TESTING AND MONITORING PLAN
40 CFR 146.90

One Earth CCS

Facility Information

Facility name: One Earth Sequestration, LLC
OES #1

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Well location: McLean County, IL
40.845427°N, -88.480010°W (NAD 1983)

This Testing and Monitoring Plan describes how One Earth Sequestration, LLC will monitor the One Earth CCS project activities pursuant to 40 CFR 146.90. The data acquired by the monitoring and testing procedures will be used to demonstrate that injection wells are operating as planned, that the carbon dioxide (CO_2) plume and pressure front are evolving as predicted, and that there is no endangerment to underground sources of drinking water (USDW). Additionally, the monitoring and testing data will be used to validate and refine geological models and simulations used to forecast the distribution of the CO_2 within the storage zone, support AoR re-evaluations, and to demonstrate non-endangerment. Results of the testing and monitoring activities described below may trigger action according to the Emergency and Remedial Response Plan.

Overall Strategy and Approach for Testing and Monitoring

This Testing and Monitoring Plan describes how the One Earth Sequestration, LLC will monitor the site pursuant to 40 CFR 146.90.

Figure 1 and **Figure 2** provide a plan view and cross section of the Area of Review (AoR). The AoR and Corrective Action Plan discuss the technical basis for determination of the AoR and how monitoring data will be used to re-evaluate the AoR during the injection phases of the project (40 CFR 146.84 (e)). Data from a characterization well drilled specifically for this project (OEE #1) were used to develop the static earth model (SEM) and perform multi-phase flow modeling (See Narrative). The results of the modeling and simulations are the basis for determining the AoR and were used to develop the Testing and Monitoring Plan. The AoR will be reevaluated upon completion and testing of the injection wells if new data are obtained from the wells that may significantly change model predictions and the delineated AOR.

Sensitive, Confidential, or Privileged Information [redacted] Three injection wells are planned for the site (**Table 1**).

The Corrective Action Plan indicates that there are/are no penetrations (except for OEE #1) within the AoR that penetrate the confining units including the Eau Claire Formation, the primary seal. OEE #1 will be utilized as an In-Zone Monitoring (IZM) well.

The Testing and Monitoring Plan has been developed to identify and reduce risks associated with CO_2 injection into the subsurface. Goals of the monitoring strategy include:

- Meet the regulatory requirements of 40 CFR 146.90
- Protect underground sources of drinking water (USDW)
- Ensure that each injection well is operating as planned
- Ensure that each injection well is maintained as planned
- Provide data to validate and calibrate the geological and dynamic models used to predict the distribution of CO_2 within the injection zone
- Support AoR re-evaluations over the course of the project

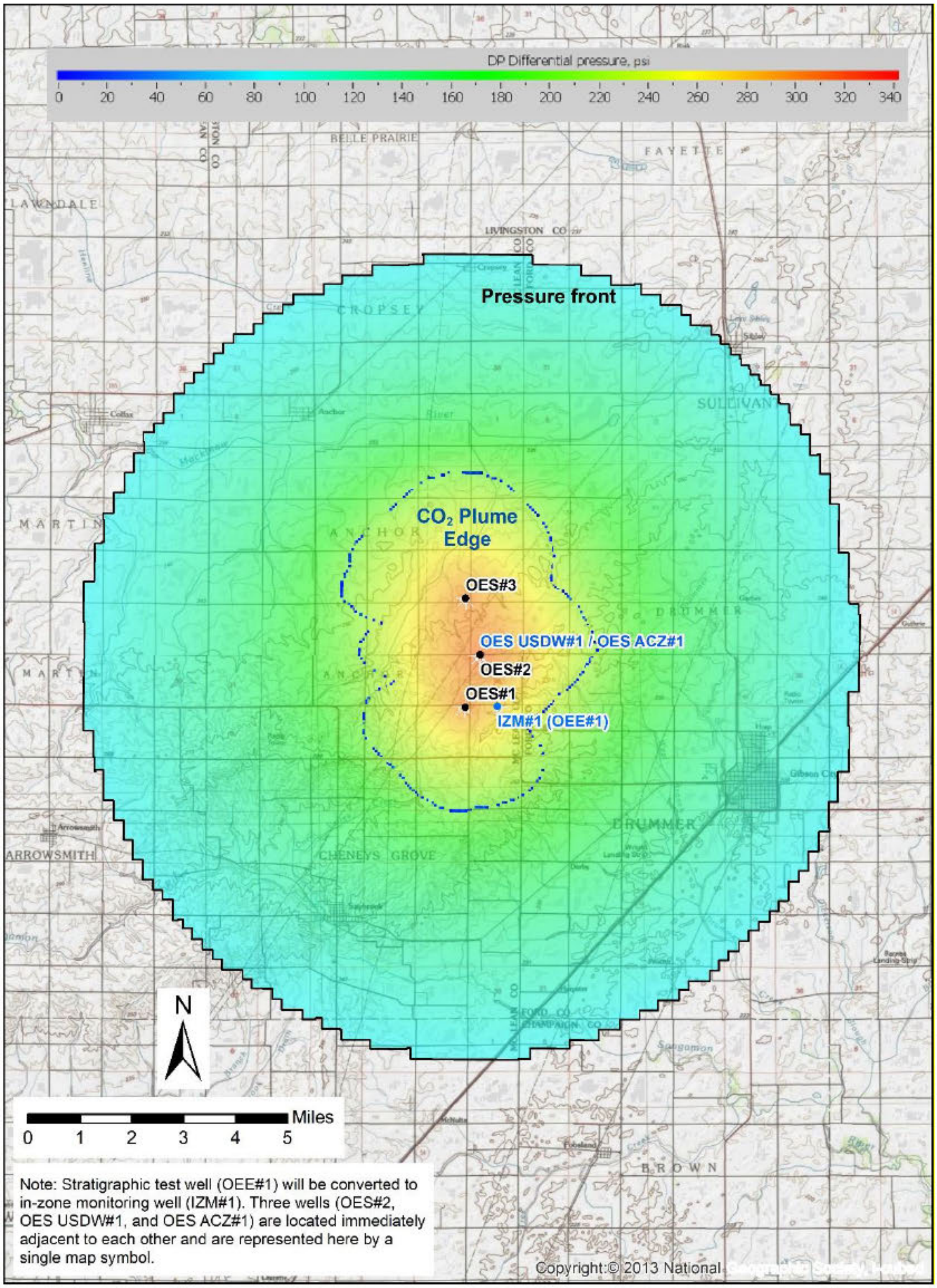

***Figure 1**. Project Area of Review. CO_2 plume and pressure front through active injection of 90 million tonnes.*

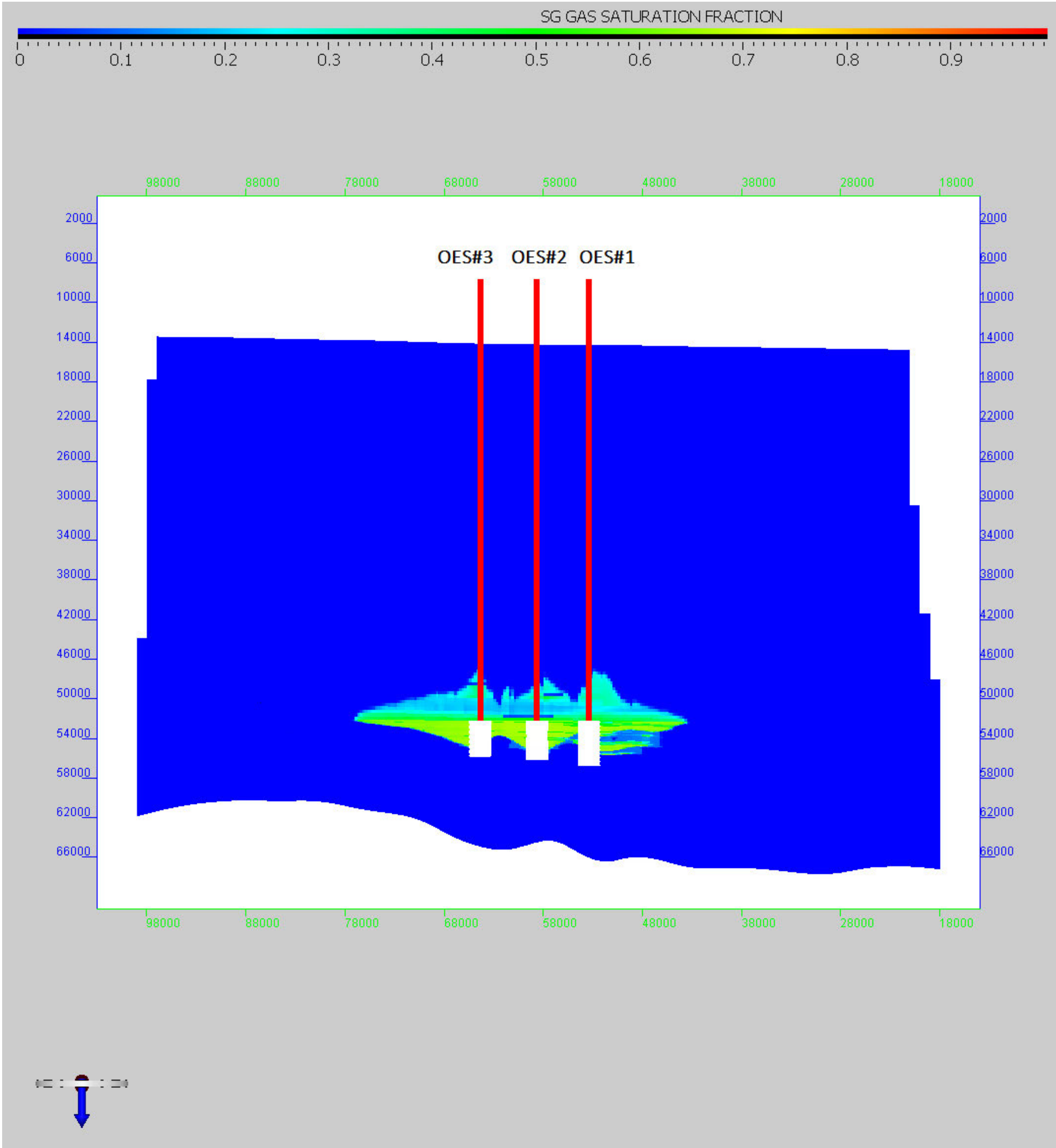

Figure 2*. Cross section of Area of Review pressure front and CO_2 plume at the end of injection.*

The Testing and Monitoring Plan will utilize direct and indirect monitoring technologies that will monitor:

- Injectate composition to demonstrate that it is consistent with the permit 40 CFR 146.90(a)
- Corrosion of well materials and components (40 CFR 146.90(c))
- Determine whether CO_2 or brine has migrated above the Confining Zone (ACZ) (40 CFR 146.90(d))
- USDW groundwater quality (40 CFR 146.95(f)(3)(i))
- Well integrity over the injection phase of the project (40 CFR 146.89(c) and 146.90)
- Near well-bore environment using pressure fall-off testing (40 CFR 146.90(f))
- Development of the CO_2 plume and pressure front in the storage formation over time (40 CFR 146.90(g))

Injection operations will be monitored using a range of techniques and methods as required by 40 CFR 146.88(e) and 146.90(b). Injection operations are discussed in more detail in Narrative Section: Well Operation. Continuous recording devices will monitor wellhead injection pressure, temperature, and flow rate (40 CFR 146.90 (b)). A Coriolis flow meter, which measures mass flow rate directly, or an orifice meter which measures flow volume with a calculated mass flow rate, will be installed on the injection line at surface.

The annular pressure between the tubing and the injection casing strings and the annular fluid volumes also will be monitored on a continuous basis (40 CFR 146.90 (b)). These data will be linked into a supervisory control and data acquisition (SCADA) system to record the operations data, control injection rates, or initiate system shutdown, if needed. The SCADA system can also be used to adjust the volume of annular fluid, and thereby pressure, in the annular space to meet the operational and regulatory objectives. Pressure and temperature will be measured continuously using pressure gauges to establish a wellhead-to-packer pressure correlation. This correlation can be used to calculate the injection pressure at the reservoir (perforated interval) at any time using the wellhead and downhole pressure data. The reservoir pressures and temperatures will also be used to calculate the injection rate at the reservoir, and the injection volumes will be used to update the computational models at regular intervals throughout the injection phase of the project (AoR and Corrective Action Plan).

Pre-operational logging and testing (See Narrative) will establish baseline mechanical integrity of the injection wells. External mechanical integrity will be monitored continuously using distributed temperature sensors (DTS) mounted to the exterior of the injection well casing and cemented into place. External mechanical integrity will be confirmed through annual logging and compared back to baseline logging data to identify deflections from that could indicate fluid flow behind the casing (40 CFR 146.90 (e)). Annual testing will include oxygen activation logging, temperature logging (wireline or DTS), or noise logging.

Monitoring wells will be used to evaluate the plume and pressure front development in the injection zone, and to assure containment and protection of USDWs. The injection wells and IZM wells will be used for wireline logging and will be equipped with gauges and instrumentation to measure pressure (downhole gauge), temperature (DTS) and acoustics (DAS). These wells will provide DTS and DAS data along the length of the well from above the perforated interval to above the lowermost USDW. The IZM wells will be utilized for fluid sampling (fluid sampling will be discontinued once there is CO_2 breakthrough at the well). Above confining zone (ACZ) monitoring wells will include a well set in the brine-saturated zone above the primary confining unit and a well in the lowermost USDW. These wells will be used for fluid sampling and will be equipped with pressure gauges.

A summary of the monitoring well type and well ID is shown in Table 1. Proposed well locations are shown in **Figure 1**.

Table 1. *One Earth CCS well summary.*

Well Type	Well ID	Notes
Injection	OES #1	Sensitive, Confidential, or Privileged Information [redacted]
	OES #2	
	OES #3	
IZM	IZM #1	
	IZM #2	
ACZ	OES USDW #1	
	OES ACZ #1	
Geophysical Monitoring Wells	TBD	

All monitoring locations are either on One Earth CCS property or will be accessible through property access agreements with the landowner. Other monitoring will include annular pressure monitoring for the injection wells and corrosion monitoring.

To date, One Earth Sequestration, LLC (OWNER) has successfully negotiated surface land access for purposes of drilling the stratigraphic well, and pre-injection (baseline) monitoring activities such as 2D and 3D seismic testing. The OWNER's proven ability to work with local landowners and public entities to obtain access to surface and subsurface areas for activities related to the project should be sufficient to demonstrate the OWNER's ability to obtain access for monitoring, and corrective actions (if they are necessary) in the future. The OWNER may acquire, by lease or purchase, additional land parcel areas and surface entry rights for the injection, monitoring, and surface and sub-surface infrastructure. Monitoring well locations could change slightly but only to the extent that they retain their monitoring intent as described in the Testing and Monitoring Plan (QASP). Monitoring locations will also consider access routes that minimize property damage, crop loss, and property owner inconvenience. And to assure safe access to each location.

The Testing and Monitoring Plan will be adaptive over time in that the plan can be adjusted to respond:

- As project risks evolve over the course of the project
- If significant differences between the monitoring data and dynamic simulation predictions are identified
- If monitoring indicates anomalous results related to well integrity or the loss of containment.

Table 2 presents the general schedule and spatial extent for the monitoring activities in the baseline and injection phases of the project based on the current understanding of the site. The monitoring program will follow the Testing and Monitoring plan to establish that CO_2 injection is occurring in a stable and predictable manner. If, however, anomalous results are identified in the monitoring data, changes to the monitoring schedule or methods may be required. Changes to the Testing and Monitoring Plan will be made in consultation with the UIC Program Director (40 CFR 146.90 (j)).

***Table 2**. Testing and monitoring activities summary for the One Earth CCS project.*

Monitoring Activity	Baseline Data Frequency	Injection Phase Frequency	Location
Operational Monitoring			
CO_2 Injectate Compositional and Isotopic Analysis	Once	Quarterly	CO_2 Delivery Pipeline
Corrosion Coupon Analysis	NA	Quarterly years 1 and 2; annually thereafter	CO_2 Delivery Pipeline
Injection Monitoring			
Injection Pressure	NA	Continuous	Injection Wellheads
Mass Injection Rate	NA	Continuous	Injection Wellheads
Injection Volume (calculated)	NA	Continuous	Reservoir
Annular Pressure	NA	Continuous	Injection Wellheads
Annular Fluid Volume	NA	Continuous	Injection Wellheads
Temperature and acoustics (DTS and DAS)	Continuous	Continuous	Injection and IZM wells. Downhole, above perforations
Mechanical Integrity Testing			
Temperature or Noise or Oxygen Activation Log	Once	Annually	Injection Wells
PFO Tests	Once	Every five years and at end of injection period	Injection Wells
DTS	Continuous	Continuous	Injection wells. Downhole, above perforations
Verification Monitoring (Fluid Sampling)			
St. Peter sandstone	Once	Annually	ACZ USDW well

Monitoring Activity	Baseline Data Frequency	Injection Phase Frequency	Location
Ironton Galesville formations	Once	Annually	ACZ Well
Mt. Simon	Once	Annually*	IZM Wells
Isotope Analysis	Once	Annually	ACZ and IZM wells
Verification Monitoring (Pressure, DTS, DAS)			
St. Peter Sandstone	Continuous	Continuous	ACZ USDW well
Ironton and Galesville formations	Continuous	Continuous	ACZ well
IZM Mt. Simon Sandstone	Continuous	Continuous	IZM wells
Pulsed Neutron Logging	Once	Annually for the first 5 years of injection then every 2 years thereafter	Injection Wells ACZ and IZM Wells
Time-lapse 2D Surface Seismic Data	Once	1st after 4 years of injection 2nd after 9 years of injection Every 10 years thereafter	Surface

*In-zone fluid sampling will be discontinued once CO_2 breakthrough occurs at the well.

Sampling frequencies during the injection period, for the One Earth Sequestration, LLC Testing and Monitoring plan, are defined as follows:

- Quarterly sampling and testing will take place by the following dates each year: 3 months after the date of authorization of injection, 6 months after the date of authorization of injection, 9 months after the date of authorization of injection, and 12 months after the date of authorization of injection and every 3 months thereafter, unless otherwise noted.
- Semi-annual sampling will take place by the following dates each year: 6 months after the date of authorization of injection and 12 months after the date of authorization of injection and every 6 months thereafter, unless otherwise noted.
- Annual sampling will occur up to 45 days before the anniversary date of authorization of injection each year and every year thereafter, unless otherwise noted. Annual logging will take place up to 45 days before the anniversary date of authorization of injection each year and every year thereafter, unless otherwise noted.

Quality assurance procedures

A quality assurance and surveillance plan (QASP) for all testing and monitoring activities, required pursuant to 146.90(k), is provided as an Appendix to this Testing and Monitoring Plan.

Reporting procedures

One Earth Sequestration, LLC will report the results of all testing and monitoring activities to the EPA in compliance with the requirements under 40 CFR 146.91.

Carbon Dioxide Stream Analysis [40 CFR 146.90(a)]

Pre-injection (baseline) samples will be collected and analyzed to demonstrate that the CO_2 stream and as required by 40 CFR 146.82(a)(7), (9), (10), and 146.88, meets permit requirements. One Earth Sequestration, LLC will analyze the CO_2 stream during the operation period to yield data representative of its chemical and physical characteristics and to meet the requirements of 40 CFR 146.90(a). The current sampling and analytical program is based on the CO_2 stream captured at the One Earth Energy, LLC ethanol production facility.

The detection of carbon isotopes ($\delta^{13}C$) in the injected CO_2 is useful in tracing the movement of CO_2 in the injection reservoir. The $\delta^{13}C$ composition of CO_2 ($\delta^{13}C_{(CO2)}$) in the gas samples is dependent on the type of plant (corn) used to produce the alcohol. Ethanol production plants that utilize different photosynthetic cycles produce different carbon isotopic compositions.

