate the cause of the pressure increase.

Additional measures include more frequent fluid sampling and analysis for geochemical parameters and well integrity tests of NV_INJ1, NV_INJ2, or NV_OBS1. Other methods such as temperature or PNL logging may be performed in NV_ACZ1 or NV_ACZ2 as contingency.

Table 4: Sampling and recording frequencies for continuous monitoring in NV_ACZ1 and NV_ACZ2

Parameter	Device(s)	Location	Minimum Sampling Frequency	Minimum Recording Frequency
Pressure	Wellhead Pressure Gauge	NV_ACZ1, NV_ACZ2	Continuous (every hour)	Continuous (every hour)
Pressure	Downhole Pressure Gauge	NV_ACZ1, NV_ACZ2	Continuous (every hour)	Continuous (every hour)

Notes:
- Sampling frequency refers to how often the monitoring device obtains data from the well for a particular parameter. For example, a recording device might sample a pressure transducer monitoring injection pressure once every two seconds and save this value in memory.
- Recording frequency refers to how often the sampled information gets recorded to digital format (such as a computer hard drive). For example, the data from the injection pressure transducer might be recorded to a hard drive once every minute.

3.2 CO_2 Plume and Pressure Front Tracking [40 CFR 146.93(a)(2)(iii)]

The project will employ direct and indirect methods to track the extent of the CO_2 plume and the presence or absence of elevated pressure throughout the PISC phase. Table 5 presents the direct and indirect methods that will be used to monitor the CO_2 plume including the activities, locations, and frequency of sampling.

The quality assurance procedures for seismic monitoring methods will be performed as described in the QASP (Attachment 11: QASP, 2023).

Table 5: Post-injection phase CO_2 plume monitoring

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
Direct Plume Monitoring				
Ironton-Galesville, Eau Claire, Mt. Simon Sandstone Formations	Pulsed Neutron Logging	[redacted]	Exact depth TBD	Year 1, Year 3, Year 5, Year 7, Year 10, Year 15
Indirect Plume Monitoring				
Overburden, Eau Claire, and Mt. Simon Formations	Time-lapse 3D Surface Seismic Data		Sufficient to image area of modeled CO_2 plume	Q1, Year 0 Q1, Year 13

The Pulsed Neutron Logging (PNL) will be received as LAS files and interpreted products that can be imported into the static model. PNL will be used to monitor the distribution and saturation of CO_2 adjacent to the wellbore in NV_INJ1, NV_INJ2, and NV_OBS1. The PNL will be run through the ACZ monitoring zone to verify that there are no accumulations of CO_2 adjacent to the wellbore above the confining zone in NV_INJ1 or NV_INJ2. Technical details on PNL tools can be found in the QASP (Attachment 11: QASP, 2023).

Surface seismic data is delivered in a variety of formats including acquisition and processing reports and SEG-Y data files from a variety of points in the processing flow. In the context of time-lapse analysis, an assessment will be provided on the differences between the baseline and time-lapse surveys as well as data files that can be incorporated into the static model. The injection of CO_2 and expansion of the plume is expected to change the acoustic impedance of intervals within the Mt. Simon Sandstone and increase the time it takes seismic waves to travel through the CO_2 plume over time. Both the acoustic impedance and travel time changes will be used to track CO_2 plume during the PISC phase of the project. In addition, time-lapse analysis metrics such as normalized root mean square (NRMS) and predictability can be used to track the plume. The time-lapse surface seismic data will also be monitored for changes that may suggest that CO_2 has migrated past the confining layer and into the ACZ monitoring zone.

At this time, no direct fluid sampling is planned for the injection zone for the PISC phase of the project. The CO_2 plume is expected to intersect NV_OBS1 within three to five years of the start of injection operations (Figure 2). Once free phase CO_2 breaks through at NV_OBS1, the project will stop taking fluid samples from the Mt Simon Sandstone.

Table 6 presents the direct and indirect methods that will be used to monitor the pressure front.

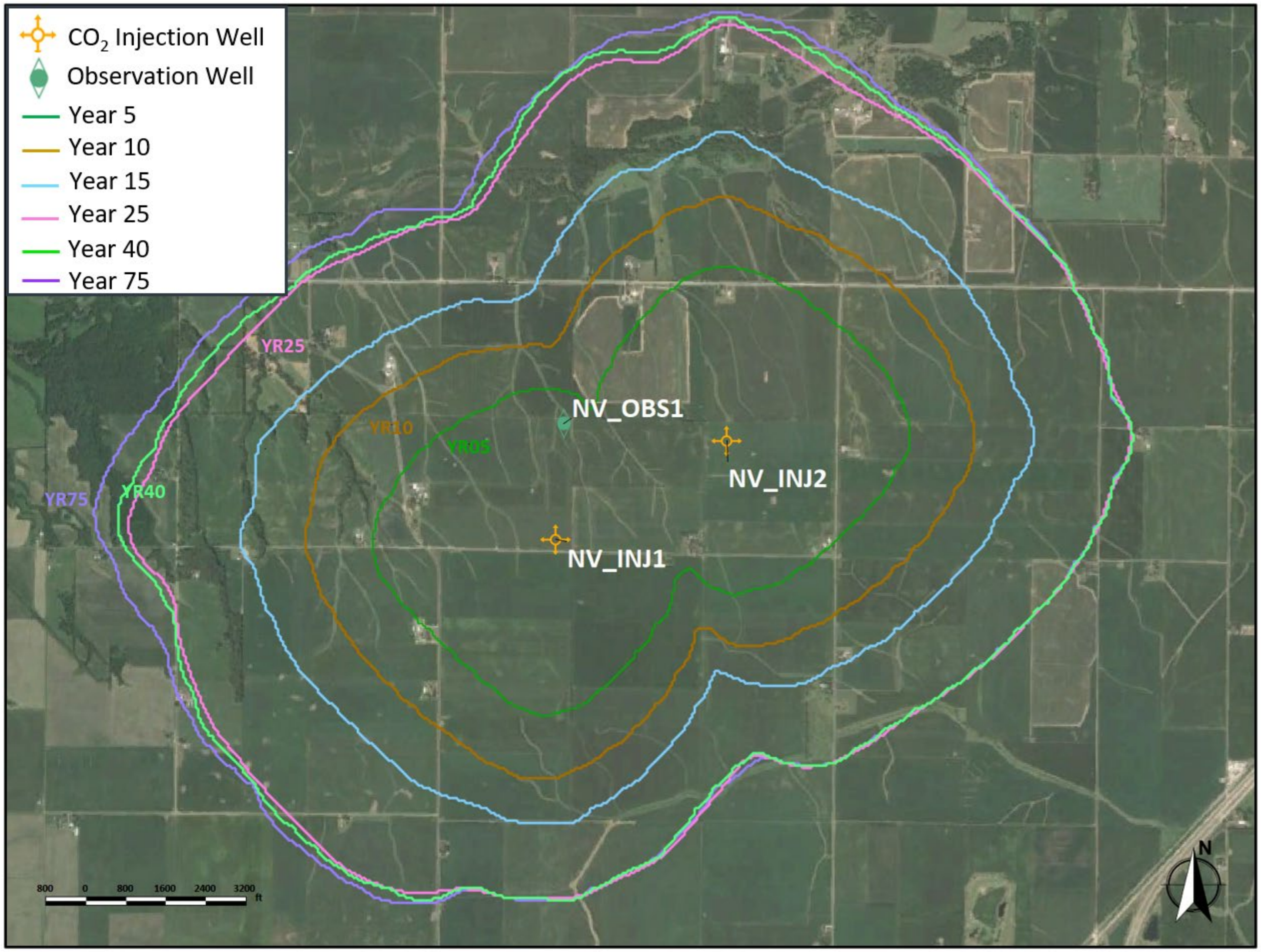

Figure 2: Time-lapse CO_2 plume development map over 5, 10, 15, 25 (injection end), 40 (15 years post injection), and 75 (50 years post injection). Note the relative stability of the CO_2 plume radius after injection operations cease after year 25.

Table 6: Post-injection phase pressure-front monitoring

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
Direct Pressure-Front Monitoring				
Mt. Simon Sandstone	Pressure Monitoring	Sensitive, Confidential, or Privileged Information [redacted]	~5,550 MD feet *TBD	Continuous (Minimum every one minute)
Indirect Pressure-Front Monitoring				
Eau Claire Formation Mt. Simon Sandstone Precambrian Basement	Passive Seismic Monitoring		Events within the pressure front	Continuous (Minimum every 10 seconds)
*Spatial Coverage TBD for NV_OBS1				

The downhole pressure sensors will be programmed to measure and record pressure and temperature data in one-minute intervals. The downhole pressure will be monitored in NV_INJ1 and NV_INJ2 until the bottom hole pressure change is below the delta pressure that has been modeled to occur within nine years. After this time, annual static gradient surveys will be collected from NV_INJ1 and NV_INJ2 via wireline, and pressure monitoring will cease in NV_OBS1.

Should either of the well's BHP gauge fail during the PISC phase while delta pressure is above 137 psi, positive pressure readings at the wellhead will be used to verify continued pressure fall-off until the gauge can be replaced. Should positive pressure at the wellhead no longer be present, a suitable, periodic method of determining hydrostatic fluid level (i.e., shooting fluid levels or similar method) will be used to calculate the BHP until the gauge can be replaced.

The final monitoring interval in the NV_OBS1 will be determined after the well has been drilled and the well logs have been analyzed (Attachment 5: Pre-Op Testing Program, 2023). It is expected to be within the Lower Mt. Simon Sandstone or Arkose zone.

The results of the aqueous geochemistry, PNL, and time-lapse 3D surface seismic data will all be integrated to develop a comprehensive understanding of the CO_2 plume behavior during the PISC phase. PNL and time-lapse 3D surface seismic data can be incorporated into the static model for comparison to the computational modeling predictions at different times. The data can be used to constrain the computational modeling results and produce more accurate plume predictions over the course of the project.

The PNL data will be used to calibrate the computational modeling and provide information on the vertical and horizontal plume behavior as well as supply more detailed and direct measurement of CO_2 saturations than indirect seismic methods. The time-lapse 3D surface seismic data will be used to update the models after the data has been analyzed. If the CO_2 plume monitoring data diverges significantly from the modeled plume predictions, it may result in a reassessment of the AoR as per the AoR and Corrective Action Plan (Attachment 2: AoR and Corrective Action Plan, 2023).

Based on the current computational modeling results, the CO_2 plume is expected to stabilize quickly during the PISC phase of the project (Figure 2). Time-lapse 3D surface seismic surveys acquired during Q1 in Year 0 and Year 13 of the PISC phase of the project will demonstrate the stabilization of the CO_2 plume and be used to verify the computational modeling results.

3.3 Schedule for Submitting Post-Injection Monitoring Results [40 CFR 146.93(a)(2)(iv)]

All PISC monitoring data and results obtained using the methods described above will be submitted to EPA in annual reports. These reports will contain information and data generated during the reporting period (i.e., well-based monitoring data, sample analysis, and results from updated site models).

4. Alternative PISC Timeframe [40 CFR 146.93(c)]

The project will conduct post-injection monitoring for a fifteen-year period following the cessation of injection operations. A justification for this alternative PISC timeframe is provided in this section.

4.1 Computational Modeling Results 40 CFR 146.93(c)(1)(i)

The CO_2 plume is expected to expand to 8.0 square miles (mi^2) after 25 years of injection (Figure 2). It will continue to expand to 8.3 mi^2 after 15 years post injection due to the buoyancy of the CO_2. Gas trapping and CO_2 dissolution in water will continue to increase over time and will mitigate the buoyancy effect to some extent. Expansion after 15 years post injection is less than 5% and therefore the plume is considered stable by 15 years post injection. Additional figures and cross sections on the CO_2 plume development can be found in the AoR and Corrective Action Plan (Attachment 2: AoR and Corrective Action Plan, 2023).

4.2 Predicted Timeframe for Pressure Decline 40 CFR 146.93(c)(1)(ii)

The maximum area of elevated pressure (i.e., AoR) is estimated to be 185 mi^2 after 25 years of injection based on a delta pressure of 137 psi. The computational modeling results show a rapid decline in the size of the AoR once injection operations cease (Figure 3) and that there is no region with delta pressure equal to or greater than the minimum delta pressure of 137 psi after a period of nine years. Figure 4 is a plot of CO_2 injection rate, bottomhole flowing pressure (BHFP), and THP for NV_INJ1 during the injection period and 50 years post injection and shows that the BHFP declines rapidly post injection; Figure 5 provides that same information for NV_INJ2.