Additional sampling and analysis may be required if other sources of CO_2 are delivered to the injection site. The Director will be notified 60 days in advance of any such changes. The sampling and analytical program will be modified as needed to meet the requirements of 40 CFR 146.90(a). One Earth Sequestration, LLC will sample and analyze the CO_2 stream as described below:

Sampling location and frequency

CO_2 stream sampling will occur in the compressor building after the last stage of compression. If other sources of CO_2 are delivered to the injection site, those will also be sampled at a location to be determined. Sampling will take place quarterly, beginning within 3 months after the date of authorization of injection, then every three months thereafter.

Analytical parameters

One Earth Sequestration, LLC will analyze the CO_2 for the constituents identified in **Table 3** using the methods listed. Additional constituents may be included if other sources of CO_2 are delivered to the site. The Director will be notified 60 days in advance of any such changes.

***Table 3**. Summary of analytical parameters for CO_2 stream.*

Parameter	Analytical Method(s)[1]
Oxygen (O_2)	ISBT 4.0 (GC/DID) GC/TCD
Nitrogen (N_2)	ISBT 4.0 (GC/DID) GC/TCD
Carbon Monoxide	ISBT 5.0 Colorimetric ISBT 4.0 (GC/DID)
Oxides of Nitrogen	ISBT 7.0 Colorimetric
Total Hydrocarbons	ISBT 10.0 THA (FID)
Methane	ISBT 10.1 GC/FID)
Acetaldehyde	ISBT 11.0 (GC/FID)
Sulfur Dioxide	ISBT 14.0 (GC/SCD)
Hydrogen Sulfide	ISBT 14.0 (GC/SCD)
Ethanol	ISBT 11.0 (GC/FID)
Carbon Isotope	Isotope ratio mass spectrometry
CO_2 Purity	ISBT 2.0 Caustic absorption Zahm-Nagel ALI method SAM 4.1 subtraction method (GC/DID) GC/TCD

Note 1: An equivalent method may be employed with the prior approval of the UIC Program Director.

Sampling methods

CO_2 stream sampling will occur in the compressor building after the last stage of compression. If other CO_2 is delivered to the site, that CO_2 will be sampled at the point of delivery or along the pipeline. A sampling station will be installed with the ability to purge and collect samples into a container that will be sealed and sent to the authorized laboratory.

All sample containers will be labeled with durable labels and indelible markings. A unique sample identification number and sampling date will be recorded on the sample containers.

Laboratory to be used/chain of custody and analysis procedures

Samples will be analyzed by a third-party laboratory using standardized procedures for gas chromatography, mass spectrometry, detector tubes, and photoionization. The sample chain-of-custody procedures described in Section B.3 of the QASP will be employed. The sample integrity and security will be documented through maintenance of a field sampling record and by use of the Chain of Custody form. The laboratory will provide, upon request, documentation of instrument calibration. The laboratory report will include the analytical results as well as reporting detection limits established for each method. The laboratory report will also include a copy of the completed Chain of Custody form.

Corrosion Monitoring

To meet the requirements of 40 CFR 146.90(c), One Earth Sequestration, LLC will monitor well materials during the operation period for loss of mass, thickness, cracking, pitting, and other signs of corrosion to ensure that the well components meet the minimum standards for material strength and performance.

One Earth Sequestration, LLC will monitor corrosion using the corrosion coupon method and will collect samples according to the description below.

Monitoring location and frequency

For the first two years of injection operations, corrosion monitoring will occur quarterly, by the following dates each year: 3 months after the date of authorization of injection, and then every three months thereafter. For the remainder of injection operations, monitoring will occur annually. There are no plans to monitor the coupons based on injection volumes. If the coupons show evidence of corrosion, the injection well can be assessed for signs of corrosion using well logging techniques such as multi-finger caliper logging or an ultrasonic casing evaluation tool.

Additional monitoring location(s) may be required if other sources of CO_2 are delivered to the injection wells via additional pipeline(s). The Director will be notified 60 days in advance of any such changes. The sampling and analytical program will be modified as needed to meet the requirements of 40 CFR 146.90(c).

Sample description

Samples of material used in the construction of the compression equipment, pipeline, and injection well, which come into contact with the CO_2 stream, will be included in the corrosion monitoring program either by using actual material and/or conventional corrosion coupons. Samples will consist of those items listed in Table 4. Each coupon will be weighed, measured,and photographed prior to initial exposure (see "Sample Handling and Monitoring" below).

***Table 4**. List of equipment coupon with material of construction.*

Equipment Coupon	Material of Construction
Pipeline(s)	e.g., CS A106B; Design is TBD
Long String Casing (Upper casing type)	Carbon Steel
Long String Casing (Deep casing type)	Chrome Alloy
Injection tubing	Chrome Alloy
Wellhead	Chrome Alloy
Packers	Chrome Alloy

Monitoring details

Sample Exposure

Each sample will be attached to an individual holder and then inserted in a flow- through pipe arrangement (**Figure 3**). The corrosion monitoring system will be located downstream of all process compression/dehydration/pumping equipment (i.e., at the beginning of the pipeline to the wellhead). To accomplish this, a parallel stream of high-pressure CO_2 will be routed from the pipeline through the corrosion monitoring system and then back into a lower pressure point upstream in the compression system. This loop will operate any time injection is occurring. No other equipment will act on the CO_2 past this point; therefore, this location will provide representative exposure of the samples to the CO_2 composition, temperature, and pressures that will be seen at the wellhead and injection tubing. The holders and location of the system will be included in the pipeline design and will allow for continuation of injection during sample removal.

Figure 3*. Coupon holder (top). Flow-through pipe arrangement (bottom).*

Sample Handling and Monitoring

The coupons will be handled and assessed for corrosion using the American Society for Testing and Materials (ASTM) G1-03, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens (ASTM 2011). The coupons will be photographed, visually inspected with a minimum of 10x power, dimensionally measured (to within 0.0001 inch), and weighed (to within 0.0001 gm).

Above Confining Zone Monitoring

One Earth Sequestration, LLC will monitor groundwater quality and geochemical changes above the confining zone during the operation period to meet the requirements of 40 CFR 146.90(d). One

ACZ monitoring well will be used to monitor the Ironton/Galesville, the aquifer immediately above the confining layer. The purpose is to monitor whether there is CO_2 or brine migration out of the storage formation. The well will be utilized for pressure and temperature monitoring as well as periodic fluid sampling. If monitoring data indicates that CO_2 has migrated out of the primary storage formation, it will trigger external well integrity testing of the injection well and the deep in zone monitor wells and may trigger an emergency response action described in the Emergency and Remedial Response Plan.

To meet the requirements at 40 CFR 146.95(f)(3)(i), One Earth Sequestration, LLC will also monitor groundwater quality, geochemical changes, and pressure in the St. Peter sandstone, the lowermost USDW above the injection zone. The USDW monitoring program will meet the requirements of 40 CFR 146.90 (d) and will include baseline groundwater samples to characterize variations in water quality within the AoR prior to the start of CO_2 injection. Once the injection phase of the project begins, the analytical results will be compared to the baseline conditions for indication of CO_2 or brine migration into the USDW. If indications of CO_2 or brine are found in the USDW, it will trigger the emergency response actions found in the Emergency and Remedial Response Plan.

Monitoring location and frequency

Table 5a shows the planned monitoring methods, locations, and frequencies for ground water quality and geochemical monitoring above the confining zone. Table 5b shows the planned wireline logging program.

The groundwater monitoring plan focuses on the following zones:

- The St. Peter Sandstone – the lowermost USDW.
- The Ironton-Galesville Formation – the zone above the Eau Claire Formation confining zone.

***Table 5a**. ACZ monitoring of groundwater quality and geochemical changes.*

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
St. Peter Formation (Lowermost ACZ USDW)	Fluid sampling	Lowermost USDW monitoring well	1 interval. Depth TBD based on site conditions	Baseline (quarterly). Annually thereafter through post-injection operations.
	Pressure/ temperature monitoring	Lowermost USDW monitoring well	1 interval. Depth TBD based on site conditions	Continuous
Ironton-Galesville (Above Confining Zone)	Fluid sampling	ACZ well	1 interval. Depth TBD based on site conditions	One baseline. Annually thereafter through post-injection operations
	Pressure/ temperature monitoring	ACZ well	1 interval. Depth TBD based on site conditions	Continuous

***Table 5b**. ACZ indirect monitoring*

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
St. Peter	Pulse Neutron Logging/RST	Lowermost USDW ACZ monitoring well	Continuous to full well depth	Baseline (Once) Annually thereafter
Ironton-Galesville	Pulse Neutron Logging/RST	ACZ Well	Continuous to full well depth	Baseline (Once) Annually thereafter

Note: Baseline sampling and analysis will be completed before injection is authorized.

Analytical parameters

Table 6 identifies the parameters to be monitored and the analytical methods One Earth Sequestration, LLC will use for ground water samples.

***Table 6**. ACZ summary of analytical and field parameters for ground water samples.*

Parameters	**Analytical Methods (1)**
	Lowermost USDW
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and Tl	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO_3, and SO_4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Isotopes: $\delta^{13}C$ of Dissolved Inorganic Carbon (DIC)	Isotope ratio mass spectrometry
Total Dissolved Solids	Gravimetry; APHA 2540C
Water Density (field)	Oscillating body method
Alkalinity	APHA 2320B
pH (field)	EPA 150.1
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple
	Above Confining Zone
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and Tl	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO_3, and SO_4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Isotopes: $\delta^{13}C$ of DIC	Isotope ratio mass spectrometry
Total Dissolved Solids	Gravimetry; APHA 2540C
Water Density(field)	Oscillating body method
Alkalinity	APHA 2320B
pH (field)	EPA 150.1
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple

Note 1: ICP = inductively coupled plasma; MS = mass spectrometry; OES = optical emission spectrometry; GC-P = gas chromatography - pyrolysis. An equivalent method may be employed with the prior approval of the UIC Program Director.

Sampling methods

Sampling will be performed as described in Section B.2 of the QASP; this section of the QASP describes the groundwater sampling methods to be employed, including sampling standard operating procedures (SOPs) (Section B.2 a/b), and sample preservation (Section B.2.f).

Laboratory to be used/chain of custody procedures

A qualified, commercial laboratory will be selected to provide analytical services in accordance with the methods and standards included here and in the QASP. Sample handling and custody will be performed as described in Section B.3 of the QASP. Quality control will be ensured using the methods described in Section B.5 of the QASP.

External Mechanical Integrity Testing

One Earth Sequestration, LLC will conduct at least one of the tests presented in **Table 7** periodically during the injection phase to verify external MI as required at 146.89(c) and 146.90. MITs will be performed annually, up to 45 days before the anniversary date of authorization of injection each year or alternatively scheduled with the prior approval of the UIC Program Director.

***Table** 7. Mechanical integrity tests.*

Test Description	Location
Temperature Log	Along wellbore using DTS or wireline well log
Noise Log	Wireline Well Log
Oxygen Activation Log	Wireline Well Log

Description of MIT(s) That May be Employed

Temperature Logging

Temperature logging detects leaks by measuring temperature anomalies due to fluid movement adjacent to the well bore. Fluid leaks from the wellbore are typically a different temperature compared to native fluids. Temperature logs are run after the well has been shut-in long enough for temperature effects to dissipate, leaving a relatively simple temperature profile (typically ~36 hours). While the absolute gradients may differ due to injection history, the relative profiles should be consistent. If there has been a leak of fluid out of the well, there may be an anomalous heating or cooling effect as compared to the baseline or another log. Gradient variation due to lithologic changes are expected. Distributed fiber sensing or electric wireline deployed temperature measurement devices can be used and should be of sufficient resolution and sufficiently calibrated to detect changes.

Temperature Logging Using Wireline

To ensure the mechanical integrity of the casing of the injection well, temperature data will be recorded across the wellbore from surface down to primary caprock. Bottom hole pressure data near the packer will also be provided. The following procedures, will be employed for temperature logging:

The well should be in a state of injection for at least 6 hours prior to commencing operations to cool injection zones.

1. Move in and rig up an electrical logging unit with lubricator.
2. Run a temperature survey from the top of the confining formation (or higher) to the deepest point reachable in the injection well while injecting at a rate that allows for safe operations. Should operational constraints or safety concerns not allow for a logging pass while injecting, an acceptable, alternate plan is to stop injecting immediately prior to the first logging pass.
3. Stop injection, pull tool back to shallow depth, wait 1 hour.
4. Run a temperature survey over the same interval as step 2.
5. Pull tool back to shallow depth, and wait 2 hours.
6. Run a temperature survey over the same interval as step 2.
7. Pull tool back to shallow depth, and wait 2 hours.
8. Run a temperature survey over the same interval as step 2.
9. Evaluate data to determine if additional passes are needed for interpretation. Should CO_2 migration be interpreted in the topmost section of the log, additional logging runs over a higher interval will be required to find the top of migration.
10. If additional passes are needed, repeat temperature surveys every 2 hours until 12 hours, over the same interval as step 2.
11. Rig down the logging equipment.
12. Data interpretation involves comparing the time-lapse well temperature profiles and looking for temperature anomalies that may indicate a failure of well integrity, i.e., tubing leak or movement of fluid behind the casing. As the well cools down the temperature profile along the length of the tubing string is compared to the baseline profile. Fluid movement into the annulus or outside the casing creates a temperature anomaly when compared to the baseline cooling profile.

Temperature Logging Using DTS Fiber Optic Line

The injection well will be equipped with a DTS fiber optic temperature monitoring system that can monitor the injection well's annular temperature along the length of the tubing string. The DTS line is used for real-time temperature monitoring and, like a conventional temperature log, can be used for early detection of temperature changes that may indicate a loss of well mechanical integrity. The procedure for using the DTS for well mechanical integrity is as follows:

1. After the well is completed and prior to injection, a baseline temperature profile will be established. This profile represents the natural temperature gradient for each stratigraphic zone.
2. During injection operation, record the temperature profile for 6 hours prior to shutting in the well.
3. Stop injection and record temperature profile for 6 hours.
4. Evaluate data to determine if additional cooling time is needed for interpretation.
5. Start injection and record temperature profile for 6 hours.
6. Data interpretation involves comparing the time-lapse well temperature profiles and looking for temperature anomalies that may indicate a failure of well integrity, i.e., tubing leak or movement of fluid behind the casing. The DTS system monitors and records the

well's temperature profiles at a pre-set frequency in real-time. As the well cools down the temperature profile along the length of the tubing string is compared to the baseline. Fluid movement into the annulus or outside the casing creates a temperature anomaly when compared to the baseline profile. This data can be continuously monitored to provide real-time MIT surveillance making this technology superior to wireline temperature logging.

Noise Logging

A wireline tool is deployed which uses sensitive microphones to detect noise due to flow behind the casing. The sounds are recorded in different frequency ranges at ~100' depth intervals for approximately three to five minutes. If anomalies are detected the depth intervals are shortened to better locate the anomaly. When the level of sound is low, a linear scale is used for reporting noise logs, and, when there are intervals with higher sound, a logarithmic scale is used. Departures from baseline noise levels in the log indicate an anomaly. Ambient noise while injecting that produces a signal greater than 10 millivolts (mV) may indicate leakage or require further investigation.

To ensure the mechanical integrity of the casing of the injection well, logging data will be recorded across the wellbore from surface down to the primary caprock. Bottom hole pressure data near the packer will also be provided. Noise logging will be carried out while injection is occurring. If ambient noise is greater than 10 mv, injection will be halted. The following procedures will be employed:

1. Move in and rig up an electrical logging unit with lubricator.
2. Run a noise survey from the top of the confining formation (or higher) to the deepestpoint reachable in the injection well while injecting at a rate that allows for safe operations.
3. Make noise measurements at intervals of 100 feet to create a log on a coarse grid.
4. If anomalies are evident on the coarse log, construct a finer grid by making noise measurements at intervals of 20 feet within the coarse intervals containing high noise levels.
5. Make noise measurements at intervals of 10 feet through the first 50 feet above the injection interval and at intervals of 20 feet within the 100-foot intervals containing:
6. The base of the lowermost bleed-off zone above the injection interval and
7. The base of the lowermost USDW.
8. Additional measurements may be made to pinpoint depths at which noise is produced.
9. Use a vertical scale of 1 or 2 inches per 100 feet.
10. Rig down the logging equipment.
11. Interpret the data as follows: Determine the base noise level in the well (dead well level). Identify departures from this level. An increase in noise near the surface due to equipment operating at the surface is to be expected in many situations. Determine the extent of fluid movement; flow into or between USDWs indicates a lack of mechanical integrity; flow from the injection zone into or above the confining zone indicates a failure ofcontainment.

Oxygen Activation (OA) Logging

A wireline tool is deployed to activate oxygen by emitting high-energy neutrons from a neutron source. The activated isotopes emit gamma radiation which is measured by the wireline tool. Gamma-ray measurements are used to calculate water flow direction and velocity. If water flow outside of the casing is detected it could indicate the potential loss of external mechanical integrity.

To minimize false positives, a calibration will be performed, and measurements will be confirmed at several nearby depths and/or under a minimum of three varying injection rates.

To ensure the mechanical integrity of the casing of the injection well, logging data will be recorded across the wellbore from surface down to primary caprock. Bottom hole pressure data near the packer will also be provided. OA logging will be carried out while injection is occurring. The following procedures will be employed:

1. Move in and rig up an electrical logging unit with lubricator.
2. Conduct a baseline Gamma-Ray Log and casing collar locator log from the top of the injection zone to the surface prior to taking the stationary readings with the OA tool. (Gamma-Ray Log is necessary to evaluate the contribution of naturally occurring background radiation to the total gamma radiation count detected by the OA tool. There are different types of natural radiation emitted from various geologic formations or zones and the natural radiation may change over time.
3. The OA log shall be used only for casing diameters of greater than 1-11/16 inches andless than 13- 3/8 inches.
4. All stationary readings should be taken with the well injecting fluid at the normal ratewith minimal rate and pressure fluctuations.
5. Prior to taking the stationary readings, the OA tool must be properly calibrated in a "no vertical flow behind the casing" section of the well to ensure accurate, repeatable tool response and for measuring background counts.
6. Take, at a minimum, a 15-minute stationary reading adjacent to the confining interval located immediately above the injection interval. This must be at least 10 feet above the injection interval so that turbulence does not affect the readings.
7. Take, at a minimum, a 15-minute stationary reading at a location approximately midway between the base of the lowermost USDW and the confining interval located immediately above the injection interval.
8. Take, at a minimum, a 15-minute stationary reading adjacent to the top of the confining zone.
9. Take, at a minimum, a 15-minute stationary reading at the base of the lowermost USDW.
10. If flow is indicated by the OA log at a location, move uphole or downhole as necessary at no more than 50-foot intervals and take stationary readings to determine the area of fluid migration.
11. Interpret the data: Identification of differences in the activated water's measured gamma ray count-rate profile versus the expected count-rate profile for a static environment. Differences between the measured and expected may indicate flow in the annulus or behind the casing. The flow velocity is determined by measuring the time that the activated water passes a detector.

<u>Pressure Fall-Off Testing</u>

One Earth Sequestration, LLC will perform pressure fall-off tests during the injection phase as described below to meet the requirements of 40 CFR 146.90(f). Pressure Fall-Off tests are required to demonstrate to measure formation properties in the vicinity of the injection well (e.g., transmissivity).

Baseline pressure fall-off tests (PFO) will be conducted as described in the Pre-Operational Testing Plan (See Narrative). During the injection phase of the project, a PFO will be conducted in the injection wells every five years and at end of the injection period. The objective of the PFO testing is to periodically monitor for changes in the near wellbore environment that would impact injectivity or cause injection pressures to increase (US EPA, 2013). The formation characteristics obtained through the PFO testing will be compared to the results from previous tests to identify changes over time, and they will be used to calibrate the computational models. Finally, if an anomalous pressure drop occurs during the PFO, it may indicate an issue with well integrity (US EPA, 2013).

Testing location and frequency

Pressure fall-off testing will be performed in each well:

- As part of pre-operational testing (baseline)
- During Injection Operations:
    - Every five years and,
    - At end of the injection period

Testing details

Pressure Fall-off Test Procedure

A pressure falloff test has a period of injection followed by a period of no-injection or shut-in. Normal injection will be used during the injection period preceding the shut-in portion of the falloff tests. However, if the rate causes relatively large changes in bottomhole pressure, the rate may be decreased. A minimum, one week of relatively continuous injection will precede the shut-in portion of the falloff test. The pressure Fall-Off data will be measured using a downhole gauge sampling at 5-second intervals. The gauges may be those used for day-to-day data acquisition, or a pressure gauge conveyed via wireline. Surface or downhole gauges will be used to inform test duration. To reduce the wellbore storage effects attributable to the pipeline and surface equipment, the well will be shut-in at the wellhead nearly instantaneously with direct coordination with the injection compression facility operator. The shut-in period of the falloff test will be adequate to assure that enough pressure transient data are collected to calculate the average pressure. Quantitative analysis of the measured data is used to estimate formation characteristics, including transmissivity, permeability, and a skin factor. The measured parameters will be compared to those used in site computational modeling and AoR delineation.

<u>Carbon Dioxide Plume and Pressure Front Tracking</u>

One Earth Sequestration, LLC will employ direct and indirect methods to track the extent of the carbon dioxide plume and the presence or absence of elevated pressure during the operation period to meet the requirements of 40 CFR 146.90(g).

Evolution of the threshold pressure gradient in the injection zone, and through injection operations, is summarized in **Figure 4**, Predicted pressure profiles of the bottom-hole pressure at the injection wells are shown in **Figure 5**.

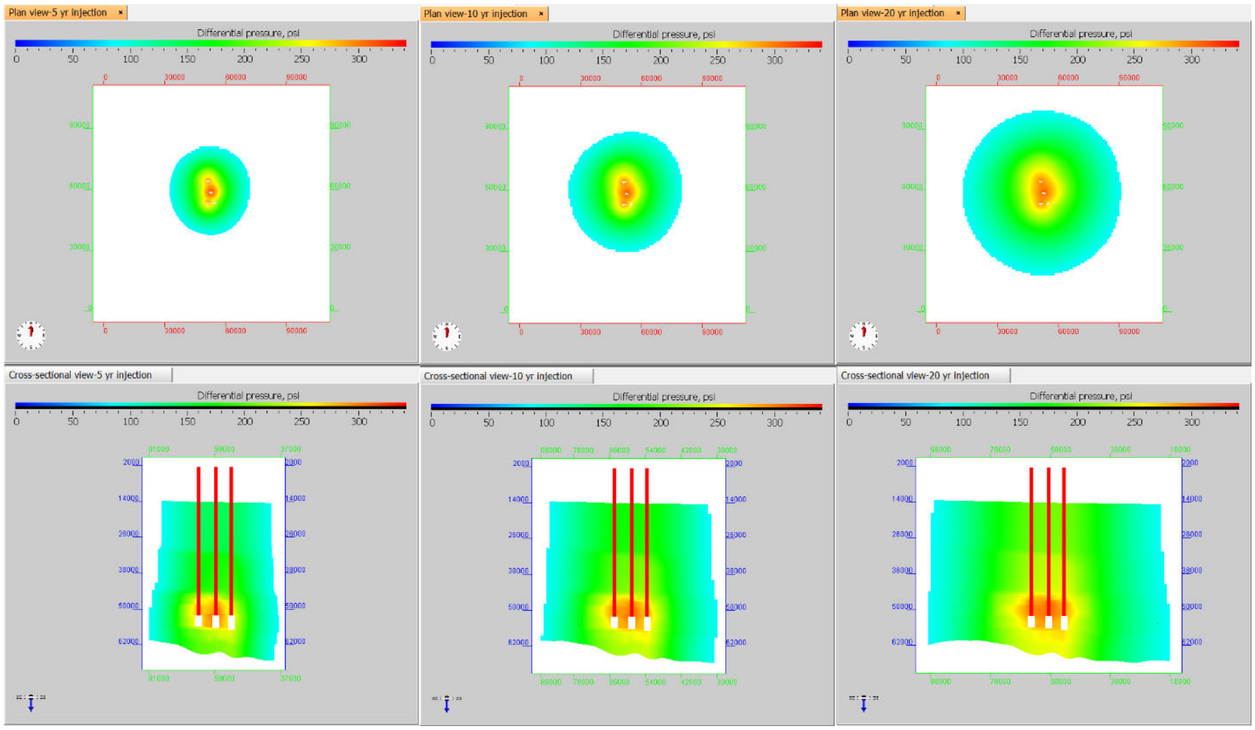

***Figure 4**. Threshold pressure front evolution.*

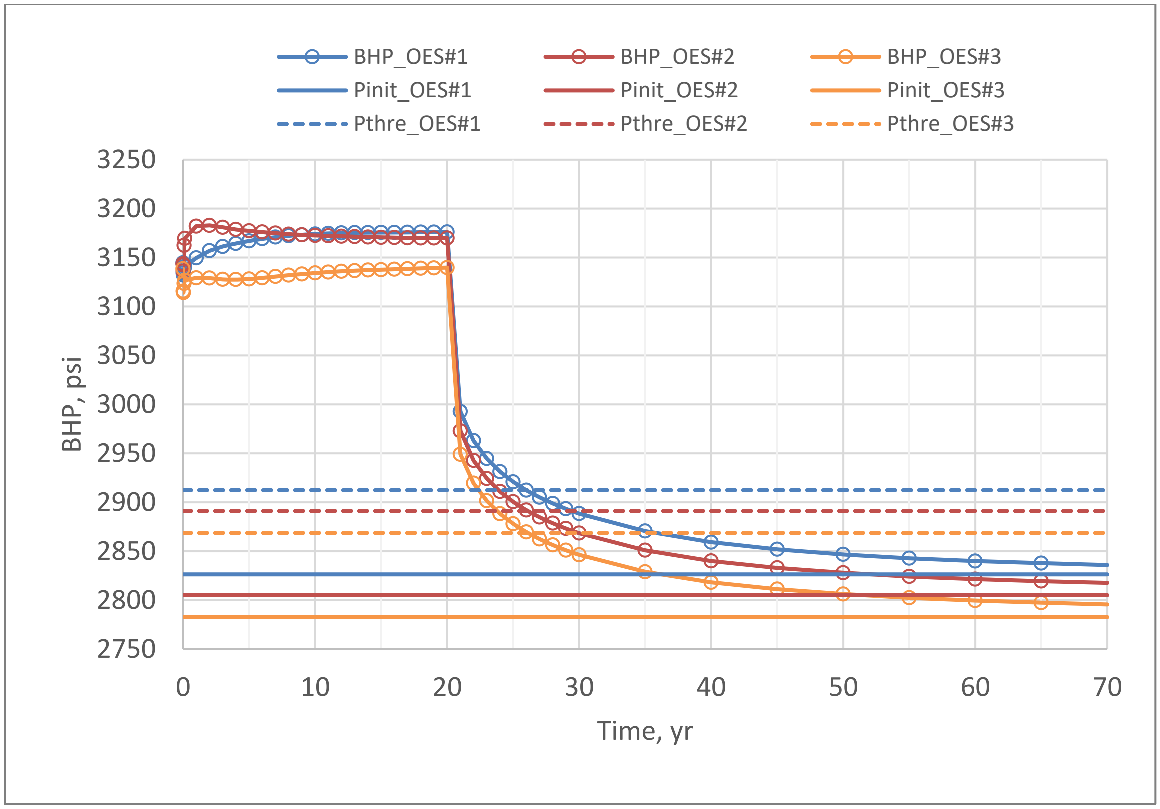

***Figure 5**. Bottomhole pressure profiles of injection wells.*

Monitoring locations relative to the predicted location of the CO_2 plume and pressure front at 5-year intervals throughout the injection phase are shown in Figures 6 through 9.

Two in-zone monitoring (IZM) wells are proposed for the site. OEE #1, the stratigraphic test well drilled for the purpose of site characterization, but constructed for the purpose of monitoring, will provide the initial in-zone monitoring location. A second IZM well, location to be determined (TBD), is also planned for installation. The location of the second IZM will be identified after 5 years of injection operations, or after 10 million tonnes of CO_2 injection, whichever occurs first. The location will be based on data from OEE #1 and, if available, the results of the first time-lapse 2D survey. As shown in **Figure 6**, the CO_2 plume is not projected to reach IZM #1 through the first five years of injection. The second in-zone monitoring well location will be proposed to the director following completion of the updated dynamic model. Based on concurrence from the Director, the well then will be installed.

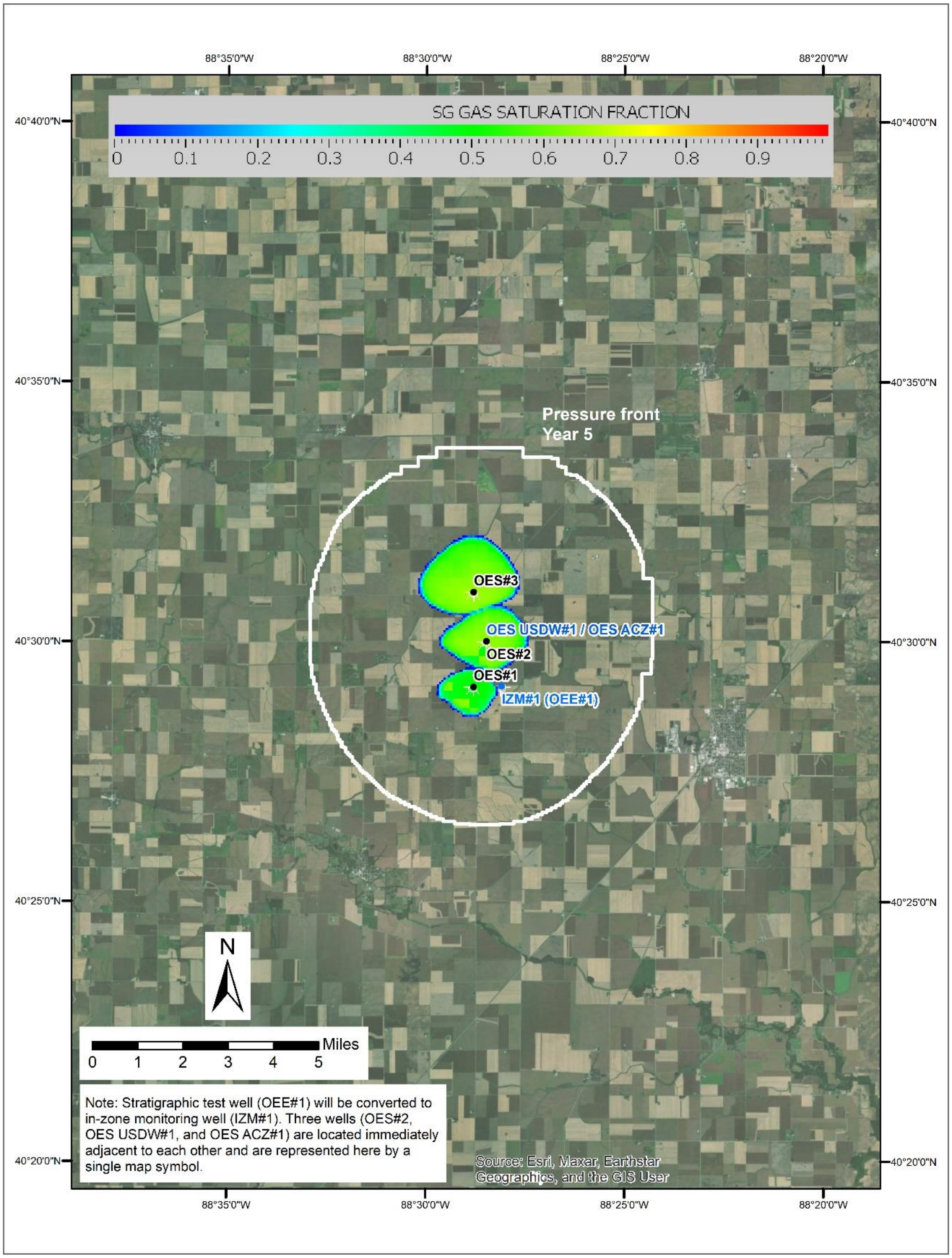

***Figure 6**. Modeled CO_2 plume location and pressure front (white line) after 5 years of injection.*

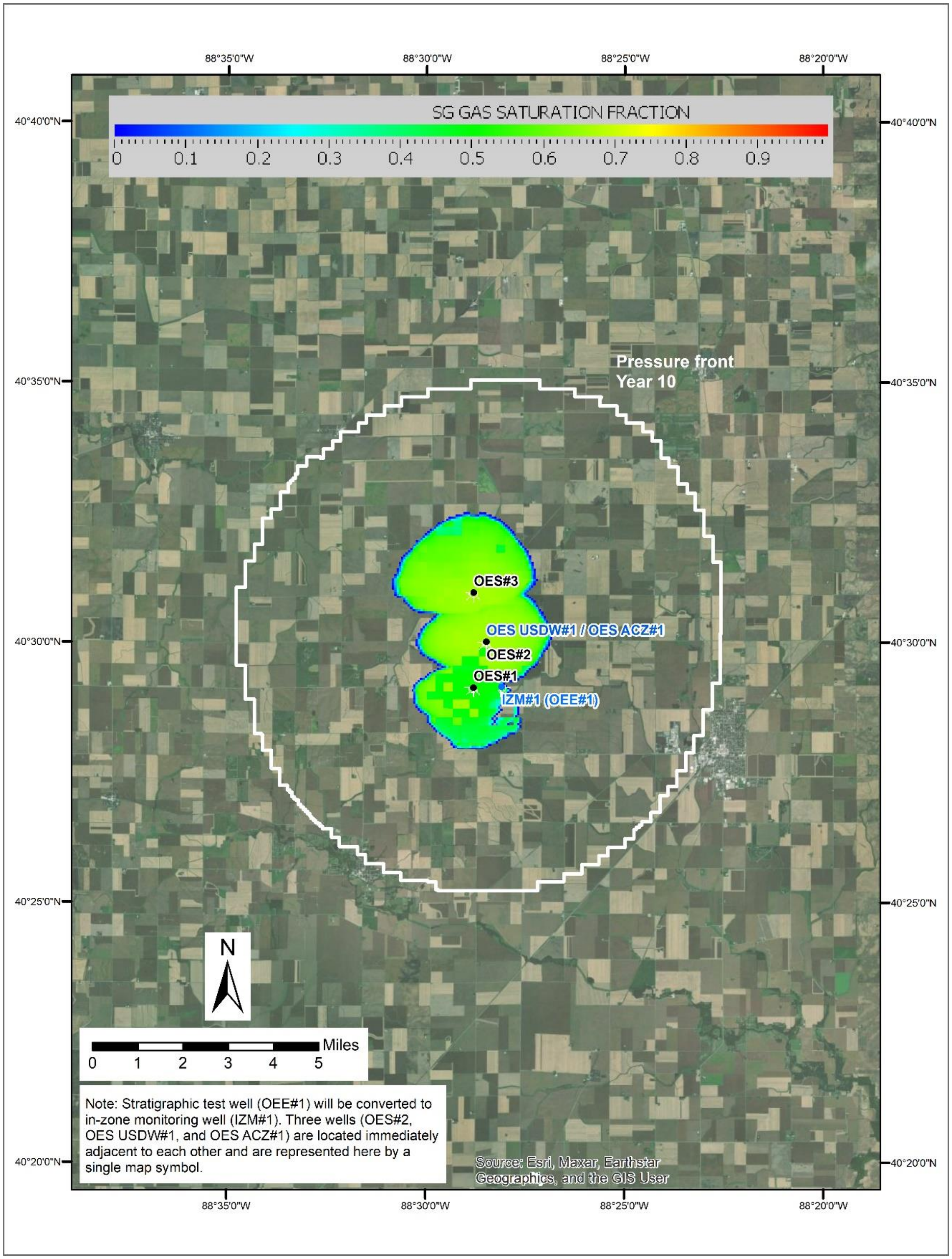

Figure 7*. Modeled CO_2 plume location and pressure front (white line) after 10 years of injection.*