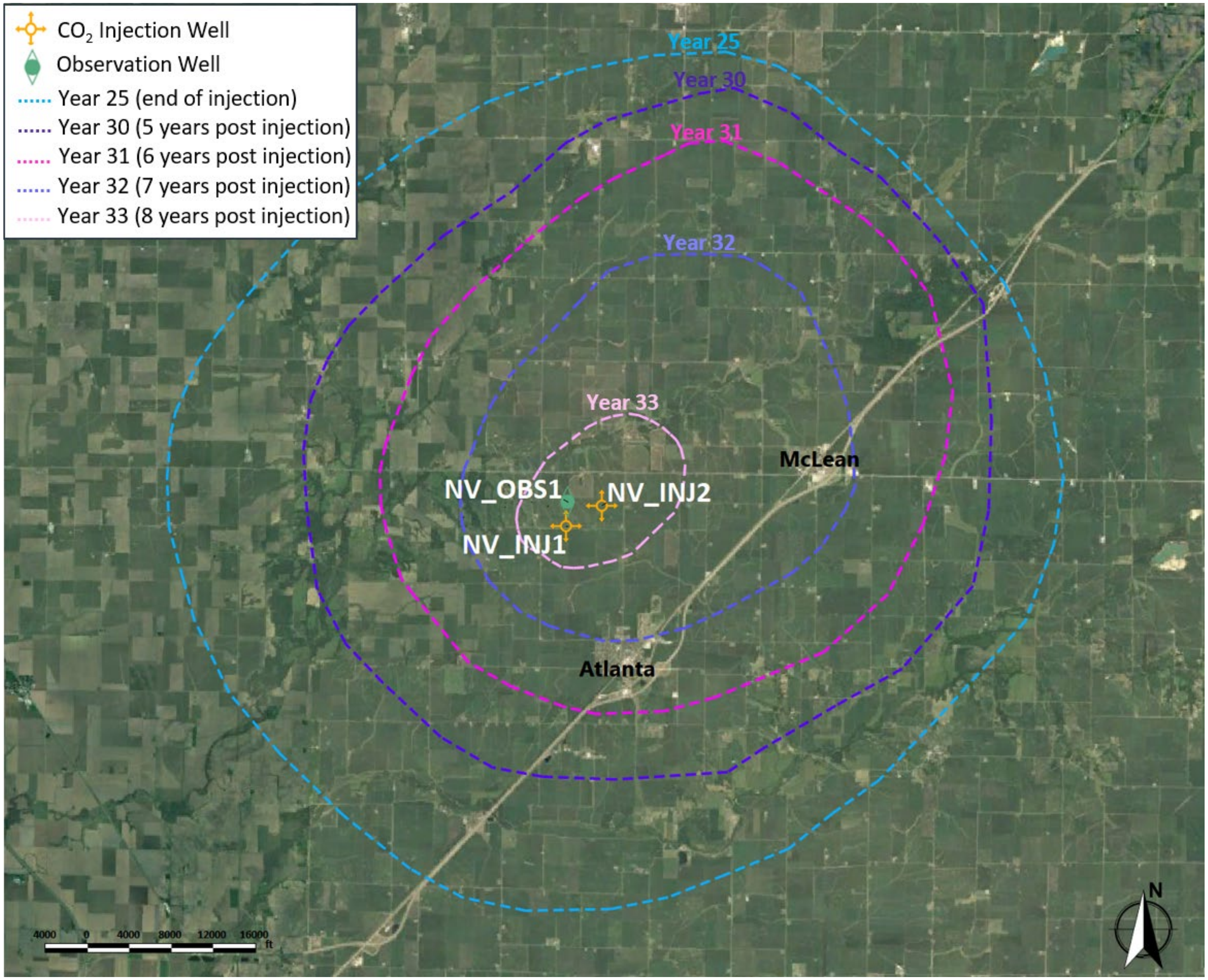

Figure 3: Delta pressure 0, 5-, 6-, 7- and 8-years post injection. The pressure front defined by a change of pressure of 137 psi, recedes progressively and is not present nine years post injection.

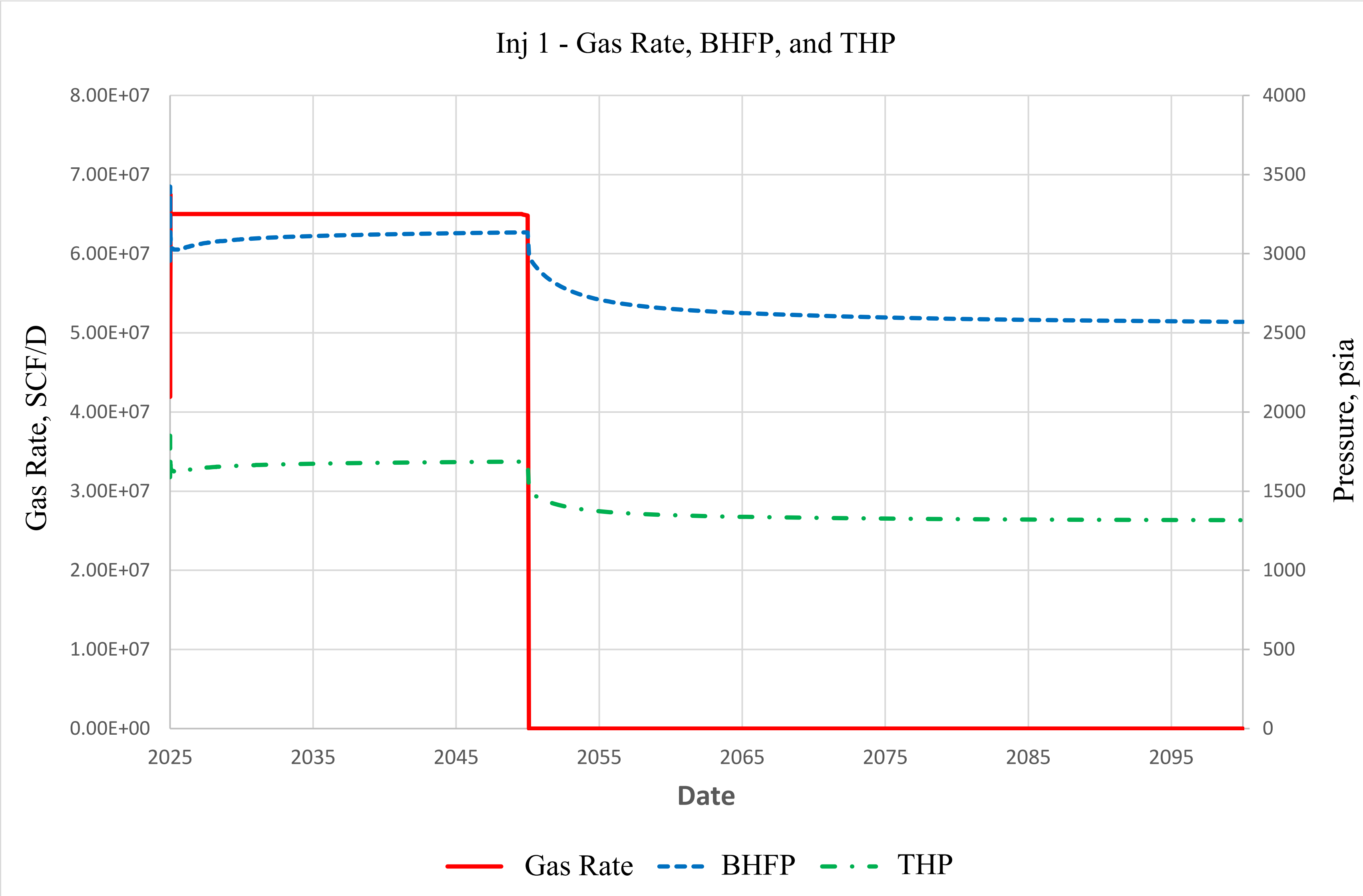

Figure 4: CO_2 injection rate, BHFP, and THP for NV_INJ1 during the injection period and 50 years post injection

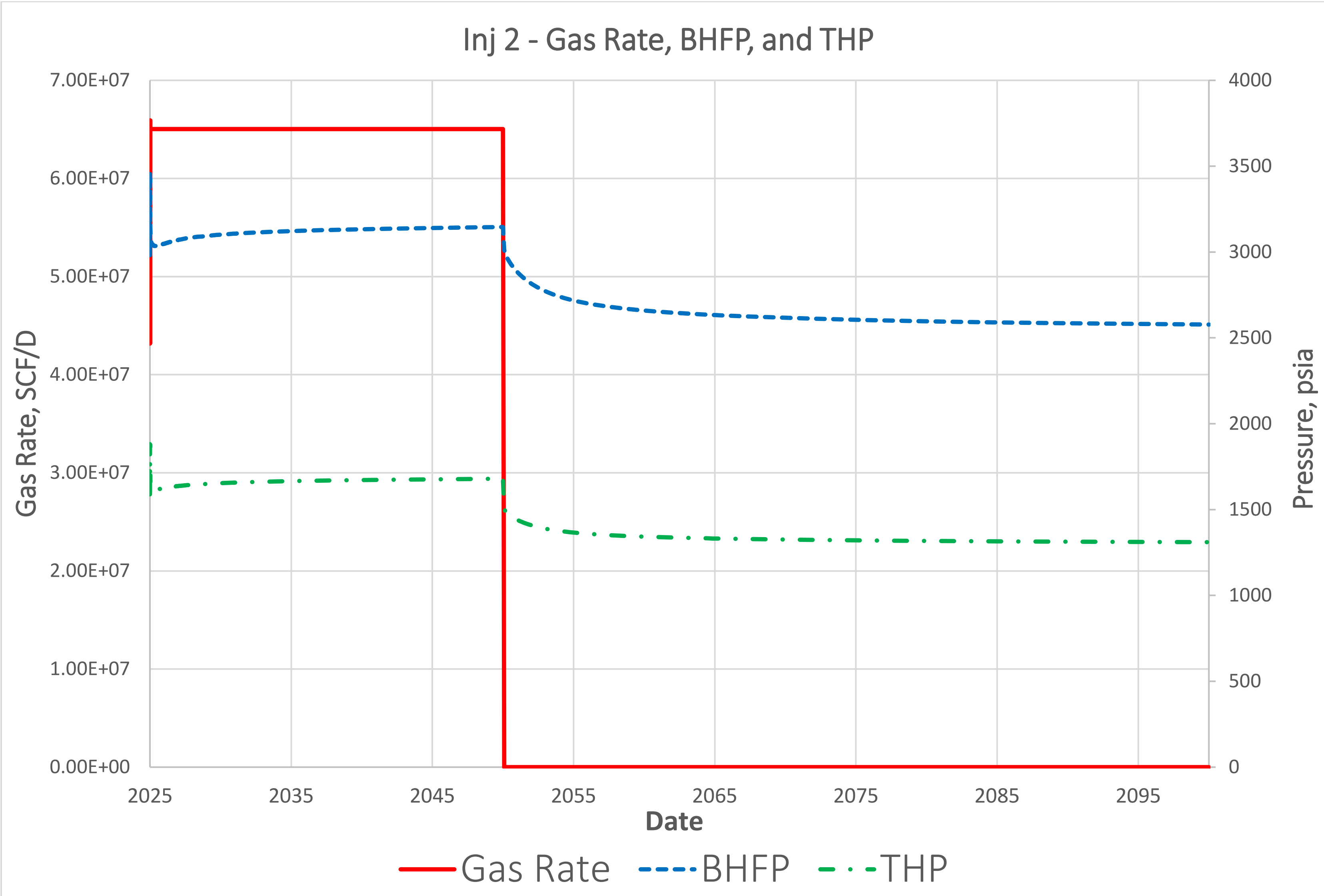

Figure 5: CO_2 injection rate, BHFP, and THP for NV_INJ2 during the injection period and 50 years post injection

4.3 Predicted Rate of Plume Migration 40 CFR 146.93(c)(1)(iii)

The CO_2 plume migration rate varies with time; however, on average, the plume migration rate during the 25-year injection period is 0.064 miles/year or 337 feet per year. The average post injection plume migration rate is 0.001 miles/year or 6.9 feet/year. The average plume migration rate during both the injection and post injection periods is 117 feet per year. The primary factors affecting CO_2 plume migration are the storativity (porosity-height), flow capacity (permeability-height, KH), and the kv/kh ratio of the formation at the injection well site.

Sensitive, Confidential, or Privileged Information

[redacted]

4.4 Site Specific Trapping Processes 40 CFR 146.93(c)(1)(iv)-(vi)

The primary trapping mechanisms considered for this project are structural, residual gas, CO_2 dissolution in water, aqueous ions, and mineralization (Attachment 2: AoR and Corrective Action Plan, 2023). Table 7 shows the proportion of the mass of the injected CO_2 trapped by the five mechanisms at 100 years post-injection. Figure 6 illustrates how the impact of each trapping mechanism changes with time according to the results of the computational modeling.

Table 7: CO_2 trapping mechanisms and percentages trapped 100 years post-injection.

Trapping Mechanism	% CO_2 trapped 100 years post-injection
Structural	44.5
Residual (immobile) gas	40.0
Dissolved gas	12.1
Aqueous ions	3.1
Mineralization	0.3

After 100 years post-injection, 44.5%, of the supercritical CO_2 injected will remain trapped in the injection zone by structural trapping. This is due to an increase in the role of other trapping mechanisms, most notably residual gas trapping and CO_2 dissolution in water. [redacted] The estimated increase in pressure in the confining zone is 10 psi, which results in an almost negligible decrease in effective mean stress. It is highly unlikely that fractures will be created in the confining zone under the planned operating conditions.

Residual gas trapping occurs when the CO_2 moves away from the wellbore through convection and begins to rise due to gravity segregation between the CO_2 and water. The CO_2 can become discontinuous in small pore spaces and residual amounts are trapped. The computational modeling estimated that 40.0% of the CO_2 injected would be trapped through residual gas trapping 100 years post injection. Initially, the gas saturation in the pore space increases as CO_2 is injected (drainage) but decreases as CO_2 migrates upwards (imbibition). The imbibition relative permeability curve is different from the drainage relative permeability curve; this difference is known as relative permeability hysteresis. Hysteresis modeling data for a two-phase system involves a bounding drainage curve, gas relative permeability (krg), and a trapping mechanism function with associated parameters. The trapping function determines the bounding/scanning imbibition curves. Sensitive, Confidential, or Privileged Information [redacted]

Gas solubility trapping is a slower process than residual gas trapping but is also an important mechanism in long-term sequestration. The computational modeling estimated that 12.1% of the CO_2 injected would be trapped by this mechanism 100 years post injection. Solubility trapping is dependent on pressure, temperature, salinity, and surface area contact with the water. The percentage of gas trapped by dissolution increases significantly over time. The solubility correlations are based on Henry's Law, and various models are available in the modeling software including Li-Nghiem and Harvey (Attachment 2: AoR and Corrective Action Plan, 2023). The effect of salinity can be modeled by either the Cramer or Bakker correlations.