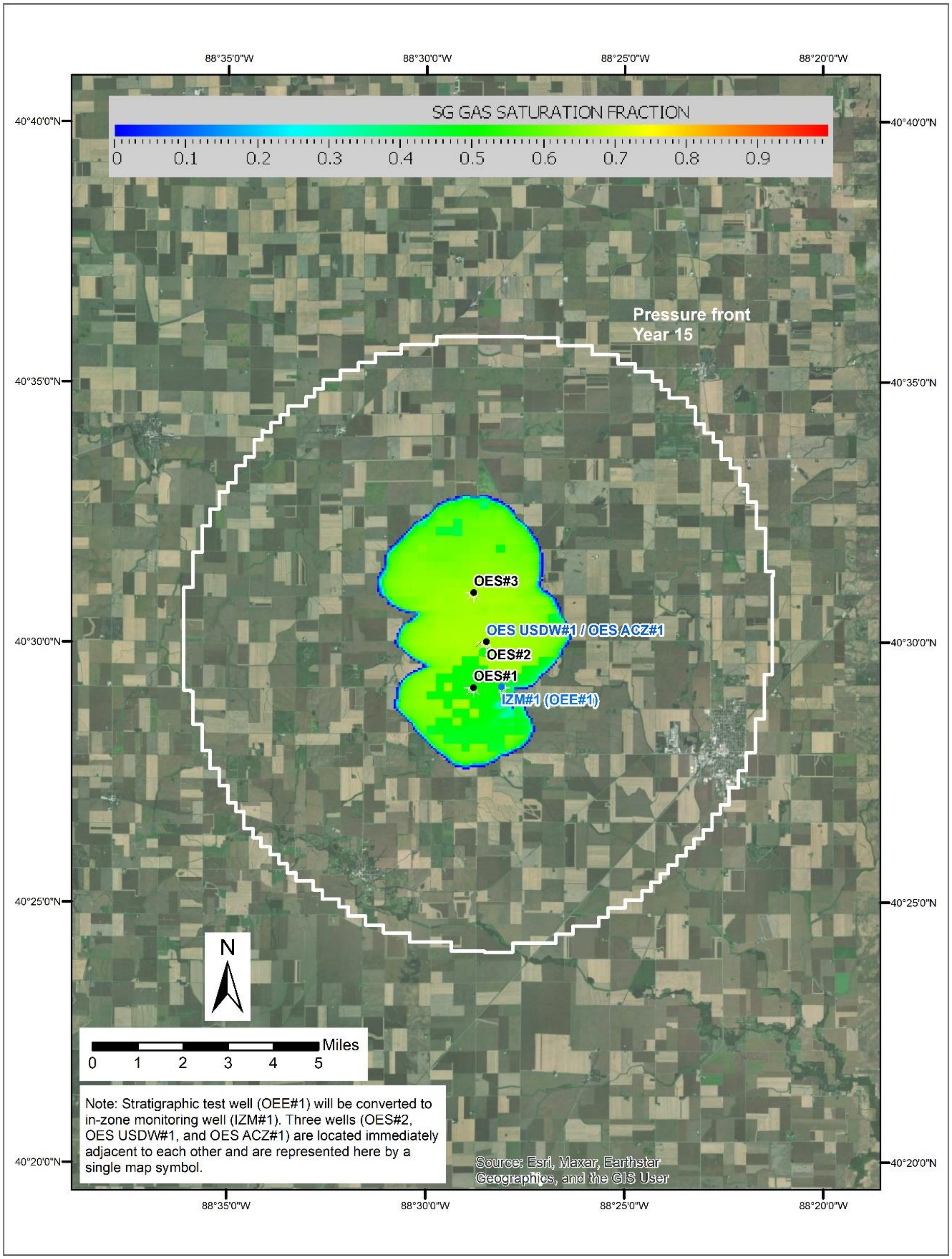

***Figure 8**. Modeled CO_2 plume location and pressure front (white line) after 15 years of injection.*

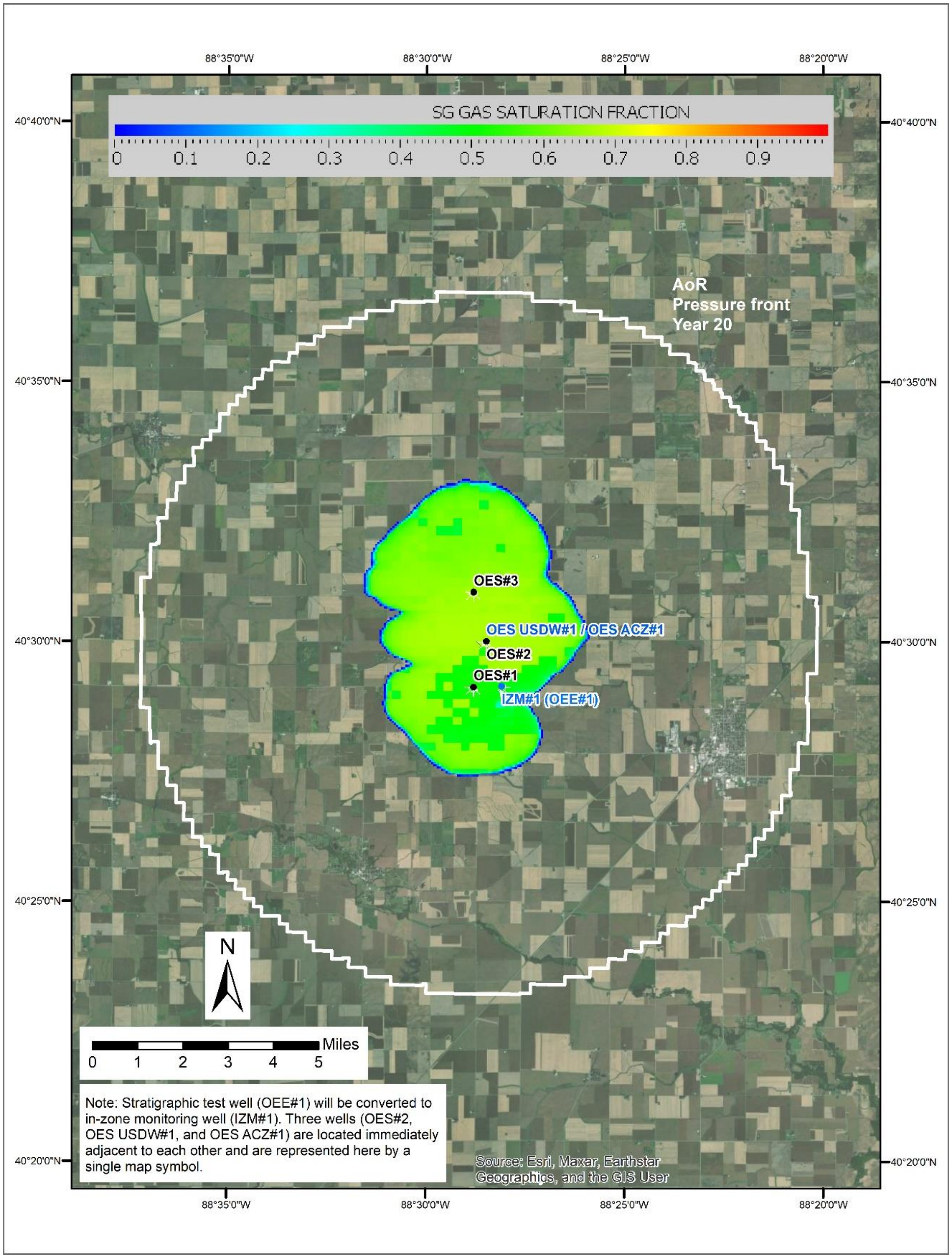

Figure 9. *Modeled CO_2 plume location and pressure front (white line) after 20 years of injection.*

Pressure and temperature sensors in the IZM wells will be used to measure pressure and temperature variations in the storage formation in the pre-operational, injection, and post-injection phases of the project (40 CFR 146.90 (g)). Note that the second IZM well will begin continuous pressure and temperature monitoring upon completion. The gauges will record the data that will be retrieved and reviewed monthly. Additional detail regarding the gauges is included in the QASP. The IZM wells also will be used to collect fluid samples from the storage formation to monitor for changes in the water chemistry over time and verify when the leading edge of the CO_2 plume reaches the IZM well. Once there is CO_2 breakthrough, fluid sampling will be discontinued in that IZM well.

Pulsed neutron logging detects leaks by measuring changes in the capture cross-section of the fluids and gasses in the pore space of the rock using a wireline tool that emits neutrons which are slowed to a thermal velocity through elastic and inelastic collisions with the nuclei of the environment's elements and ultimately captured. These interactions are sensitive to fluid type and saturation changes in the formation and in the casing-formation annulus. Therefore, pulsed neutron measurements can be used to monitor the formation fluids as well as identify mechanical integrity problems. The pulsed neutron Sigma (Σ) is the thermal neutron capture cross-section or the rate at which thermal neutrons are captured by the formation matrix and fluids. The capture cross-section can be used to detect fluid changes behind the casing over time to verify the well external mechanical integrity. Open hole wireline logs for lithologic definition and baseline pulsed neutron logs are key inputs to this type of monitoring.

Pulsed neutron (sigma mode)/RST logs will be acquired in the injection and IZM wells to identify the saturation of CO_2 close to the well bores and the stratigraphic intervals that may contain CO_2. This monitoring activity also will be used to examine for the presence of CO_2 above the confining zone. The pressure and pulsed neutron log data will be used to calibrate the dynamic simulation during the injection and post-injection phases of the project.

Indirect techniques will be used to monitor the development of the CO_2 plume and the associated pressure front through the injection and post injection project phases (40 CFR 146.90 (g)). Time-lapse 2D surface seismic data will be used to qualitatively monitor the CO_2 plume distribution and calibrate the computational modeling results over time. The time-lapse 2D surface seismic data will also be used to verify CO_2 containment within the storage formation.

Plume monitoring location and frequency

One Earth Sequestration, LLC will conduct fluid sampling and analysis to detect changes in groundwater to directly monitor the carbon dioxide plume. The parameters to be analyzed as part of fluid sampling in the injection zone and analytical methods are described above in the monitoring section. One Earth Sequestration, LLC will additionally deploy pressure/temperature sensors coupled with DTS to directly monitor the position of the pressure front and temperature changes in and above the primary confining unit.

Indirect plume monitoring will include pulsed neutron capture RST logs to monitor CO_2 saturation in the injection and IZM wells. In addition, time-lapse 2D seismic will be used to assess the extent

and position of the CO_2 plume. **Figure 10** shows the location of the 2D lines acquired as part of site characterization. The repeat 2D seismic will follow Line 1 and the 2019 Gibson line.

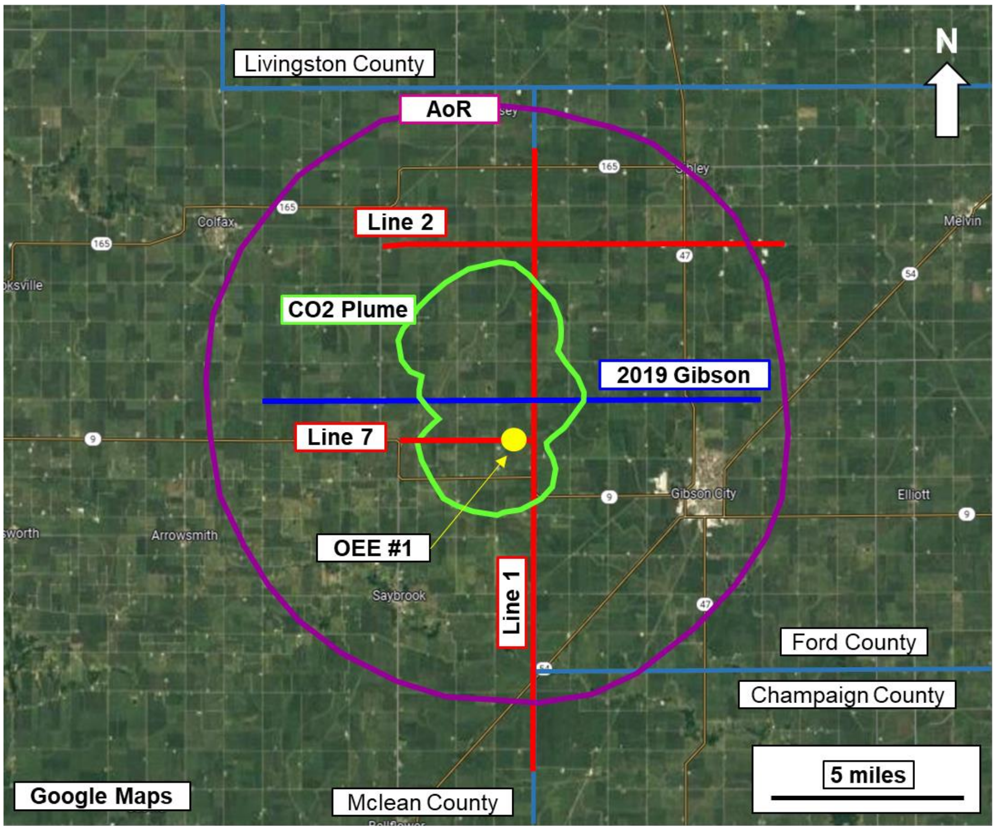

Figure 10. *2D seismic lines acquired during site characterization. Note CO_2 plume (in green) and AoR (purple) outlines have been generalized.*

Quality assurance procedures for seismic monitoring methods are presented in Section B.9 of the QASP.

Plume monitoring details

Table 8 presents the methods that One Earth Sequestration, LLC will use to monitor the position of the CO_2 plume, including the activities, locations, and frequencies One Earth Sequestration, LLC will employ. The parameters to be analyzed as part of fluid sampling in the injection zone and associated analytical methods are presented in **Table 9**. Quality assurance procedures for these methods are presented in the QASP.

***Table 8**. Plume monitoring activities.*

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
		Direct Plume Monitoring		
Injection Zone	Fluid sampling	IZM wells	1 interval. Depth TBD based on site conditions	Baseline (Once); Annual starting at end of first year of injection. (Fluid sampling will be discontinued at each respective IZM well once the monitoring zone is saturated with CO_2)
		Indirect Plume Monitoring		
Injection Zone	Pulse Neutron Logging/RST	Deep monitoring wells	Continuous to full well depth	Baseline (once), Annually thereafter
Injection Zone	Pulse Neutron Logging/RST	Injection Well	Continuous to full well depth	Baseline (once), Annually thereafter through injection operations (and PISC until P&A)
Injection Zone	2D surface seismic survey	Cross-sectional coverage	Fold Image Coverage approximately 40 miles	Baseline (once) 1st after 4 years of injection 2nd after 9 years of injection Every 10 years thereafter

***Table 9.** IZM summary of analytical and field parameters for fluid sampling.*

Parameters	Analytical Methods
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and Tl	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO3, and SO4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Isotopes: $\delta^{13}C$ of DIC	Isotope ratio mass spectrometry
Total Dissolved Solids	Gravimetry; APHA 2540C
Water Density (field)	Oscillating body method
Alkalinity	APHA 2320B
pH (field)	EPA 150.1
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple

Pressure-front monitoring location and frequency

Table 10 presents the methods that One Earth Sequestration, LLC will use to monitor the position of the pressure front, including the activities, locations, and frequencies.

Table 10. *Pressure front monitoring.*

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
Direct Pressure-Front Monitoring				
Mt. Simon	Pressure/ temperature monitoring	IZM #1	Sensitive, Confidential, or Privileged Information [redacted]	Continuous
		IZM #2	[redacted]	Continuous
		Injection Wells	[redacted]	Continuous

Quality assurance procedures for these methods are presented in Section A.4 of the QASP.

Continuous Recording of Injection Pressure, Rate, and Volume; Annulus Pressure

One Earth Sequestration, LLC will install and use continuous recording devices to monitor injection pressure, rate, and volume, the pressure on the annulus between the tubing and the long string casing, and the annulus fluid volume added.

One Earth Sequestration, LLC will perform the activities identified in Table 11 to verify internal mechanical integrity of the injection well and monitor injection pressure, rate, volume, and annular pressure as required at 40 CFR 146.88, 146.89, and 146.90(b). All monitoring will be continuous for the duration of the operation period, and at the locations shown in the table. The injection wells will have pressure/temperature gauges at the surface and in the tubing at the packer. In addition, there will be DTS and DAS fibers in the injection wells.

Table 11. *Locations for continuous monitoring in injection wells.*

Test Description	Location
Annular Pressure Monitoring	Surface
Injection Pressure Monitoring	Surface
Injection Pressure Monitoring	Reservoir - Proximate to packer
Injection Rate Monitoring	Surface
Injection Volume Monitoring	Surface
Temperature Monitoring	Surface
Temperature Monitoring	Reservoir - Proximate to packer
Temperature Monitoring	Along wellbore to packer using DTS
Acoustic Monitoring	Along wellbore to packer using DAS

Above-ground pressure and temperature instruments shall be calibrated over the full operational range at least annually using ANSI or other recognized standards. In lieu of removing the injection tubing, downhole gauges will demonstrate accuracy by using a second pressure gauge, with current certified calibration, that will be lowered into the well to the same depth as the permanent downhole gauge. Pressure transducers shall have a drift stability of less than 1 psi over the operational period of the instrument and an accuracy of ± 5 psi. Sampling rates will be at least once per 5 seconds. Temperature sensors will be accurate to within one degree Celsius. DTS sampling rate will be once per 10 seconds.

Flow will be monitored with a mass flowmeter at the wellhead. The flow meter will be either an orifice meter with flow computer or a Coriolis meter. The meter will be calibrated using accepted standards and be accurate to within ± 0.1 percent. The meter will be calibrated for the entire expected range of flow rates.

Injection Rate and Pressure Monitoring

One Earth Sequestration, LLC will monitor injection operations using a process control system, as presented below. For remote instrumentation installed at the wellhead, data will be transmitted back to the process control system via a secure data transmission system that allows for continuous monitoring and alarming to the operator. Loss of communication with the remote monitoring equipment will be alarmed to the operator as well.

The Surface Facility Equipment & Control System will limit maximum flow to 4,225 MT/day per well, and/or limit the well head pressure to 2,498 psia, 2,480 psia, and 2,462 psia for injection wells OES #1, OES #2, and OES #3, respectively, which corresponds to the regulatory requirement to not exceed 90% of the injection zone's fracture pressure. All injection operations will be continuously monitored and controlled by the One Earth Sequestration, LLC operations staff using the distributed process control system. This system will continuously monitor, control, record, and will alarm and shutdown if specified control parameters exceed their normal operating range.

More specifically, all critical system parameters, e.g., pressure, temperature, and flow rate will have continuous electronic monitoring with signals transmitted back to a master control system. One Earth Sequestration, LLC supervisors and operators will have the capability to monitor the status of the entire system from the distributed control center.

Calculation of Injection Volumes

Flow rate is measured at ground surface. Actual density is computed from pressure and temperature measurements at the flow meter location. The downhole pressure and temperature data will be used to perform the injectate density calculation.

The volume of CO_2 injected will be calculated from the mass flow rate obtained from the mass flow meter installed on the injection line. The mass flow rate will be divided by density and multiplied by injection time to determine the volume injected.

Density will be calculated using an industry standard correlation. The Standard Annulus Pressure Test (SAPT) is used to demonstrate the absence of significant leaks in tubing, casing, and packer.

This test is based on the principle that a pressure applied to fluids filling a sealed vessel will persist. A well's annulus system, though closed to transfer of matter, is not closed to energy transfer because it is not isolated from transfer of heat from its surroundings, therefore an allowance for small pressure changes is necessary. The test provides an immediate demonstration of whether leaks, detectable by these means, exist.

The interpretation and confirmation of the SAPT included: Comparison of the pressure change through the test period to 3% of the test pressure (0.03 X test pressure). If the annulus test pressure changes by this amount or more (gain or loss), the well has failed to demonstrate mechanical integrity, and operation may constitute a violation of the UIC regulations. If the annulus test pressure changes by less than 3 percent (gain or loss) over the test period, the well has demonstrated mechanical integrity, pursuant to 40 C.F.R. § 146.8(a)(1).

Appendix: Quality Assurance and Surveillance Plan

(Submitted as separate files)

TESTING AND MONITORING PLAN
40 CFR 146.90

One Earth CCS

Facility Information

Facility name: One Earth Sequestration, LLC
OES #2

Facility contact: Mark Ditsworth, VP of Technology and Special Projects
One Earth Sequestration, LLC, 202 N Jordan Drive, Gibson City
(217) 784-5321 ext. 215
mditsworth@oneearthenergy.com

Well location: McLean County, IL
40.500096°N, -88.474625°W (NAD 1983)

This Testing and Monitoring Plan describes how One Earth Sequestration LLC will monitor the One Earth CCS project activities pursuant to 40 CFR 146.90. The data acquired by the monitoring and testing procedures will be used to demonstrate that injection wells are operating as planned, that the carbon dioxide (CO_2) plume and pressure front are evolving as predicted, and that there is no endangerment to underground sources of drinking water (USDW). Additionally, the monitoring and testing data will be used to validate and refine geological models and simulations used to forecast the distribution of the CO_2 within the storage zone, support AoR re-evaluations, and to demonstrate non-endangerment. Results of the testing and monitoring activities described below may trigger action according to the Emergency and Remedial Response Plan.

Overall Strategy and Approach for Testing and Monitoring

This Testing and Monitoring Plan describes how the One Earth Sequestration LLC will monitor the site pursuant to 40 CFR 146.90.

Figure 1 and **Figure 2** provide a plan view and cross section of the Area of Review (AoR). The AoR and Corrective Action Plan discuss the technical basis for determination of the AoR and how monitoring data will be used to re-evaluate the AoR during the injection phases of the project (40 CFR 146.84 (e)). Data from a characterization well drilled specifically for this project (OEE #1) were used to develop the static earth model (SEM) and perform multi-phase flow modeling (See Narrative). The results of the modeling and simulations are the basis for determining the AoR and were used to develop the Testing and Monitoring Plan. The AoR will be reevaluated upon completion and testing of the injection wells if new data are obtained from the wells that may significantly change model predictions and the delineated AOR.

Sensitive, Confidential, or Privileged Information [redacted] Three injection wells are planned for the site (**Table 1**).

The Corrective Action Plan indicates that there are/are no penetrations (except for OEE #1) within the AoR that penetrate the confining units including the Eau Claire Formation, the primary seal. OEE #1 will be utilized as an In-Zone Monitoring (IZM) well.

The Testing and Monitoring Plan has been developed to identify and reduce risks associated with CO_2 injection into the subsurface. Goals of the monitoring strategy include:

- Meet the regulatory requirements of 40 CFR 146.90
- Protect underground sources of drinking water (USDW)
- Ensure that each injection well is operating as planned
- Ensure that each injection well is maintained as planned
- Provide data to validate and calibrate the geological and dynamic models used to predict the distribution of CO_2 within the injection zone
- Support AoR re-evaluations over the course of the project

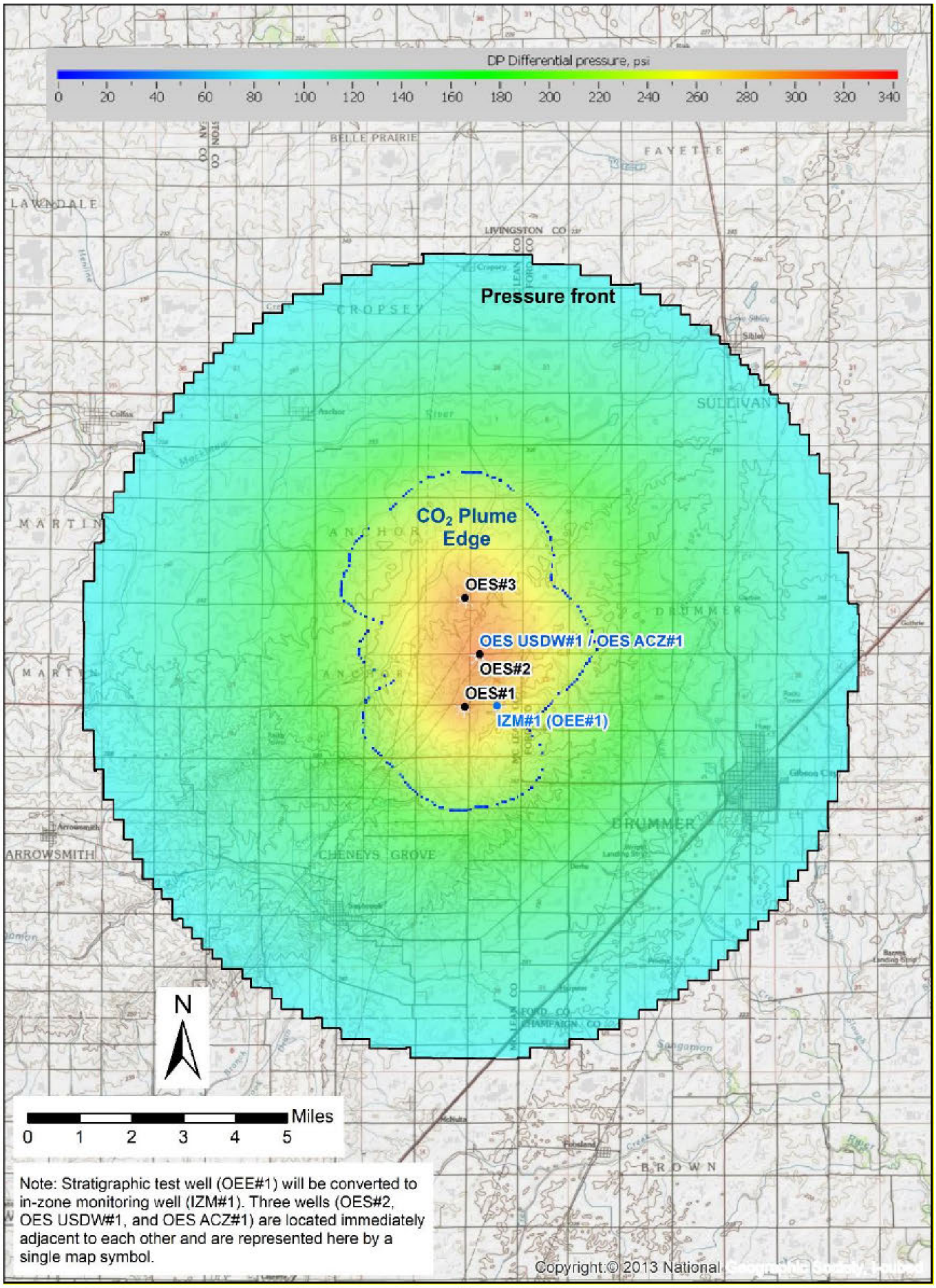

Figure 1*. Project Area of Review. CO_2 plume and pressure front through active injection of 90 million tonnes.*

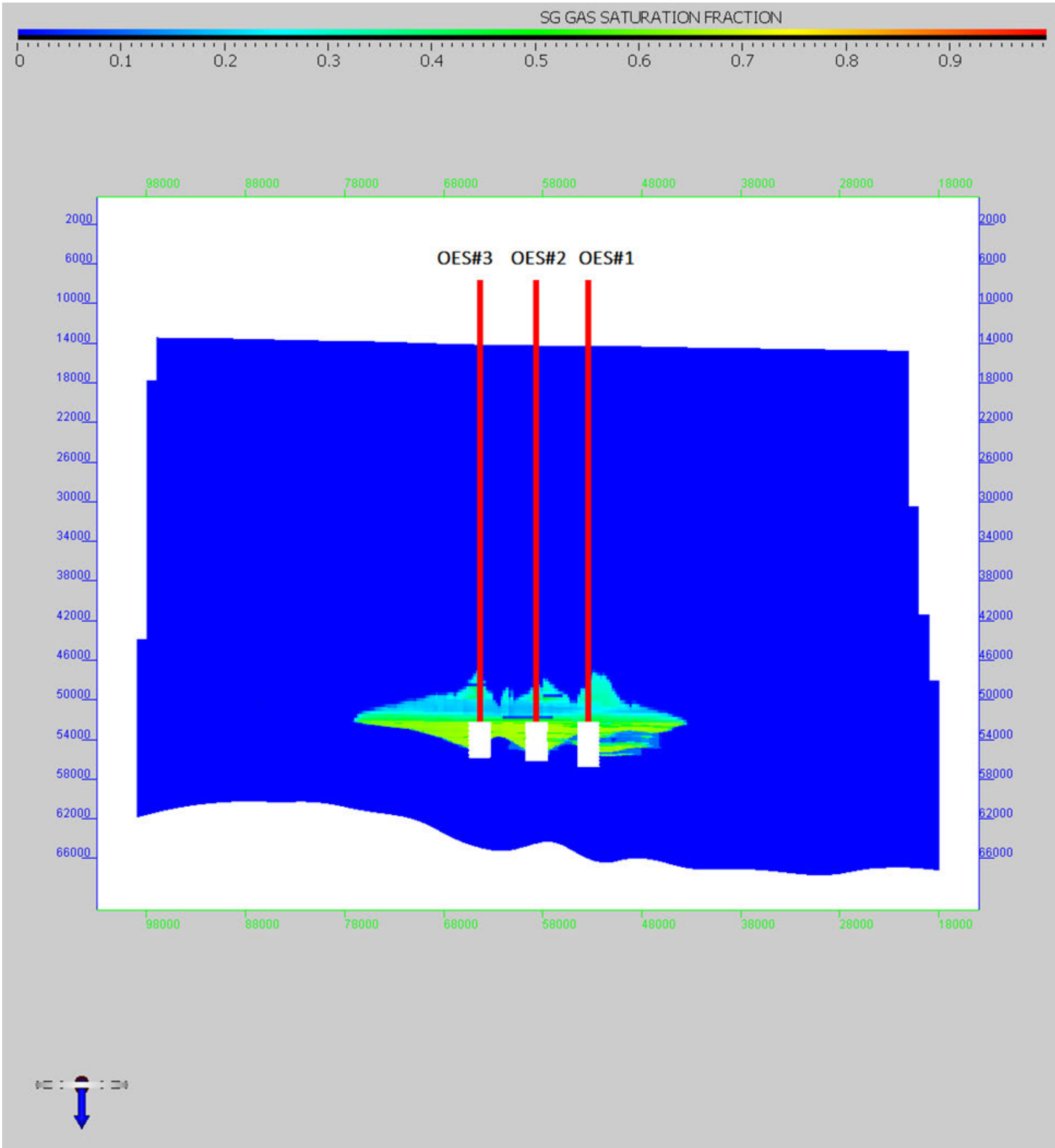

Figure 2*. Cross section of Area of Review pressure front and CO_2 plume at the end of injection.*

The Testing and Monitoring Plan will utilize direct and indirect monitoring technologies that will monitor:

- Injectate composition to demonstrate that it is consistent with the permit 40 CFR 146.90(a)
- Corrosion of well materials and components (40 CFR 146.90(c))
- Determine whether CO_2 or brine has migrated above the Confining Zone (ACZ) (40 CFR 146.90(d))
- USDW groundwater quality (40 CFR 146.95(f)(3)(i))
- Well integrity over the injection phase of the project (40 CFR 146.89(c) and 146.90)
- Near well-bore environment using pressure fall-off testing (40 CFR 146.90(f))
- Development of the CO_2 plume and pressure front in the storage formation over time (40 CFR 146.90(g))

Injection operations will be monitored using a range of techniques and methods as required by 40 CFR 146.88(e) and 146.90(b). Injection operations are discussed in more detail in Narrative Section: Well Operation. Continuous recording devices will monitor wellhead injection pressure, temperature, and flow rate (40 CFR 146.90 (b)). A Coriolis flow meter, which measures mass flow rate directly, or an orifice meter which measures flow volume with a calculated mass flow rate, will be installed on the injection line at surface.

The annular pressure between the tubing and the injection casing strings and the annular fluid volumes also will be monitored on a continuous basis (40 CFR 146.90 (b)). These data will be linked into a supervisory control and data acquisition (SCADA) system to record the operations data, control injection rates, or initiate system shutdown, if needed. The SCADA system can also be used to adjust the volume of annular fluid, and thereby pressure, in the annular space to meet the operational and regulatory objectives. Pressure and temperature will be measured continuously using pressure gauges to establish a wellhead-to-packer pressure correlation. This correlation can be used to calculate the injection pressure at the reservoir (perforated interval) at any time using the wellhead and downhole pressure data. The reservoir pressures and temperatures will also be used to calculate the injection rate at the reservoir, and the injection volumes will be used to update the computational models at regular intervals throughout the injection phase of the project (AoR and Corrective Action Plan).

Pre-operational logging and testing (See Narrative) will establish baseline mechanical integrity of the injection wells. External mechanical integrity will be monitored continuously using distributed temperature sensors (DTS) mounted to the exterior of the injection well casing and cemented into place. External mechanical integrity will be confirmed through annual logging and compared back to baseline logging data to identify deflections from that could indicate fluid flow behind the casing (40 CFR 146.90 (e)). Annual testing will include oxygen activation logging, temperature logging (wireline or DTS), or noise logging.

Monitoring wells will be used to evaluate the plume and pressure front development in the injection zone, and to assure containment and protection of USDWs. The injection wells and IZM wells will be used for wireline logging and will be equipped with gauges and instrumentation to measure pressure (downhole gauge), temperature (DTS) and acoustics (DAS). These wells will provide DTS and DAS data along the length of the well from above the perforated interval to above the lowermost USDW. The IZM wells will be utilized for fluid sampling (fluid sampling will be discontinued once there is CO_2 breakthrough at the well). Above confining zone (ACZ) monitoring wells will include a well set in the brine-saturated zone above the primary confining unit and a well in the lowermost USDW. These wells will be used for fluid sampling and will be equipped with pressure gauges.

A summary of the monitoring well type and well ID is shown in Table 1. Proposed well locations are shown in **Figure 1**.

***Table 1**. One Earth CCS well summary.*

Well Type	Well ID	Notes
Injection	OES #1	Sensitive, Confidential, or Privileged Information [redacted]
	OES #2	
	OES #3	
IZM	IZM #1	
	IZM #2	
ACZ	OES USDW #1	
	OES ACZ #1	
Geophysical Monitoring Wells	TBD	

All monitoring locations are either on One Earth CCS property or will be accessible through property access agreements with the landowner. Other monitoring will include annular pressure monitoring for the injection wells and corrosion monitoring.

To date, One Earth Sequestration, LLC (OWNER) has successfully negotiated surface land access for purposes of drilling the stratigraphic well, and pre-injection (baseline) monitoring activities such as 2D and 3D seismic testing. The OWNER's proven ability to work with local landowners and public entities to obtain access to surface and subsurface areas for activities related to the project should be sufficient to demonstrate the OWNER's ability to obtain access for monitoring, and corrective actions (if they are necessary) in the future. The OWNER may acquire, by lease or purchase, additional land parcel areas and surface entry rights for the injection, monitoring, and surface and sub-surface infrastructure. Monitoring well locations could change slightly but only to the extent that they retain their monitoring intent as described in the Testing and Monitoring Plan (QASP). Monitoring locations will also consider access routes that minimize property damage, crop loss, and property owner inconvenience. And to assure safe access to each location.

The Testing and Monitoring Plan will be adaptive over time in that the plan can be adjusted to respond:

- As project risks evolve over the course of the project
- If significant differences between the monitoring data and dynamic simulation predictions are identified
- If monitoring indicates anomalous results related to well integrity or the loss of containment.

Table 2 presents the general schedule and spatial extent for the monitoring activities in the baseline and injection phases of the project based on the current understanding of the site. The monitoring program will follow the Testing and Monitoring plan to establish that CO_2 injection is occurring in a stable and predictable manner. If, however, anomalous results are identified in the monitoring data, changes to the monitoring schedule or methods may be required. Changes to the Testing and Monitoring Plan will be made in consultation with the UIC Program Director (40 CFR 146.90 (j)).

***Table 2**. Testing and monitoring activities summary for the One Earth CCS project.*

Monitoring Activity	Baseline Data Frequency	Injection Phase Frequency	Location
Operational Monitoring			
CO_2 Injectate Compositional and Isotopic Analysis	Once	Quarterly	CO_2 Delivery Pipeline
Corrosion Coupon Analysis	NA	Quarterly years 1 and 2; annually thereafter	CO_2 Delivery Pipeline
Injection Monitoring			
Injection Pressure	NA	Continuous	Injection Wellheads
Mass Injection Rate	NA	Continuous	Injection Wellheads
Injection Volume (calculated)	NA	Continuous	Reservoir
Annular Pressure	NA	Continuous	Injection Wellheads
Annular Fluid Volume	NA	Continuous	Injection Wellheads
Temperature and acoustics (DTS and DAS)	Continuous	Continuous	Injection and IZM wells. Downhole, above perforations
Mechanical Integrity Testing			
Temperature or Noise or Oxygen Activation Log	Once	Annually	Injection Wells
PFO Tests	Once	Every five years and at end of injection period	Injection Wells
DTS	Continuous	Continuous	Injection wells. Downhole, above perforations
Verification Monitoring (Fluid Sampling)			

Monitoring Activity	Baseline Data Frequency	Injection Phase Frequency	Location
St. Peter sandstone	Once	Annually	ACZ USDW well
Ironton Galesville formations	Once	Annually	ACZ Well
Mt. Simon	Once	Annually*	IZM Wells
Isotope Analysis	Once	Annually	ACZ and IZM wells
Verification Monitoring (Pressure, DTS, DAS)			
St. Peter Sandstone	Continuous	Continuous	ACZ USDW well
Ironton and Galesville formations	Continuous	Continuous	ACZ well
IZM Mt. Simon Sandstone	Continuous	Continuous	IZM wells
Pulsed Neutron Logging	Once	Annually for the first 5 years of injection then every 2 years thereafter	Injection Wells ACZ and IZM Wells
Time-lapse 2D Surface Seismic Data	Once	1st after 4 years of injection 2nd after 9 years of injection Every 10 years thereafter	Surface

*In-zone fluid sampling will be discontinued once CO_2 breakthrough occurs at the well.

Sampling frequencies during the injection period, for the One Earth Sequestration LLC Testing and Monitoring plan, are defined as follows:

- Quarterly sampling and testing will take place by the following dates each year: 3 months after the date of authorization of injection, 6 months after the date of authorization of injection, 9 months after the date of authorization of injection, and 12 months after the date of authorization of injection and every 3 months thereafter, unless otherwise noted.
- Semi-annual sampling will take place by the following dates each year: 6 months after the date of authorization of injection and 12 months after the date of authorization of injection and every 6 months thereafter, unless otherwise noted.
- Annual sampling will occur up to 45 days before the anniversary date of authorization of injection each year and every year thereafter, unless otherwise noted. Annual logging will take place up to 45 days before the anniversary date of authorization of injection each year and every year thereafter, unless otherwise noted.

Quality assurance procedures

A quality assurance and surveillance plan (QASP) for all testing and monitoring activities, required pursuant to 146.90(k), is provided as an Appendix to this Testing and Monitoring Plan.

Reporting procedures

One Earth Sequestration LLC will report the results of all testing and monitoring activities to the EPA in compliance with the requirements under 40 CFR 146.91.

Carbon Dioxide Stream Analysis [40 CFR 146.90(a)]

Pre-injection (baseline) samples will be collected and analyzed to demonstrate that the CO_2 stream and as required by 40 CFR 146.82(a)(7), (9), (10), and 146.88, meets permit requirements. One Earth Sequestration LLC will analyze the CO_2 stream during the operation period to yield data representative of its chemical and physical characteristics and to meet the requirements of 40 CFR 146.90(a). The current sampling and analytical program is based on the CO_2 stream captured at the One Earth Energy, LLC ethanol production facility.

The detection of carbon isotopes ($\delta^{13}C$) in the injected CO_2 is useful in tracing the movement of CO_2 in the injection reservoir. The $\delta^{13}C$ composition of CO_2 ($\delta^{13}C_{(CO2)}$) in the gas samples is dependent on the type of plant (corn) used to produce the alcohol. Ethanol production plants that utilize different photosynthetic cycles produce different carbon isotopic compositions.

Additional sampling and analysis may be required if other sources of CO_2 are delivered to the injection site. The Director will be notified 60 days in advance of any such changes. The sampling and analytical program will be modified as needed to meet the requirements of 40 CFR 146.90(a). One Earth Sequestration LLC will sample and analyze the CO2 stream as described below:

Sampling location and frequency

CO_2 stream sampling will occur in the compressor building after the last stage of compression. If other sources of CO_2 are delivered to the injection site, those will also be sampled at a location to be determined. Sampling will take place quarterly, beginning within 3 months after the date of authorization of injection, then every three months thereafter.

Analytical parameters

One Earth Sequestration LLC will analyze the CO_2 for the constituents identified in **Table 3** using the methods listed. Additional constituents may be included if other sources of CO_2 are delivered to the site. The Director will be notified 60 days in advance of any such changes.

***Table 3**. Summary of analytical parameters for CO_2 stream.*

Parameter	**Analytical Method(s)**[1]
Oxygen (O_2)	ISBT 4.0 (GC/DID) GC/TCD
Nitrogen (N_2)	ISBT 4.0 (GC/DID) GC/TCD
Carbon Monoxide	ISBT 5.0 Colorimetric ISBT 4.0 (GC/DID)
Oxides of Nitrogen	ISBT 7.0 Colorimetric
Total Hydrocarbons	ISBT 10.0 THA (FID)
Methane	ISBT 10.1 GC/FID)
Acetaldehyde	ISBT 11.0 (GC/FID)
Sulfur Dioxide	ISBT 14.0 (GC/SCD)
Hydrogen Sulfide	ISBT 14.0 (GC/SCD)
Ethanol	ISBT 11.0 (GC/FID)
Carbon Isotope	Isotope ratio mass spectrometry
CO_2 Purity	ISBT 2.0 Caustic absorption Zahm-Nagel ALI method SAM 4.1 subtraction method (GC/DID) GC/TCD

Note 1: An equivalent method may be employed with the prior approval of the UIC Program Director.

Sampling methods

CO_2 stream sampling will occur in the compressor building after the last stage of compression. If other CO_2 is delivered to the site, that CO_2 will be sampled at the point of delivery or along the pipeline. A sampling station will be installed with the ability to purge and collect samples into a container that will be sealed and sent to the authorized laboratory.

All sample containers will be labeled with durable labels and indelible markings. A unique sample identification number and sampling date will be recorded on the sample containers.

Laboratory to be used/chain of custody and analysis procedures

Samples will be analyzed by a third-party laboratory using standardized procedures for gas chromatography, mass spectrometry, detector tubes, and photoionization. The sample chain-of-custody procedures described in Section B.3 of the QASP will be employed. The sample integrity and security will be documented through maintenance of a field sampling record and by use of the Chain of Custody form. The laboratory will provide, upon request, documentation of instrument calibration. The laboratory report will include the analytical results as well as reporting detection limits established for each method. The laboratory report will also include a copy of the completed Chain of Custody form.

Corrosion Monitoring

To meet the requirements of 40 CFR 146.90(c), One Earth Sequestration LLC will monitor well materials during the operation period for loss of mass, thickness, cracking, pitting, and other signs of corrosion to ensure that the well components meet the minimum standards for material strength and performance.

One Earth Sequestration LLC will monitor corrosion using the corrosion coupon method and will collect samples according to the description below.

Monitoring location and frequency

For the first two years of injection operations, corrosion monitoring will occur quarterly, by the following dates each year: 3 months after the date of authorization of injection, and then every three months thereafter. For the remainder of injection operations, monitoring will occur annually. There are no plans to monitor the coupons based on injection volumes. If the coupons show evidence of corrosion, the injection well can be assessed for signs of corrosion using well logging techniques such as multi-finger caliper logging or an ultrasonic casing evaluation tool.

Additional monitoring location(s) may be required if other sources of CO_2 are delivered to the injection wells via additional pipeline(s). The Director will be notified 60 days in advance of any such changes. The sampling and analytical program will be modified as needed to meet the requirements of 40 CFR 146.90(c).

Sample description

Samples of material used in the construction of the compression equipment, pipeline, and injection well, which come into contact with the CO_2 stream, will be included in the corrosion monitoring program either by using actual material and/or conventional corrosion coupons. Samples will consist of those items listed in Table 4. Each coupon will be weighed, measured,and photographed prior to initial exposure (see "Sample Handling and Monitoring" below).