The formation of aqueous ions (i.e., a weak acid) will trap 3.1% of the CO_2 injected 100 years post injection. Mineral dissolution and precipitation reactions are very slow, and it is estimated that mineral trapping will be significant only after hundreds or thousands of years post injection. After 100-years post injection, the mineralization of CO_2 accounted for only 0.3% of the total gas trapped (Figure 6).

It is generally accepted by the CCS community that over a period of 10,000 years 90% of the injected CO_2 will be immobilized in the injection zone because of the mechanisms described above. The remaining 10% will continue to be trapped by the confining layer until eventually all the CO_2 becomes immobile.

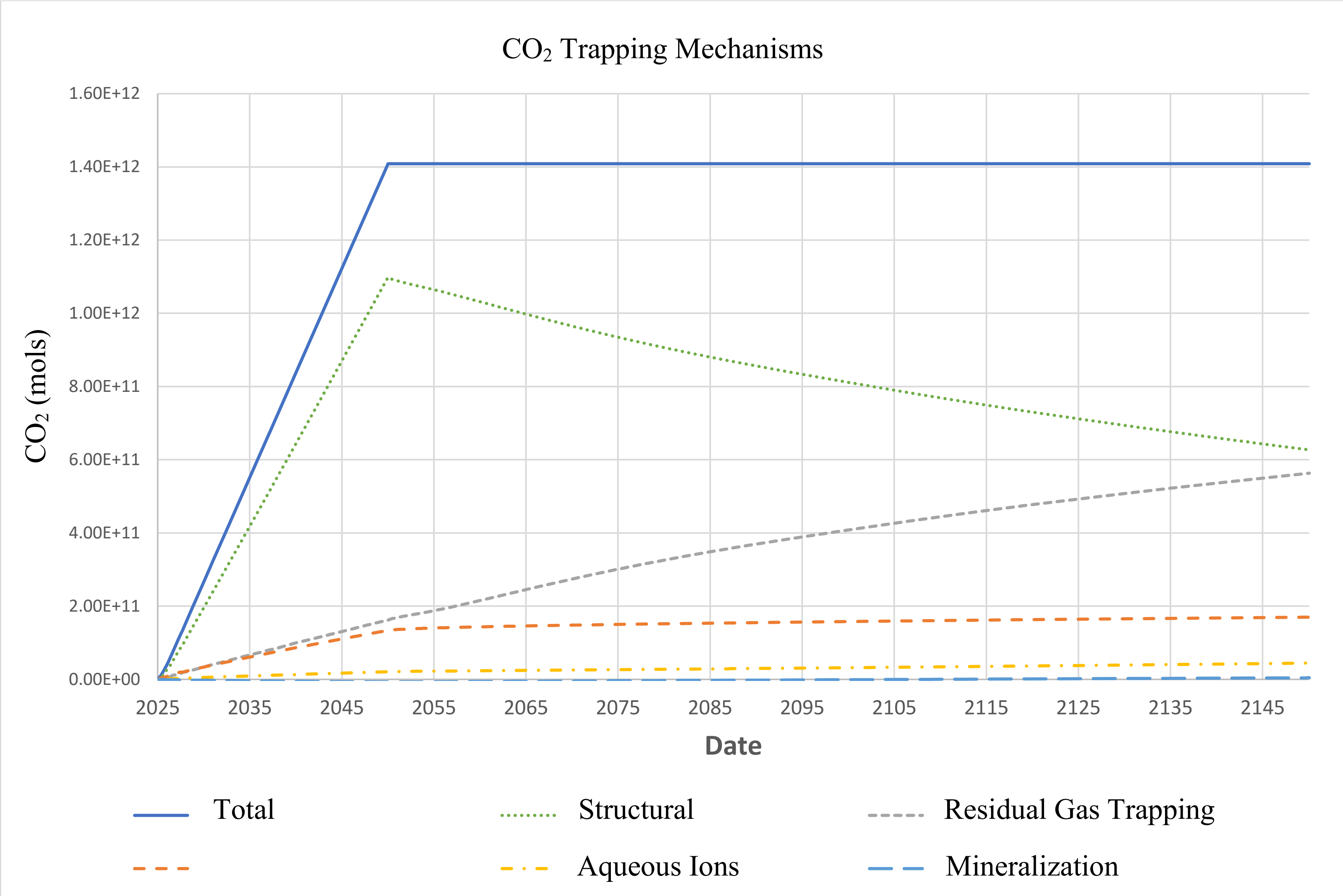

Figure 6: Breakdown of CO_2 mols for structural, residual gas, dissolution, aqueous ions, and mineralization trapping mechanisms during the injection period and 100 years post injection. Note that mineralization is negligible during this period (<1%).

4.5 Confining Zone Characterization 40 CFR 146.93(c)(1)(vii)

The Eau Claire Formation will serve as a competent confining zone for the project and supports the demonstration of the alternative PISC timeframe based on the following characteristics:

- It is predicted to be approximately 400 feet thick at the project site,
- It is laterally extensive, existing across the Illinois Basin,
- It has formation properties (facies, lithology, ductility, porosity, and permeability) across the region that are consistent with it being a barrier to vertical fluid migration,
- It is not penetrated by faults within the project area.

Computational modeling of injection into the Lower Mt. Simon Sandstone and Mt. Simon Sandstone Arkose shows the CO_2 migrating slightly into the Middle Mt. Simon Sandstone and never reaching the Upper Mt. Simon Sandstone or the Eau Claire Formation confining zone. The geomechanical modeling indicates that the pressure exerted on the confining zone within the AoR will not be high enough to compromise the integrity of the formation even if the project were to inject at much higher annual rates (Attachment 1:Project Narrative, 2023). In the post injection phase of the project, injection zone pressures are predicted to decline quickly and return to pre-injection levels within nine years. The risks to confining zone integrity will also decrease significantly as injection zone pressures decrease.

The Project Narrative and the AoR and Corrective Action Plan include further information on the site characterization and computational modeling work that has been completed to support the project (Attachment 1:Project Narrative, 2023), (Attachment 2: AoR and Corrective Action Plan, 2023). As site specific data is collected through the Pre-Operational Testing Program, the static and computational modeling will be updated, and the conclusions regarding the confining zone suitability will be verified or re-evaluated as needed.

4.6 Assessment of Fluid Movement Potential 40 CFR 146.93(c)(1)(viii)-(ix)

The two-dimensional (2D) surface seismic data does not indicate that there are any faults in the immediate area that impact the confining zone (Attachment 1:Project Narrative, 2023).There are no known artificial penetrations of the confining zone within the project AoR (Attachment 2: AoR and Corrective Action Plan, 2023). Sensitive, Confidential, or Privileged Information [redacted] As there are no artificial penetrations of the confining interval within the AoR no corrective action is required for the project. The requirement for corrective action will be re-assessed should the AoR change over the course of the project.