Table 4*. List of equipment coupon with material of construction.*

Equipment Coupon	Material of Construction
Pipeline(s)	e.g., CS A106B; Design is TBD
Long String Casing (Upper casing type)	Carbon Steel
Long String Casing (Deep casing type)	Chrome Alloy
Injection tubing	Chrome Alloy
Wellhead	Chrome Alloy
Packers	Chrome Alloy

Monitoring details

Sample Exposure

Each sample will be attached to an individual holder and then inserted in a flow- through pipe arrangement (**Figure 3**). The corrosion monitoring system will be located downstream of all process compression/dehydration/pumping equipment (i.e., at the beginning ofthe pipeline to the wellhead). To accomplish this, a parallel stream of high-pressure CO_2 will be routed from the pipeline through the corrosion monitoring system and then back into a lower pressure point upstream in the compression system. This loop will operate any time injection is occurring. No other equipment will act on the CO_2 past this point; therefore, this location will provide representative exposure of the samples to the CO_2 composition, temperature, and pressures that will be seen at the wellhead and injection tubing. The holders and location of the system will be included in the pipeline design and will allow for continuation of injection during sample removal.

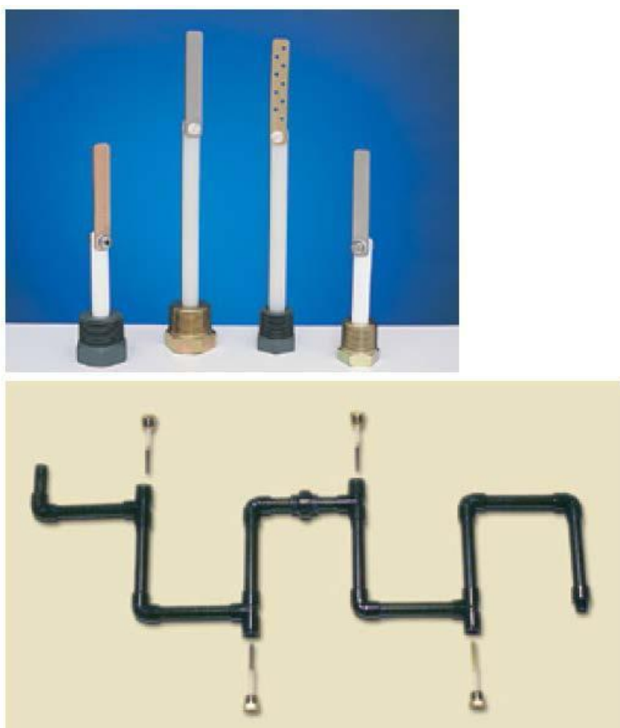

Figure 3. *Coupon holder (top). Flow-through pipe arrangement (bottom).*

Sample Handling and Monitoring

The coupons will be handled and assessed for corrosion using the American Society for Testing and Materials (ASTM) G1-03, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens (ASTM 2011). The coupons will be photographed, visually inspected with a minimum of 10x power, dimensionally measured (to within 0.0001 inch), and weighed (to within 0.0001 gm).

Above Confining Zone Monitoring

One Earth Sequestration LLC will monitor groundwater quality and geochemical changes above the confining zone during the operation period to meet the requirements of 40 CFR 146.90(d). One

ACZ monitoring well will be used to monitor the Ironton/Galesville, the aquifer immediately above the confining layer. The purpose is to monitor whether there is CO_2 or brine migration out of the storage formation. The well will be utilized for pressure and temperature monitoring as well as periodic fluid sampling. If monitoring data indicates that CO_2 has migrated out of the primary storage formation, it will trigger external well integrity testing of the injection well and the deep in zone monitor wells and may trigger an emergency response action described in the Emergency and Remedial Response Plan.

To meet the requirements at 40 CFR 146.95(f)(3)(i), One Earth Sequestration LLC will also monitor groundwater quality, geochemical changes, and pressure in the St. Peter sandstone, the lowermost USDW above the injection zone. The USDW monitoring program will meet the requirements of 40 CFR 146.90 (d) and will include baseline groundwater samples to characterize variations in water quality within the AoR prior to the start of CO_2 injection. Once the injection phase of the project begins, the analytical results will be compared to the baseline conditions for indication of CO_2 or brine migration into the USDW. If indications of CO_2 or brine are found in the USDW, it will trigger the emergency response actions found in the Emergency and Remedial Response Plan.

Monitoring location and frequency

Table 5a shows the planned monitoring methods, locations, and frequencies for ground water quality and geochemical monitoring above the confining zone. Table 5b shows the planned wireline logging program.

The groundwater monitoring plan focuses on the following zones:

- The St. Peter Sandstone – the lowermost USDW.
- The Ironton-Galesville Formation – the zone above the Eau Claire Formation confining zone.

Table 5a. *ACZ monitoring of groundwater quality and geochemical changes.*

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
St. Peter Formation (Lowermost ACZ USDW)	Fluid sampling	Lowermost USDW monitoring well	1 interval. Depth TBD based on site conditions	Baseline (quarterly). Annually thereafter through post-injection operations.
	Pressure/ temperature monitoring	Lowermost USDW monitoring well	1 interval. Depth TBD based on site conditions	Continuous
Ironton-Galesville (Above Confining Zone)	Fluid sampling	ACZ well	1 interval. Depth TBD based on site conditions	One baseline. Annually thereafter through post-injection operations
	Pressure/ temperature monitoring	ACZ well	1 interval. Depth TBD based on site conditions	Continuous

Table 5b. *ACZ indirect monitoring*

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
St. Peter	Pulse Neutron Logging/RST	Lowermost USDW ACZ monitoring well	Continuous to full well depth	Baseline (Once) Annually thereafter
Ironton-Galesville	Pulse Neutron Logging/RST	ACZ Well	Continuous to full well depth	Baseline (Once) Annually thereafter

Note: Baseline sampling and analysis will be completed before injection is authorized.

Analytical parameters

Table 6 identifies the parameters to be monitored and the analytical methods One Earth Sequestration LLC will use for ground water samples.

***Table 6**. ACZ summary of analytical and field parameters for ground water samples.*

Parameters	**Analytical Methods (1)**
Lowermost USDW	
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and Tl	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO_3, and SO_4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Isotopes: $\delta^{13}C$ of Dissolved Inorganic Carbon (DIC)	Isotope ratio mass spectrometry
Total Dissolved Solids	Gravimetry; APHA 2540C
Water Density (field)	Oscillating body method
Alkalinity	APHA 2320B
pH (field)	EPA 150.1
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple
Above Confining Zone	
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and Tl	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO_3, and SO_4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Isotopes: $\delta^{13}C$ of DIC	Isotope ratio mass spectrometry
Total Dissolved Solids	Gravimetry; APHA 2540C
Water Density(field)	Oscillating body method
Alkalinity	APHA 2320B
pH (field)	EPA 150.1
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple

Note 1: ICP = inductively coupled plasma; MS = mass spectrometry; OES = optical emission spectrometry; GC-P = gas chromatography - pyrolysis. An equivalent method may be employed with the prior approval of the UIC Program Director.

Sampling methods

Sampling will be performed as described in Section B.2 of the QASP; this section of the QASP describes the groundwater sampling methods to be employed, including sampling standard operating procedures (SOPs) (Section B.2 a/b), and sample preservation (Section B.2.f).

Laboratory to be used/chain of custody procedures

A qualified, commercial laboratory will be selected to provide analytical services in accordance with the methods and standards included here and in the QASP. Sample handling and custody will be performed as described in Section B.3 of the QASP. Quality control will be ensured using the methods described in Section B.5 of the QASP.

External Mechanical Integrity Testing

One Earth Sequestration LLC will conduct at least one of the tests presented in **Table 7** periodically during the injection phase to verify external MI as required at 146.89(c) and 146.90. MITs will be performed annually, up to 45 days before the anniversary date of authorization of injection each year or alternatively scheduled with the prior approval of the UIC Program Director.

Table 7. *Mechanical integrity tests.*

Test Description	Location
Temperature Log	Along wellbore using DTS or wireline well log
Noise Log	Wireline Well Log
Oxygen Activation Log	Wireline Well Log

Description of MIT(s) That May be Employed

Temperature Logging

Temperature logging detects leaks by measuring temperature anomalies due to fluid movement adjacent to the well bore. Fluid leaks from the wellbore are typically a different temperature compared to native fluids. Temperature logs are run after the well has been shut-in long enough for temperature effects to dissipate, leaving a relatively simple temperature profile (typically ~36 hours). While the absolute gradients may differ due to injection history, the relative profiles should be consistent. If there has been a leak of fluid out of the well, there may be an anomalous heating or cooling effect as compared to the baseline or another log. Gradient variation due to lithologic changes are expected. Distributed fiber sensing or electric wireline deployed temperature measurement devices can be used and should be of sufficient resolution and sufficiently calibrated to detect changes.

Temperature Logging Using Wireline

To ensure the mechanical integrity of the casing of the injection well, temperature data will be recorded across the wellbore from surface down to primary caprock. Bottom hole pressure data near the packer will also be provided. The following procedures, will be employed for temperature logging:

The well should be in a state of injection for at least 6 hours prior to commencing operations to cool injection zones.

1. Move in and rig up an electrical logging unit with lubricator.
2. Run a temperature survey from the top of the confining formation (or higher) to thedeepest point reachable in the injection well while injecting at a rate that allows for safe operations. Should operational constraints or safety concerns not allow for a logging pass while injecting, an acceptable, alternate plan is to stop injecting immediately prior to the first logging pass
3. Stop injection, pull tool back to shallow depth, wait 1 hour.
4. Run a temperature survey over the same interval as step 2.
5. Pull tool back to shallow depth and wait 2 hours.
6. Run a temperature survey over the same interval as step 2.
7. Pull tool back to shallow depth and wait 2 hours.
8. Run a temperature survey over the same interval as step 2.
9. Evaluate data to determine if additional passes are needed for interpretation. Should CO_2 migration be interpreted in the topmost section of the log, additional logging runs over a higher interval will be required to find the top of migration.
10. If additional passes are needed, repeat temperature surveys every 2 hours until 12 hours, over the same interval as step 2.
11. Rig down the logging equipment.
12. Data interpretation involves comparing the time-lapse well temperature profiles and looking for temperature anomalies that may indicate a failure of well integrity, i.e., tubing leak or movement of fluid behind the casing. As the well cools down the temperature profile along the length of the tubing string is compared to the baseline profile. Fluid movement into the annulus or outside the casing creates a temperature anomaly when compared to the baseline cooling profile.

Temperature Logging Using DTS Fiber Optic Line

The injection well will be equipped with a DTS fiber optic temperature monitoring system that can monitor the injection well's annular temperature along the length of the tubing string. The DTS line is used for real-time temperature monitoring and, like a conventional temperature log, can be used for early detection of temperature changes that may indicate a loss of well mechanical integrity. The procedure for using the DTS for well mechanical integrity is asfollows:

1. After the well is completed and prior to injection, a baseline temperature profile will be established. This profile represents the natural temperature gradient for each stratigraphic zone.
2. During injection operation, record the temperature profile for 6 hours prior to shutting in well.
3. Stop injection and record temperature profile for 6 hours.
4. Evaluate data to determine if additional cooling time is needed for interpretation.
5. Start injection and record temperature profile for 6 hours.
6. Data interpretation involves comparing the time-lapse well temperature profiles and looking for temperature anomalies that may indicate a failure of well integrity, i.e., tubing leak or movement of fluid behind the casing. The DTS system monitors and records the

well's temperature profiles at a pre-set frequency in real-time. As the well cools down the temperature profile along the length of the tubing string is compared to the baseline. Fluid movement into the annulus or outside the casing creates a temperature anomaly when compared to the baseline profile. This data can be continuously monitored to provide real-time MIT surveillance making this technology superior to wireline temperature logging.

Noise Logging

A wireline tool is deployed which uses sensitive microphones to detect noise due to flow behind the casing. The sounds are recorded in different frequency ranges at ~100' depth intervals for approximately three to five minutes. If anomalies are detected the depth intervals are shortened to better locate the anomaly. When the level of sound is low, a linear scale is used for reporting noise logs, and, when there are intervals with higher sound, a logarithmic scale is used. Departures from baseline noise levels in the log indicate an anomaly. Ambient noise while injecting that produces a signal greater than 10 millivolts (mV) may indicate leakage or require further investigation.

To ensure the mechanical integrity of the casing of the injection well, logging data will be recorded across the wellbore from surface down to the primary caprock. Bottom hole pressure data near the packer will also be provided. Noise logging will be carried out while injection is occurring. If ambient noise is greater than 10 mv, injection will be halted. The following procedures will be employed:

1. Move in and rig up an electrical logging unit with lubricator.
2. Run a noise survey from the top of the confining formation (or higher) to the deepestpoint reachable in the injection well while injecting at a rate that allows for safe operations.
3. Make noise measurements at intervals of 100 feet to create a log on a coarse grid.
4. If anomalies are evident on the coarse log, construct a finer grid by making noise measurements at intervals of 20 feet within the coarse intervals containing high noiselevels.
5. Make noise measurements at intervals of 10 feet through the first 50 feet above the injection interval and at intervals of 20 feet within the 100-foot intervals containing:
6. The base of the lowermost bleed-off zone above the injection interval and
7. The base of the lowermost USDW.
8. Additional measurements may be made to pinpoint depths at which noise is produced.
9. Use a vertical scale of 1 or 2 inches per 100 feet.
10. Rig down the logging equipment.
11. Interpret the data as follows: Determine the base noise level in the well (dead well level). Identify departures from this level. An increase in noise near the surface due to equipment operating at the surface is to be expected in many situations. Determine the extent of fluid movement; flow into or between USDWs indicates a lack of mechanical integrity; flow from the injection zone into or above the confining zone indicates a failure ofcontainment.

Oxygen Activation (OA) Logging

A wireline tool is deployed to activate oxygen by emitting high-energy neutrons from a neutron source. The activated isotopes emit gamma radiation which is measured by the wireline tool. Gamma-ray measurements are used to calculate water flow direction and velocity. If water flow outside of the casing is detected it could indicate the potential loss of external mechanical integrity.

To minimize false positives, a calibration will be performed, and measurements will be confirmed at several nearby depths and/or under a minimum of three varying injection rates.

To ensure the mechanical integrity of the casing of the injection well, logging data will be recorded across the wellbore from surface down to primary caprock. Bottom hole pressure data near the packer will also be provided. OA logging will be carried out while injection is occurring. The following procedures will be employed:

1. Move in and rig up an electrical logging unit with lubricator.
2. Conduct a baseline Gamma-ray Log and casing collar locator log from the top of the injection zone to the surface prior to taking the stationary readings with the OA tool. (Gamma-ray Log is necessary to evaluate the contribution of naturally occurring background radiation to the total gamma radiation count detected by the OA tool. There are different types of natural radiation emitted from various geologic formations or zones and the natural radiation may change over time.
3. The OA log shall be used only for casing diameters of greater than 1-11/16 inches andless than 13- 3/8 inches.
4. All stationary readings should be taken with the well injecting fluid at the normal ratewith minimal rate and pressure fluctuations.
5. Prior to taking the stationary readings, the OA tool must be properly calibrated in a “no vertical flow behind the casing” section of the well to ensure accurate, repeatable tool response and for measuring background counts.
6. Take, at a minimum, a 15-minute stationary reading adjacent to the confining interval located immediately above the injection interval. This must be at least 10 feet above the injection interval so that turbulence does not affect the readings.
7. Take, at a minimum, a 15-minute stationary reading at a location approximately midway between the base of the lowermost USDW and the confining interval located immediately above the injection interval.
8. Take, at a minimum, a 15-minute stationary reading adjacent to the top of the confining zone.
9. Take, at a minimum, a 15-minute stationary reading at the base of the lowermost USDW.
10. If flow is indicated by the OA log at a location, move uphole or downhole as necessary at no more than 50-foot intervals and take stationary readings to determine the area of fluid migration.
11. Interpret the data: Identification of differences in the activated water’s measured gamma-ray count-rate profile versus the expected count-rate profile for a static environment. Differences between the measured and expected may indicate flow in the annulus or behind the casing. The flow velocity is determined by measuring the time that the activated water passes a detector.

<u>Pressure Fall-Off Testing</u>

One Earth Sequestration LLC will perform pressure fall-off tests during the injection phase as described below to meet the requirements of 40 CFR 146.90(f). Pressure Fall-Off tests are required to demonstrate to measure formation properties in the vicinity of the injection well (e.g., transmissivity).

Baseline pressure fall-off tests (PFO) will be conducted as described in the Pre-Operational Testing Plan (See Narrative). During the injection phase of the project, a PFO will be conducted in the injection wells every five years and at end of the injection period. The objective of the PFO testing is to periodically monitor for changes in the near wellbore environment that would impact injectivity or cause injection pressures to increase (US EPA, 2013). The formation characteristics obtained through the PFO testing will be compared to the results from previous tests to identify changes over time, and they will be used to calibrate the computational models. Finally, if an anomalous pressure drop occurs during the PFO, it may indicate an issue with well integrity (US EPA, 2013).

Testing location and frequency

Pressure fall-off testing will be performed in each well:

- As part of pre-operational testing (baseline)
- During Injection Operations:
    - Every five years and,
    - At end of the injection period

Testing details

Pressure Fall-off Test Procedure

A pressure falloff test has a period of injection followed by a period of no-injection or shut-in. Normal injection will be used during the injection period preceding the shut-in portion of the falloff tests. However, if the rate causes relatively large changes in bottomhole pressure, the rate may be decreased. A minimum, one week of relatively continuous injection will precede the shut-in portion of the falloff test. The pressure fall-off data will be measured using a downhole gauge sampling at 5-second intervals. The gauges may be those used for day-to-day data acquisition, or a pressure gauge conveyed via wireline. Surface or downhole gauges will be used to inform test duration. To reduce the wellbore storage effects attributable to the pipeline and surface equipment, the well will be shut-in at the wellhead nearly instantaneously with direct coordination with the injection compression facility operator. The shut-in period of the falloff test will be adequate to assure that enough pressure transient data are collected to calculate the average pressure. Quantitative analysis of the measured data is used to estimate formation characteristics, including transmissivity, permeability, and a skin factor. The measured parameters will be compared to those used in site computational modeling and AoR delineation.

Carbon Dioxide Plume and Pressure Front Tracking

One Earth Sequestration LLC will employ direct and indirect methods to track the extent of the carbon dioxide plume and the presence or absence of elevated pressure during the operation period to meet the requirements of 40 CFR 146.90(g).

Evolution of the threshold pressure gradient in the injection zone, and through injection operations, is summarized in **Figure 4**, Predicted pressure profiles of the bottom-hole pressure at the injection wells are shown in **Figure 5**.