The project plans to monitor the wellhead pressure of NV_ACZ1 and NV_ACZ2, as well as take fluid samples from the ACZ intervals within the Ironton-Galesville Formation during the injection and PISC phases of the project. If any indicators of injection formation fluids are identified within the ACZ monitoring interval, the project wells will be investigated for any potential well integrity issues. It is expected that any migration of injection zone fluids into the ACZ monitoring interval will be identified before any injection zone fluids can intersect any of the shallower well penetrations.

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[redacted]

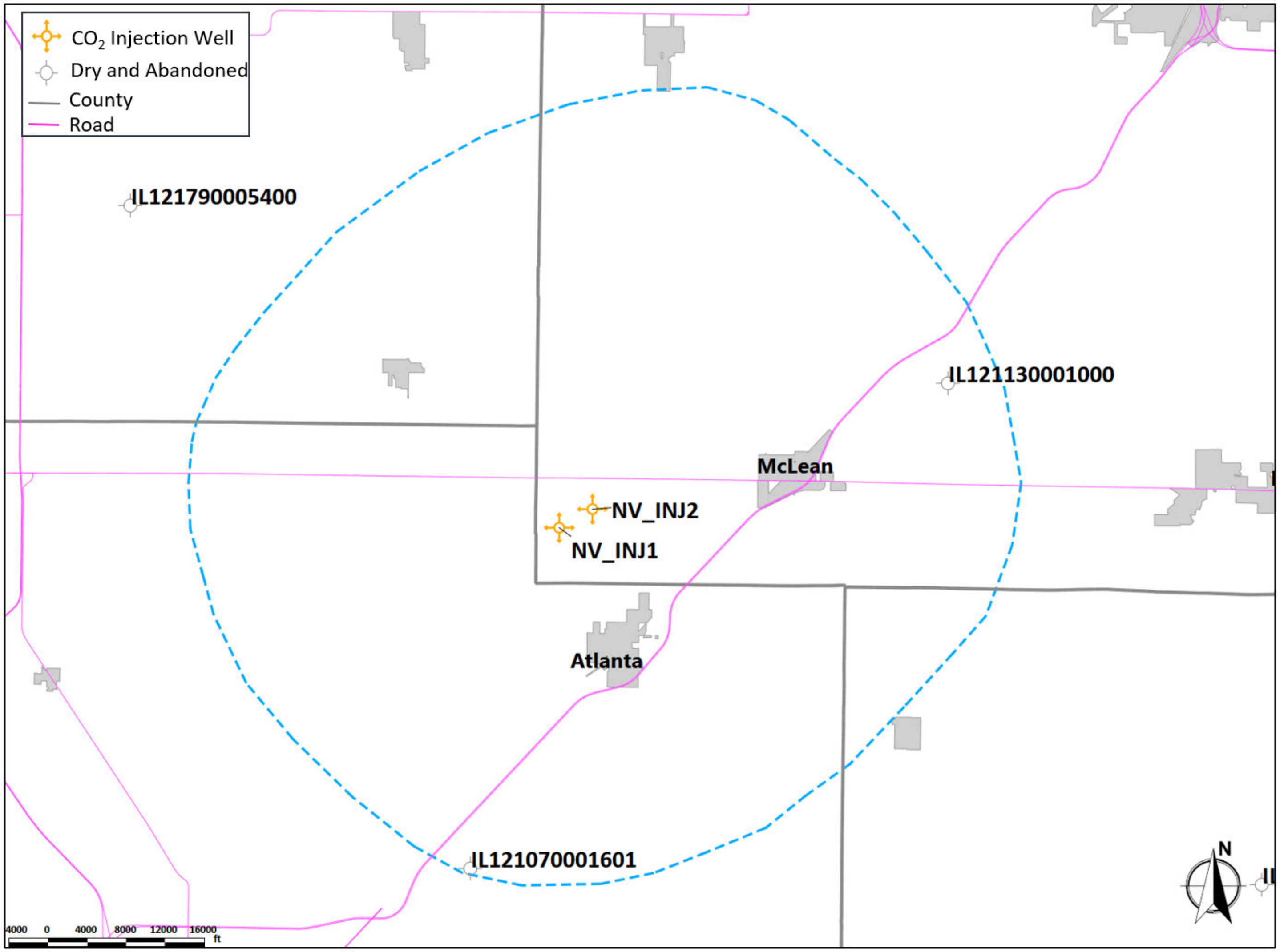

Figure 7: Location of the two wells that penetrate the Trenton Formation within the Vervain AoR.

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[redacted]

Figure 8: Map of the 481 shallow groundwater wells in the AoR.

When the injection wells are drilled and completed, the long string casing will be cemented to surface (Attachment 4A: NV_INJ1 Well Construction Plan, 2023); (Attachment 4B: NV_INJ2 Well Construction Plan, 2023). After cementing is complete, cement integrity will be evaluated along the length of the well using a cement bond log with radial arms, and an ultrasonic cement evaluation tool will be used to evaluate the cement through the injection zone, confining layer, and ACZ interval (Attachment 5: Pre-Op Testing Program, 2023).

Through the injection phase of the project, the integrity of the injection wells will regularly be assessed through continuous wellhead pressure, annular pressure and fluid volume, annual external mechanical integrity, and periodic pressure fall-off tests (Attachment 7: Testing And Monitoring Plan, 2023). During the PISC phase of the project, the well integrity of the injection wells will continue to be monitored through continuous wellhead and downhole pressure, and temperature logging every five years (Table 1). PNL will also be used every second year to identify any CO_2 accumulations adjacent to the wellbore in NV_INJ1, NV_INJ2, and NV_OBS1.

4.7 Location of USDWs 40 CFR 146.93(c)(1)(x)

As discussed in detail in the Project Narrative and Financial Assurance sections, the St. Peter Sandstone is expected to be the lowermost USDW with a depth of 2,233 fbgl (Attachment 1:Project Narrative, 2023). [redacted] This calculation is based on the regional ISGS aquifer mapping, and the St. Peter Sandstone was confirmed to be the lowermost USDW at the IBDP site (35 miles to the southeast of the Vervain Project Site, (Attachment 1:Project Narrative, 2023; Attachment 3: Financial Assurance, 2023). [redacted] During the post injection phase of this project, the vertical extent of injected CO_2 is relatively consistent, and the CO_2 is expected to remain in the injection zone.

5. Non-Endangerment Demonstration Criteria

Prior to approval of the end of the post-injection phase, Heartland Greenway Carbon Storage, LLC (HGCS) will submit a demonstration of non-endangerment of USDWs to the UIC Program Director, per 40 CFR 146.93(b)(2) and (3).

The owner or operator will issue a report to the UIC Program Director. This report will make a demonstration of USDW non-endangerment based on the evaluation of the site monitoring data used in conjunction with the project's computational model. The report will detail how the non-endangerment demonstration evaluation uses site-specific conditions to confirm and demonstrate non-endangerment. It will also include all relevant monitoring data and interpretations upon which the non-endangerment demonstration is based, model documentation and all supporting data, and any other information necessary for the UIC Program Director to review the analysis. The report will include the following sections.