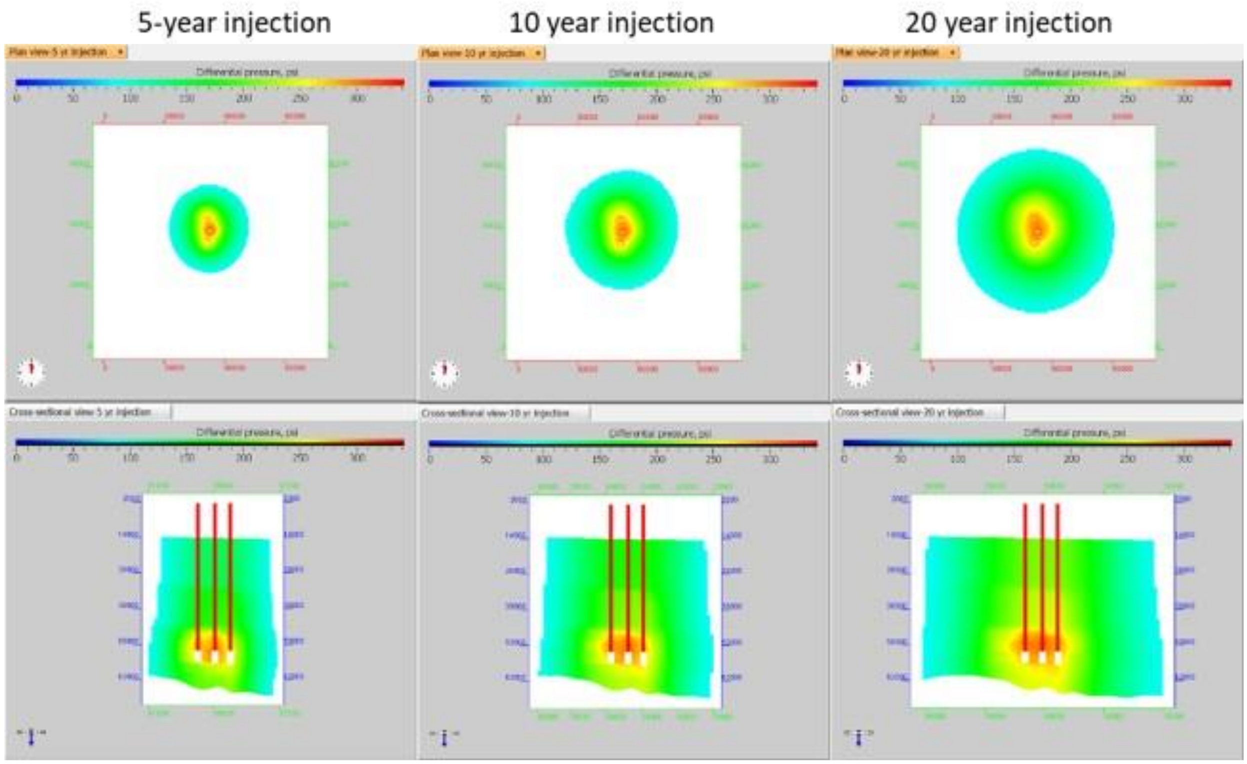

Figure 4. *Threshold pressure front evolution.*

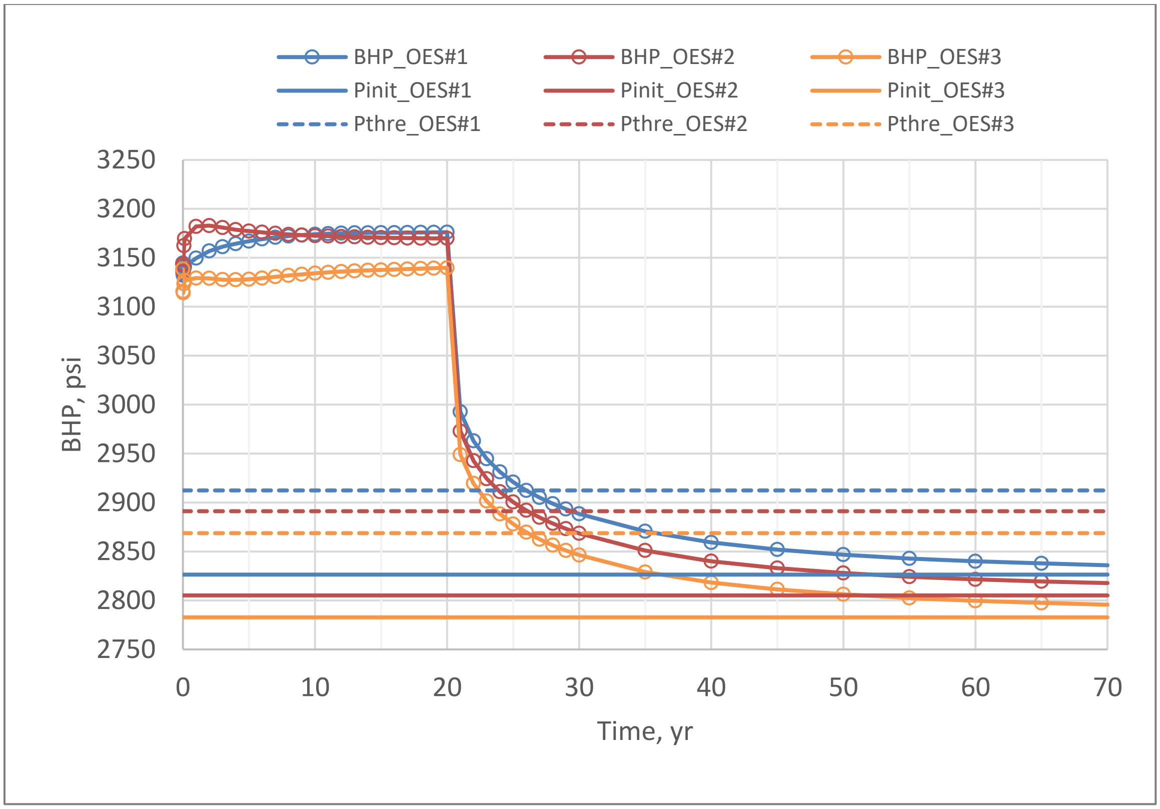

***Figure 5**. Bottomhole pressure profiles of injection wells.*

Monitoring locations relative to the predicted location of the CO_2 plume and pressure front at 5-year intervals throughout the injection phase are shown in Figures 6 through 9.

Two in-zone monitoring (IZM) wells are proposed for the site. OEE #1, the stratigraphic test well drilled for the purpose of site characterization, but constructed for the purpose of monitoring, will provide the initial in-zone monitoring location. A second IZM well, location to be determined (TBD), is also planned for installation. The location of the second IZM will be identified after 5 years of injection operations, or after 10 million tonnes of CO_2 injection, whichever occurs first. The location will be based on data from OEE #1 and, if available, the results of the first time-lapse 2D survey. As shown in **Figure 6**, the CO_2 plume is not projected to reach IZM #1 through the first five years of injection. The second in-zone monitoring well location will be proposed to the director following completion of the updated dynamic model. Based on concurrence from the Director, the well then will be installed.

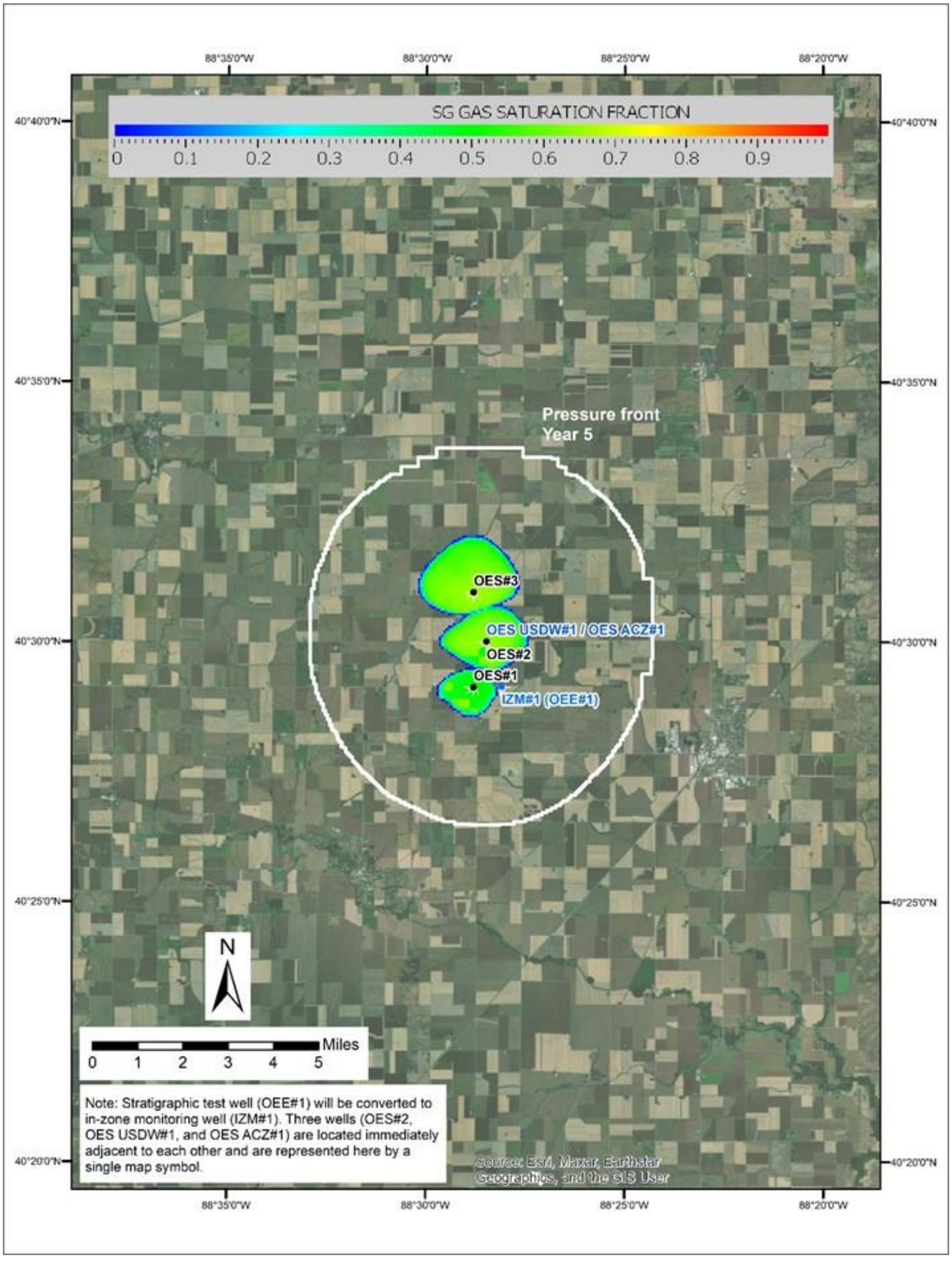

Figure 6. *Modeled CO_2 plume location and pressure front (white line) after 5 years of injection.*

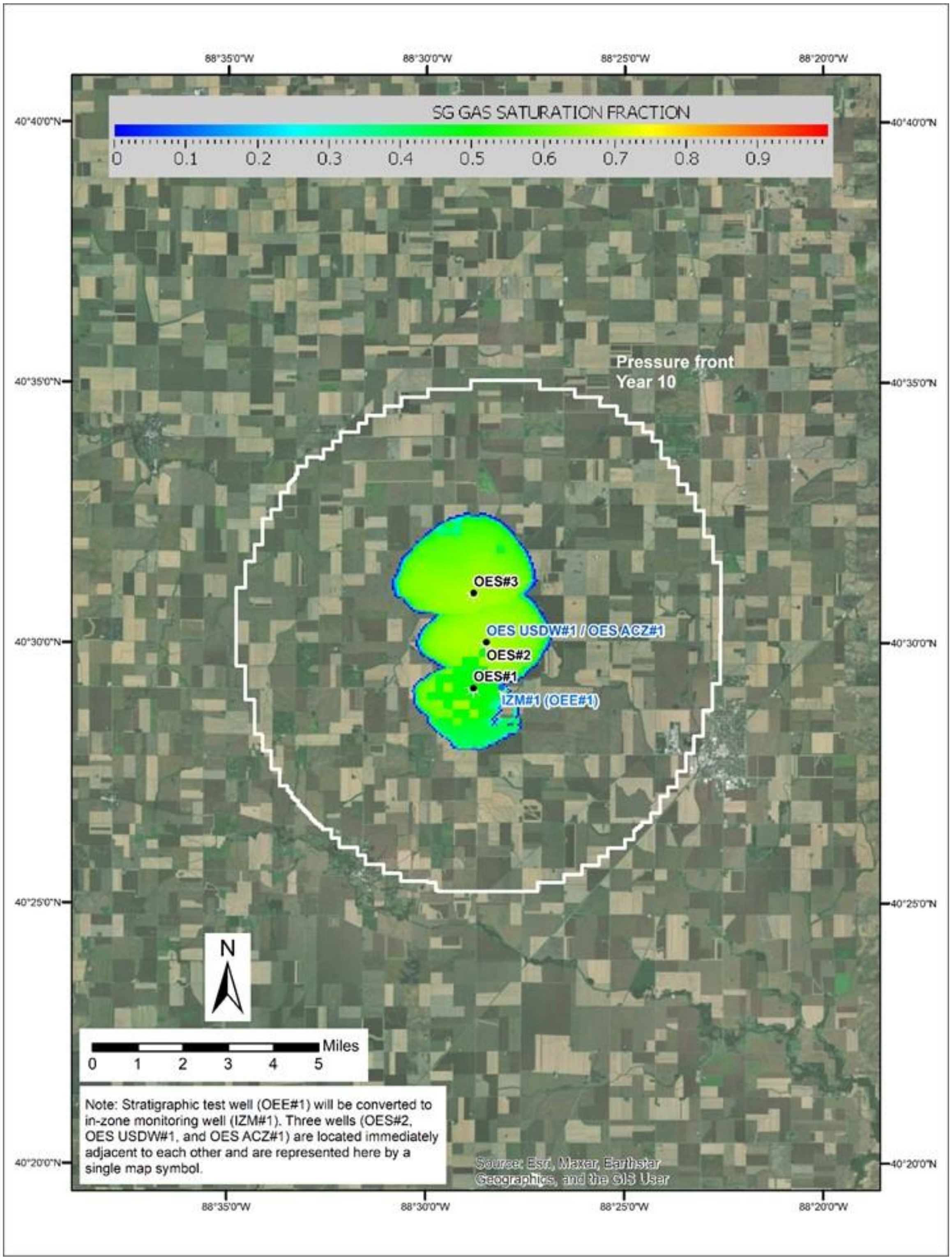

Figure 7*. Modeled CO_2 plume location and pressure front (white line) after 10 years of injection.*

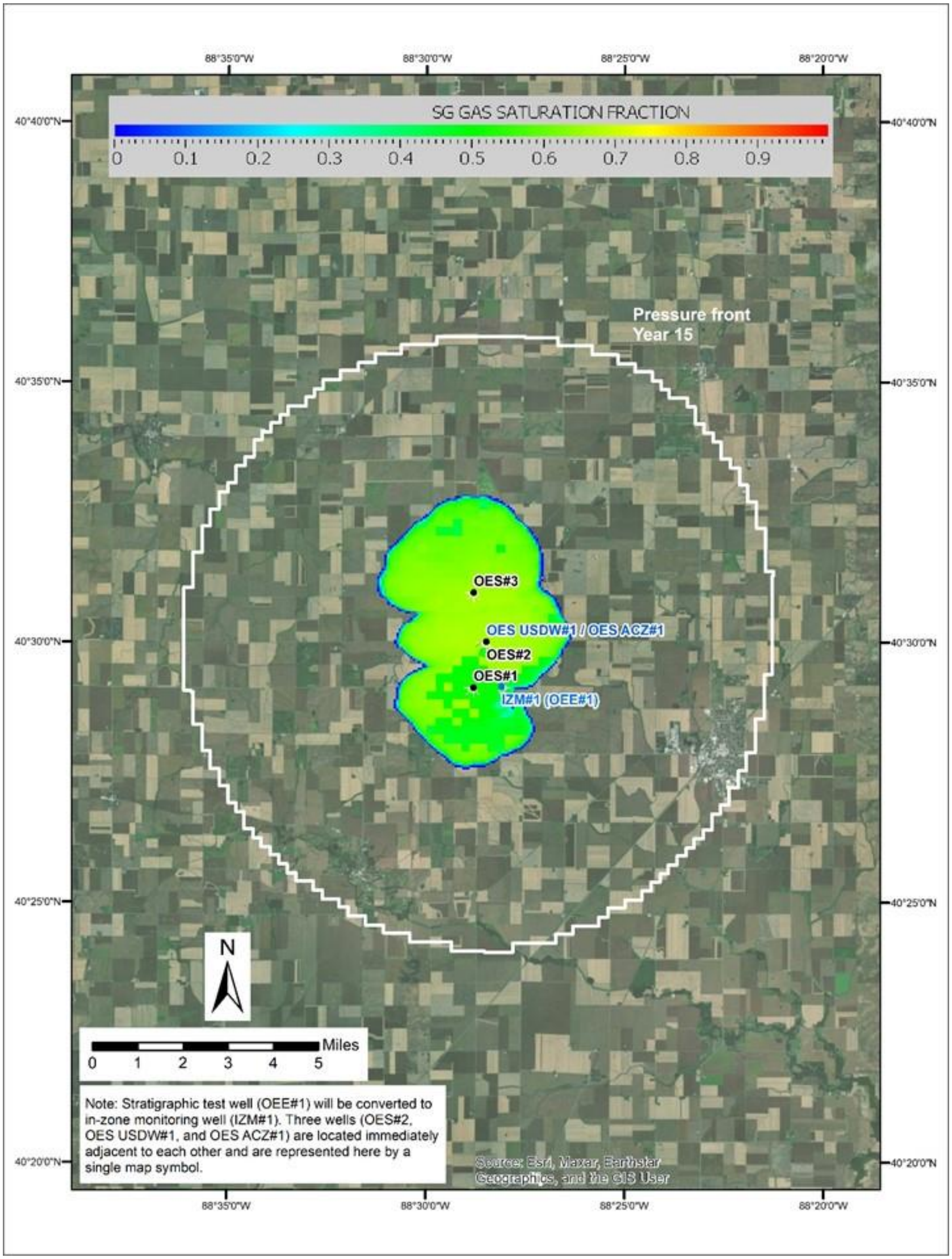

***Figure 8**. Modeled CO_2 plume location and pressure front (white line) after 15 years of injection.*

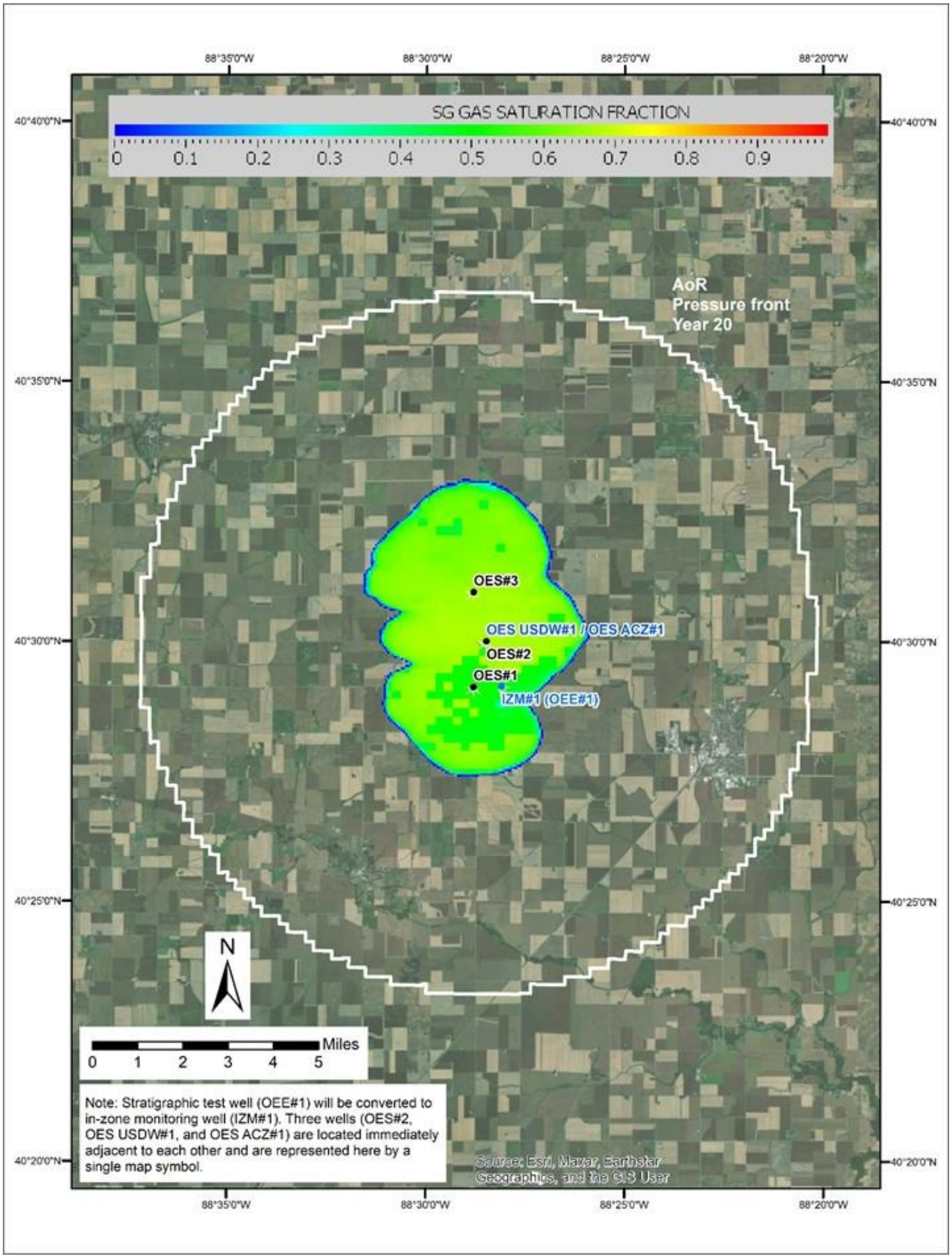

Figure 9*. Modeled CO_2 plume location and pressure front (white line) after 20 years of injection.*

Pressure and temperature sensors in the IZM wells will be used to measure pressure and temperature variations in the storage formation in the pre-operational, injection, and post-injection phases of the project (40 CFR 146.90 (g)). Note that the second IZM wells will begin continuous pressure and temperature monitoring upon completion. The gauges will record the data that will be retrieved and reviewed monthly. Additional detail regarding the gauges is included in the QASP. The IZM wells also will be used to collect fluid samples from the storage formation to monitor for changes in the water chemistry over time and verify when the leading edge of the CO_2 plume reaches the IZM well. Once there is CO_2 breakthrough, fluid sampling will be discontinued in that IZM well.