5.1 Introduction and Overview

A summary of relevant background information will be provided, including the operational history of the injection project, the date of the non-endangerment demonstration relative to the post-injection period outlined in this PISC and Site Closure Plan, and a general overview of how monitoring and modeling results will be used together to support a demonstration of USDW non-endangerment.

5.2 Summary of Existing Monitoring Data

A summary of all previous monitoring data collected at the site, pursuant to the Testing and Monitoring Plan and this PISC and Site Closure Plan, including data collected during the injection and post-injection phases of the project, will be submitted to help demonstrate USDW non-endangerment (Attachment 7: Testing And Monitoring, 2023). Data submittals will be in a format acceptable to the UIC Program Director [40 CFR 146.91(e)], and will include a narrative explanation of monitoring activities, including the dates of all monitoring events, changes to the monitoring program over time, and an explanation of all monitoring infrastructure that has existed at the site. Data will be compared with baseline data collected during the site characterization and pre-operational phases of the project [40 CFR 146.82(a)(6) and 146.87(d)(3)] (Attachment 5: Pre-Op Testing Program, 2023).

5.3 Summary of Computational Modeling History

The computational modeling demonstrates non-endangerment of USDWs in several ways:

- Computational modeling indicates that the CO_2 plume migrates vertically only into the Middle Mt. Simon Sandstone over the operational and PISC phases of the project, and never contacts the Eau Claire Formation,
- The CO_2 plume stabilizes quickly once injection operations cease (Figure 2),
- Injection zone pressures decline rapidly once injection operations cease and will fall below the delta pressure of 137 psi after nine years (Section 4.2),
- Residual gas, gas solubility, aqueous ions, and mineralization trapping of the CO_2 will increase with time and contribute to trapping the CO_2 more effectively than structural trapping alone (Section 4.4)
- Geomechanical modeling shows that integrity of the confining layer will not be impacted by planned injection rates and would be maintained at even higher annual injection rates (Attachment 1:Project Narrative, 2023).

Table 8 summarizes the monitoring data that will be used to verify and calibrate the computational modeling and support the demonstration of non-endangerment of USDWs.

Table 8: Summary of monitoring data that will be used to verify and calibrate the computational modeling and support the demonstration of non-endangerment of USDWs.

Monitoring Data	Location	Demonstration of Non-Endangerment
Injection Zone Pressure	NV_INJ1, NV_INJ2 NV_OBS1	Monitor and verify that injection zone pressures are declining as predicted
PNL	NV_INJ1, NV_INJ2 NV_OBS1	Monitor vertical plume development adjacent to wellbores
Time-lapse 3D Surface Seismic Data	Area sufficient to image modeled area of CO_2 plume	Stabilization of the CO_2 plume once injection operations cease
Passive Seismic Monitoring	Events within pressure front around injectors	Decrease in induced seismic events will demonstrate declining pressures in the injection zone

The monitoring data will be compared to predicted properties from the computational model such as vertical and horizontal plume location, rate of movements, and pressure decline. These data will be used to verify that computational model predictions accurately represent CO_2 plume and pressure front behavior and that they can be confidently used as proxy for future plume behavior. The monitoring and modeling results will be compared using maps and graphs of the CO_2 plume and pressure front development over time. If there is inconsistency between modeling and monitoring results at the time of the demonstration, the models will be updated to reflect the monitoring results.

5.4 Evaluation of Reservoir Pressure

Injection zone pressures will be monitored on a continuous basis in NV_INJ1, NV_INJ2, and NV_OBS1 (Table 8) until the pressure change is below the delta pressure. Thereafter static gradient surveys will be performed annually in NV_INJ1 and NV_INJ2, and BHP will no longer be monitored in NV_OBS1. Pressure decreases predicted by the model can be compared to the monitor data at regular intervals to verify and calibrate the model during the PISC phase.

If CO_2 injection operations result in induced seismicity, it is expected that the rate of the events generated will decrease as injection zone pressure decreases. The rates of induced seismicity will provide further qualitative information about the decrease in pressure throughout the injection zone during the PISC phase.

Increased pressure in the injection zone is one of the main drivers for fluid migration through the confining layer via conduits such as well penetrations. As the injection zone pressure decreases during the PISC phase so too will the risk of fluid migration out of the injection zone and the potential risk to USDWs.

5.5 Evaluation of CO_2 Plume

Table 8 summarizes the monitoring data that will be used to evaluate the extent of the CO_2 plume starting in Year 1 of the PISC phase until the pressure is below the delta pressure of 137 psi. PNL logging will be used to monitor the distribution and saturation of CO_2 adjacent to the wellbore in NV_INJ1, INJ2, and NV_OBS1 every second year. The PNL will be run through the ACZ monitoring zone to verify that there are no accumulations of CO_2 adjacent to the wellbore above the confining layer in NV_INJ1, NV_INJ2, and NV_OBS1.

The time-lapse 3D surface seismic data will be acquired in Year 0 and Year 13 of the PISC phase. Data from these surveys will be used demonstrate the stabilization of the CO_2 plume predicted by the computational modeling once injection ceases. The data will also be used to confirm the continued absence of any accumulations of CO_2 above the confining zone within the CO_2 plume extent.

5.6 Evaluation of Emergencies or Other Events

Table 9 provides a summary of the monitoring data that will be used to demonstrate that injection zone fluids have not migrated above the confining layer. Data acquired through the injection and PISC phases of the project will be compared to the baseline data gathered for the project to ensure that there are no indications that injection zone fluids have migrated into the ACZ monitoring interval. If the PISC monitoring data shows no significant changes from the baseline data, it will demonstrate the integrity of the confining layer and that injection zone fluids are not an endangerment to USDWs.

Table 9: Summary of monitoring data used to demonstrate non-endangerment of USDWs.

Monitoring Data	Location	Demonstration of Non-Endangerment
ACZ Pressure	NV_ACZ1, NV_ACZ2	• No pressure increases that could indicate fluid migration out of injection zone
ACZ Fluid Sampling	NV_ACZ1, NV_ACZ2	• No geochemical indicators of fluid migration out of injection zone • Includes changes to salinity
Temperature Logging	NV_INJ1, NV_INJ2 NV_OBS1	• No CO_2 migration along the wellbores
PNL	NV_INJ1, NV_INJ2 NV_OBS1	• No CO_2 accumulations adjacent to wellbores • No increase in salinity adjacent to wellbores
Time-lapse 3D Surface Seismic Data	Area sufficient to image modeled area of CO2 plume	• Verify the absence of CO_2 accumulations
Passive Seismic Monitoring	Events within the pressure extent	• Monitor for seismic events in the confining layer that might indicate issues with confining zone integrity

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[redacted] The maximum extent of the pressure front at the end of injection (Year 25) is predicted to be 8.3mi^2. The closest well that penetrates the storage interval will still be more than 13 miles away from the maximum AoR extent. No other conduits for fluid flow through the confining layer have been identified in the AoR (Attachment 1:Project Narrative, 2023).

The well integrity of the NV_INJ1 and NV_INJ2 will be thoroughly assessed during the Pre-Operational Testing Program using Cement Bond Logs and Variably Density Logs (CBL-VDL) as well as ultrasonic cement evaluation tools that will be run specifically over the injection zone, confining layer, and ACZ monitoring interval (Attachment 5: Pre-Op Testing Program, 2023).

During the injection phase, the well integrity of NV_INJ1 and NV_INJ2 will be continuously monitored using wellhead pressure gauges and annular pressure and fluid volume levels for any indications that there may be problems (Attachment 7: Testing And Monitoring Plan, 2023). Wellhead and downhole pressures will continue be monitored in NV_INJ1 and NV_INJ2 during the PISC phase. HGCS will continue to run temperature logs at a maximum of every five years and PNL logs every second year starting in Year 1 until pressure dissipation to ensure that NV_INJ1, NV_INJ2, and NV_OBS1 are not providing a conduit for injection zone fluids to migrate above the confining layer.

The Emergency and Remedial Response Plan (ERRP) includes further discussion of how emergencies or other events will be addressed by the project (Attachment 10: ERRP, 2023).

6. Site Closure Plan

HGCS will conduct site closure activities to meet the requirements of 40 CFR 146.93(e) as described below. HGCS will submit a final Site Closure Plan and notify the permitting agency at least 120 days prior of its intent to close the site. Once the permitting agency has approved closure of the site, HGCS will plug the monitoring wells and submit a site closure report to EPA. The activities, as described below, represent the planned activities based on information provided to the EPA. The actual site closure plan may employ different methods and procedures. A final Site Closure Plan will be submitted to the UIC Program Director for approval with the notification of the intent to close the site.

6.1 Plugging Monitoring Wells

As discussed in the testing and monitoring section of the application, there will be several dedicated monitor wells (Attachment 7: Testing And Monitoring Plan, 2023). Of those presented in the section, the NV_OBS1, NV_ACZ1, and NV_ACZ2 wells will be plugged as part of the site closure process.

This subsection serves to provide the methods and procedures that will be utilized to plug each of the wells. In addition to discussing the methodology and procedures to be utilized, schematics displaying the anticipated layout of the well following completion of the plugging and abandonment (P&A) operations are provided. The cost estimates developed for these activities are provided in the Financial Assurance section of this application.

6.1.1 NV_OBS1 Plugging and Abandonment

The techniques used to P&A NV_OBS1 will be similar to those applied to NV_INJ1 and NV_INJ2, as discussed in the plugging and abandonment (P&A) sections for the injection wells(Attachment 8A: NV_INJ1 Well Plugging Plan, 2023), (Attachment 8B: NV_INJ2 Well Plugging Plan, 2023). CO_2 resistant cement will be placed from the bottom of the well, to above the confining zone, then normal cement will be used above that.

Cement volumes are anticipated to be lower than those used for the injection well as NV_OBS1 will use smaller sized tubulars. The cement volumes to be used to P&A the NV_OBS1 well will be finalized following the installation of the well. Figure 9 displays the proposed P&A schematic for NV_OBS1

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[redacted]

6.1.2 NV_ACZ1 and NV_ACZ2 Plugging and Abandonment

The techniques used to P&A NV_ACZ1 and NV_ACZ2 will be similar to those applied to NV_OBS1, NV_INJ1, and NV_INJ2 (Attachment 8A: NV_INJ1 Well Plugging Plan, 2023), (Attachment 8B: NV_INJ2 Well Plugging Plan, 2023). Normal cement will be placed from the bottom of the well to surface.

Cement volumes are anticipated to be lower than those used for the injection well as NR_ACZ1 and NV_ACZ2 are shallower wells that use smaller sized tubulars. The cement volumes to be used to P&A the NV_ACZ1 and NV_ACZ2 will be finalized following the installation of the wells.

Figure 10 and Figure 11 display the P&A schematics for NV_ACZ1 and NV_ACZ2.

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[redacted]

Figure 10: NV_ACZ1 Well Plugging and Abandonment Schematic

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[redacted]

Figure 11: NV_ACZ2 Well Plugging and Abandonment Schematic

6.2 Site Closure Report

In accordance with 40 CFR 146.93(f), a site closure report will be prepared and submitted within 90 days following site closure, documenting the information required by 40 CFR 146.93(f), as applicable, including but not limited to the following:

- Plugging of the monitor wells as well as NV_INJ1 and NV_INJ2 if they have not previously been plugged,
- Location of abandoned NV_INJ1 and NV_INJ2 on a plat of survey that has been submitted to the local zoning authority,
- Notifications to state and local authorities as required at 40 CFR 146.93(f)(2),
- Records regarding the nature, composition, and volume of the injected CO_2, and
- Post-injection monitoring records.

In accordance with 40 CFR 146.93(g), HGCS will record in the real property records of the county where the project is located notice of the property tracts integrated for the sequestration facility and proper notice of the injection wells that will include the following:

- That the property was used for CO_2 sequestration,
- The name of the local, state, federal, etc. agencies to which a plat of survey with NV_INJ1 and NV_INJ2 locations were submitted,
- The volume of fluid injected,
- The formation into which the fluid was injected, and
- The period over which the injection occurred.

In accordance with 40 CFR 146.93(h), the site closure report will be submitted to the permitting agency (EPA) and maintained by the owner or operator for a period of ten (10) years following site closure. Additionally, the owner or operator will maintain the records collected during the post-injection period for a period of fifteen (15) years after which these records will be delivered to the UIC Program Director

6.3 Quality Assurance and Surveillance Plan

The Quality Assurance and Surveillance Plan is presented in (Attachment 11: QASP, 2023).

7. References

(2023). *Attachment 1:Project Narrative.* Class VI Permit Application Project Narrative; Vervain.

(2023). *Attachment 10: ERRP.* Class VI Permit Application Emergency And Remedial Response Plan; Vervain.

(2023). *Attachment 11: QASP.* Class VI Permit Application Quality Assurance and Surveillence Plan; Vervain.

(2023). *Attachment 2: AoR and Corrective Action Plan.* Class VI Permit Application Area Of Review And Corrective Action Plan; Vervain.

(2023). *Attachment 3: Financial Assurance.* Class VI Permit Application Financial Responsibility; Vervain.

(2023). *Attachment 4A: NV_INJ1 Well Construction Plan.* Class VI Permit Application Injection Well #1 Construction Plan; Vervain.

(2023). *Attachment 4B: NV_INJ2 Well Construction Plan.* Class VI Permit Application Injection Well #2 Construction Plan; Vervain.

(2023). *Attachment 5: Pre-Op Testing Program.* Class VI Permit Application Pre-Operational Formation Testing Program; Vervain.

(2023). *Attachment 7: Testing And Monitoring Plan.* Class VI Permit Application Testing And Monitoring Plan; Vervain.

(2023). *Attachment 8A: NV_INJ1 Well Plugging Plan.* Class VI Permit Application Injection Well #1 Plugging Plan; Vervain.

(2023). *Attachment 8B: NV_INJ2 Well Plugging Plan.* Class VI Permit Application Injection Well #2 Plugging Plan; Vervain.