Pulsed neutron logging detects leaks by measuring changes in the capture cross-section of the fluids and gasses in the pore space of the rock using a wireline tool that emits neutrons which are slowed to a thermal velocity through elastic and inelastic collisions with the nuclei of the environment's elements and ultimately captured. These interactions are sensitive to fluid type and saturation changes in the formation and in the casing-formation annulus. Therefore, pulsed neutron measurements can be used to monitor the formation fluids as well as identify mechanical integrity problems. The pulsed neutron Sigma (Σ) is the thermal neutron capture cross-section or the rate at which thermal neutrons are captured by the formation matrix and fluids. The capture cross-section can be used to detect fluid changes behind the casing over time to verify the well external mechanical integrity. Open hole wireline logs for lithologic definition and baseline pulsed neutron logs are key inputs to this type of monitoring.

Pulsed neutron (sigma mode)/RST logs will be acquired in the injection and IZM wells to identify the saturation of CO_2 close to the well bores and the stratigraphic intervals that may contain CO_2. This monitoring activity also will be used to examine for the presence of CO_2 above the confining zone. The pressure and pulsed neutron log data will be used to calibrate the dynamic simulation during the injection and post-injection phases of the project.

Indirect techniques will be used to monitor the development of the CO_2 plume and the associated pressure front through the injection and post injection project phases (40 CFR 146.90 (g)). Time-lapse 2D surface seismic data will be used to qualitatively monitor the CO_2 plume distribution and calibrate the computational modeling results over time. The time-lapse 2D surface seismic data will also be used to verify CO_2 containment within the storage formation.

Plume monitoring location and frequency

One Earth Sequestration LLC will conduct fluid sampling and analysis to detect changes in groundwater to directly monitor the carbon dioxide plume. The parameters to be analyzed as part of fluid sampling in the injection zone and analytical methods are described above in the monitoring section. One Earth Sequestration LLC will additionally deploy pressure/temperature sensors coupled with DTS to directly monitor the position of the pressure front and temperature changes in and above the primary confining unit.

Indirect plume monitoring will include pulsed neutron capture RST logs to monitor CO_2 saturation in the injection and IZM wells. In addition, time-lapse 2D seismic will be used to assess the extent

and position of the CO_2 plume. **Figure 10** shows the location of the 2D lines acquired as part of site characterization. The repeat 2D seismic will follow Line 1 and the 2019 Gibson line.

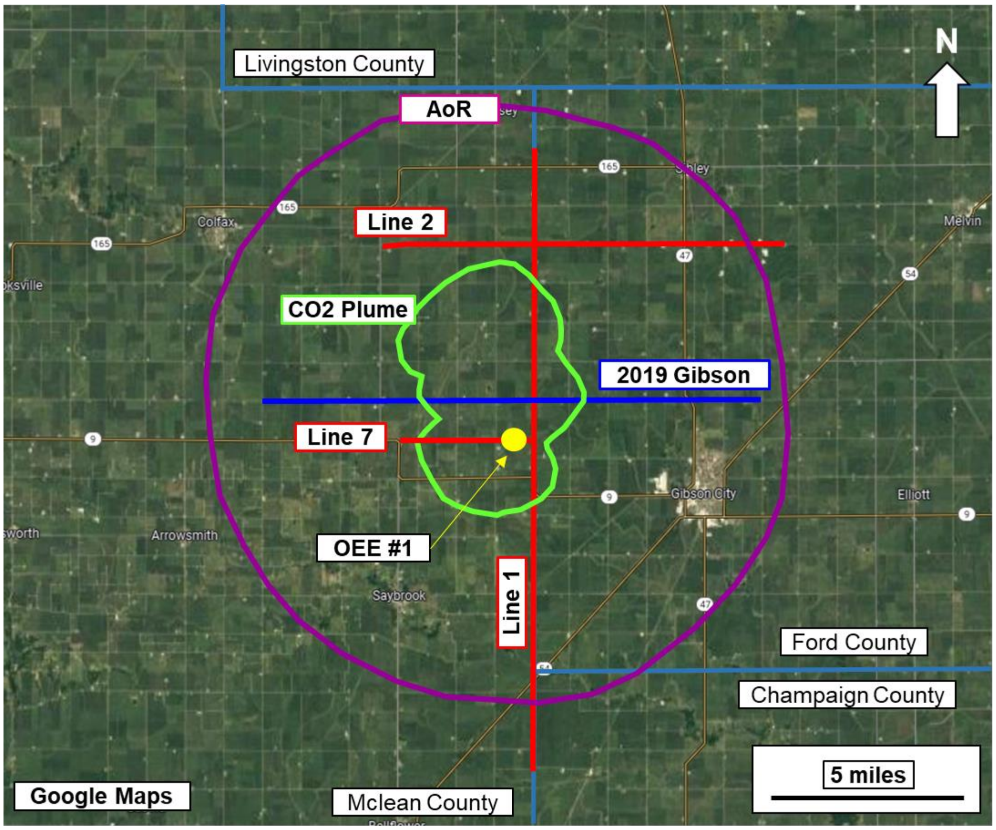

Figure 10. *2D seismic lines acquired during site characterization. Note CO_2 plume (in green) and AoR (purple) outlines have been generalized.*

Quality assurance procedures for seismic monitoring methods are presented in Section B.9 of the QASP.

Plume monitoring details

Table 8 presents the methods that One Earth Sequestration LLC will use to monitor the position of the CO_2 plume, including the activities, locations, and frequencies One Earth Sequestration LLC will employ. The parameters to be analyzed as part of fluid sampling in the injection zone and associated analytical methods are presented in **Table 9**. Quality assurance procedures for these methods are presented in the QASP.

Table 8. *Plume monitoring activities.*

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
		Direct Plume Monitoring		
Injection Zone	Fluid sampling	IZM wells	1 interval. Depth TBD based on site conditions	Baseline (Once); Annual starting at end of first year of injection. (Fluid sampling will be discontinued at each respective IZM well once the monitoring zone is saturated with CO_2)
		Indirect Plume Monitoring		
Injection Zone	Pulse Neutron Logging/RST	Deep monitoring wells	Continuous to full well depth	Baseline (once), Annually thereafter
		Injection Well	Continuous to full well depth	Baseline (once), Annually thereafter through injection operations (and PISC until P&A)
	2D surface seismic survey	Cross-sectional coverage	Fold Image Coverage approximately 40 miles	Baseline (once) 1st after 4 years of injection 2nd after 9 years of injection Every 10 years thereafter

Table 9. *IZM summary of analytical and field parameters for fluid sampling.*

Parameters	Analytical Methods
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and Tl	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO_3, and SO_4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Isotopes: $\delta^{13}C$ of DIC	Isotope ratio mass spectrometry
Total Dissolved Solids	Gravimetry; APHA 2540C
Water Density (field)	Oscillating body method
Alkalinity	APHA 2320B
pH (field)	EPA 150.1
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple

Pressure-front monitoring location and frequency

Table 10 presents the methods that One Earth Sequestration LLC will use to monitor the position of the pressure front, including the activities, locations, and frequencies.

Table 10. *Pressure front monitoring.*

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
Direct Pressure-Front Monitoring				
Mt. Simon	Pressure/ temperature monitoring	IZM #1	Sensitive, Confidential, or Privileged Information [redacted]	Continuous
		IZM #2		Continuous
		Injection Wells		Continuous

Quality assurance procedures for these methods are presented in Section A.4 of the QASP.

<u>Continuous Recording of Injection Pressure, Rate, and Volume; Annulus Pressure</u>

One Earth Sequestration LLC will install and use continuous recording devices to monitor injection pressure, rate, and volume, the pressure on the annulus between the tubing and the long string casing, and the annulus fluid volume added.

One Earth Sequestration LLC will perform the activities identified in Table 11 to verify internal mechanical integrity of the injection well and monitor injection pressure, rate, volume, and annular pressure as required at 40 CFR 146.88, 146.89, and 146.90(b). All monitoring will be continuous for the duration of the operation period, and at the locations shown in the table. The injection wells will have pressure/temperature gauges at the surface and in the tubing at the packer. In addition, there will be DTS and DAS fibers in the injection wells.

Table 11. *Locations for continuous monitoring in injection wells.*

Test Description	Location
Annular Pressure Monitoring	Surface
Injection Pressure Monitoring	Surface
Injection Pressure Monitoring	Reservoir - Proximate to packer
Injection Rate Monitoring	Surface
Injection Volume Monitoring	Surface
Temperature Monitoring	Surface
Temperature Monitoring	Reservoir - Proximate to packer
Temperature Monitoring	Along wellbore to packer using DTS
Acoustic Monitoring	Along wellbore to packer using DAS

Above-ground pressure and temperature instruments shall be calibrated over the full operational range at least annually using ANSI or other recognized standards. In lieu of removing the injection tubing, downhole gauges will demonstrate accuracy by using a second pressure gauge, with current certified calibration, that will be lowered into the well to the same depth as the permanent downhole gauge. Pressure transducers shall have a drift stability of less than 1 psi over the operational period of the instrument and an accuracy of ± 5 psi. Sampling rates will be at least once per 5 seconds. Temperature sensors will be accurate to within one degree Celsius. DTS sampling rate will be once per 10 seconds.

Flow will be monitored with a mass flowmeter at the wellhead. The flow meter will be either an orifice meter with flow computer or a Coriolis meter. The meter will be calibrated using accepted standards and be accurate to within ± 0.1 percent. The meter will be calibrated for the entire expected range of flow rates.

Injection Rate and Pressure Monitoring

One Earth Sequestration LLC will monitor injection operations using a process control system, as presented below. For remote instrumentation installed at the wellhead, data will be transmitted back to the process control system via a secure data transmission system that allows for continuous monitoring and alarming to the operator. Loss of communication with the remote monitoring equipment will be alarmed to the operator as well.

The Surface Facility Equipment & Control System will limit maximum flow to 4,225 MT/day per well, and/or limit the well head pressure to 2,498 psia, 2,480 psia, and 2,462 psia for injection wells OES #1, OES #2, and OES #3, respectively, which corresponds to the regulatory requirement to not exceed 90% of the injection zone's fracture pressure. All injection operations will be continuously monitored and controlled by the One Earth Sequestration LLC operations staff using the distributed process control system. This system will continuously monitor, control, record, and will alarm and shutdown if specified control parameters exceed their normal operating range.

More specifically, all critical system parameters, e.g., pressure, temperature, and flow rate will have continuous electronic monitoring with signals transmitted back to a master control system. One Earth Sequestration LLC supervisors and operators will have the capability to monitor the status of the entire system from the distributed control center.

Calculation of Injection Volumes

Flow rate is measured at ground surface. Actual density is computed from pressure and temperature measurements at the flow meter location. The downhole pressure and temperature data will be used to perform the injectate density calculation.

The volume of CO_2 injected will be calculated from the mass flow rate obtained from the mass flow meter installed on the injection line. The mass flow rate will be divided by density and multiplied by injection time to determine the volume injected.

Density will be calculated using an industry standard correlation. The Standard Annulus Pressure Test (SAPT) is used to demonstrate the absence of significant leaks in tubing, casing, and packer.

This test is based on the principle that a pressure applied to fluids filling a sealed vessel will persist. A well's annulus system, though closed to transfer of matter, is not closed to energy transfer because it is not isolated from transfer of heat from its surroundings, therefore an allowance for small pressure changes is necessary. The test provides an immediate demonstration of whether leaks, detectable by these means, exist.

The interpretation and confirmation of the SAPT included: Comparison of the pressure change through the test period to 3% of the test pressure (0.03 X test pressure). If the annulus test pressure changes by this amount or more (gain or loss), the well has failed to demonstrate mechanical integrity, and operation may constitute a violation of the UIC regulations. If the annulus test pressure changes by less than 3 percent (gain or loss) over the test period, the well has demonstrated mechanical integrity, pursuant to 40 C.F.R. § 146.8(a)(1).

Appendix: Quality Assurance and Surveillance Plan

(Submitted as separate files)

TESTING AND MONITORING PLAN
40 CFR 146.90

One Earth CCS

Facility Information

Facility name:	One Earth Sequestration LLC OES #3
Facility contact:	Mark Ditsworth, VP of Technology and Special Projects One Earth Sequestration LLC, 202 N Jordan Drive, Gibson City (217) 784-5321 ext. 215 mditsworth@oneearthenergy.com
Well location:	McLean County, IL 40.515829°N, -88.479947°W, (NAD 1983)

This Testing and Monitoring Plan describes how One Earth Sequestration LLC will monitor the One Earth CCS project activities pursuant to 40 CFR 146.90. The data acquired by the monitoring and testing procedures will be used to demonstrate that injection wells are operating as planned, that the carbon dioxide (CO_2) plume and pressure front are evolving as predicted, and that there is no endangerment to underground sources of drinking water (USDW). Additionally, the monitoring and testing data will be used to validate and refine geological models and simulations used to forecast the distribution of the CO_2 within the storage zone, support AoR re-evaluations, and to demonstrate non-endangerment. Results of the testing and monitoring activities described below may trigger action according to the Emergency and Remedial Response Plan.

Overall Strategy and Approach for Testing and Monitoring

This Testing and Monitoring Plan describes how the One Earth Sequestration LLC will monitor the site pursuant to 40 CFR 146.90.

Figure 1 and **Figure 2** provide a plan view and cross section of the Area of Review (AoR). The AoR and Corrective Action Plan discuss the technical basis for determination of the AoR and how monitoring data will be used to re-evaluate the AoR during the injection phases of the project (40 CFR 146.84 (e)). Data from a characterization well drilled specifically for this project (OEE #1) were used to develop the static earth model (SEM) and perform multi-phase flow modeling (See Narrative). The results of the modeling and simulations are the basis for determining the AoR and were used to develop the Testing and Monitoring Plan. The AoR will be reevaluated upon completion and testing of the injection wells if new data are obtained from the wells that may significantly change model predictions and the delineated AOR.

Sensitive, Confidential, or Privileged Information [redacted] Three injection wells are planned for the site (**Table 1**).

The Corrective Action Plan indicates that there are/are no penetrations (except for OEE #1) within the AoR that penetrate the confining units including the Eau Claire Formation, the primary seal. OEE #1 will be utilized as an In-Zone Monitoring (IZM) well.

The Testing and Monitoring Plan has been developed to identify and reduce risks associated with CO_2 injection into the subsurface. Goals of the monitoring strategy include:

- Meet the regulatory requirements of 40 CFR 146.90
- Protect underground sources of drinking water (USDW)
- Ensure that each injection well is operating as planned
- Ensure that each injection well is maintained as planned
- Provide data to validate and calibrate the geological and dynamic models used to predict the distribution of CO_2 within the injection zone
- Support AoR re-evaluations over the course of the project

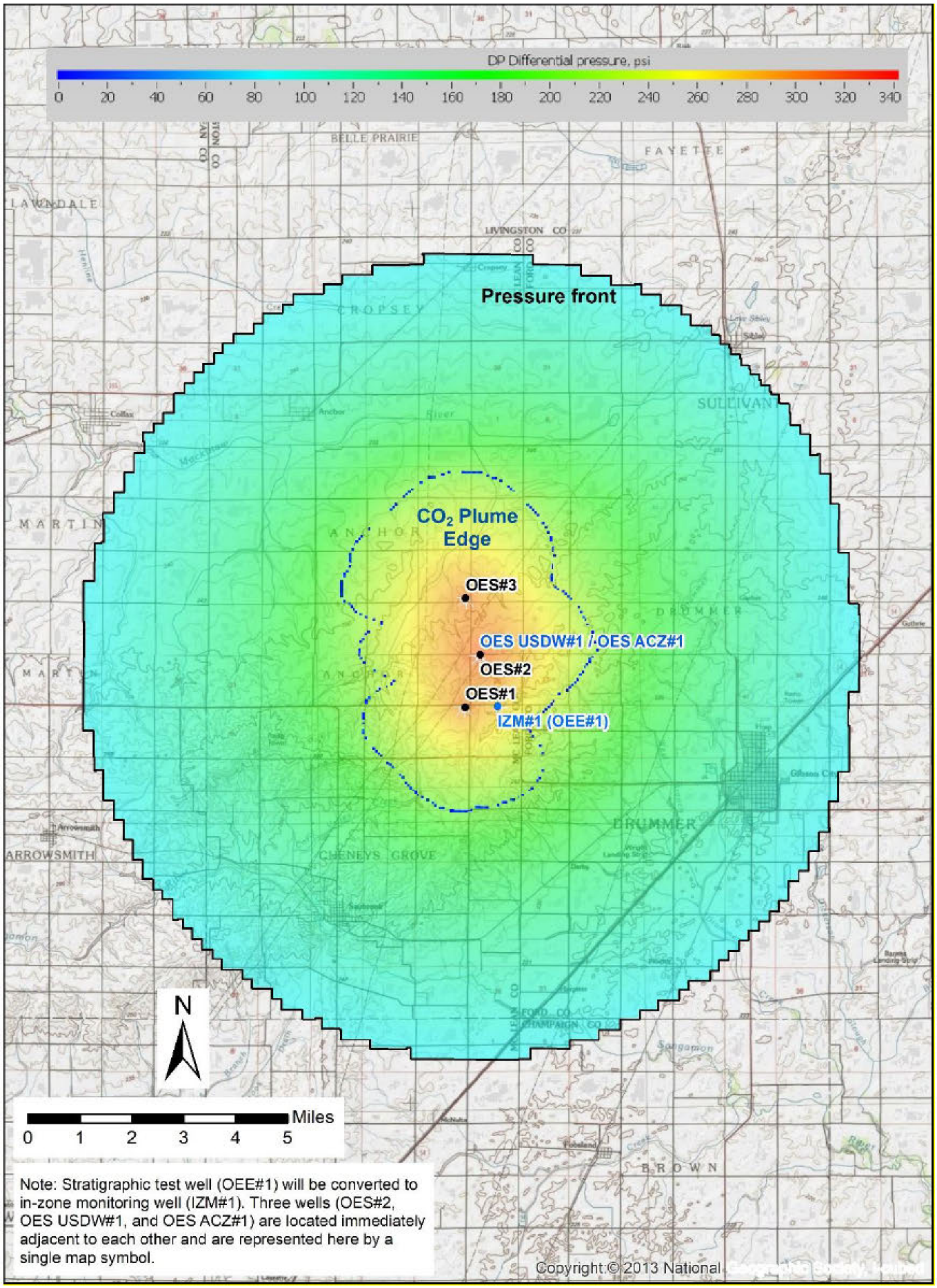

***Figure 1**. Project Area of Review. CO_2 plume and pressure front through active injection of 90 million tonnes.*

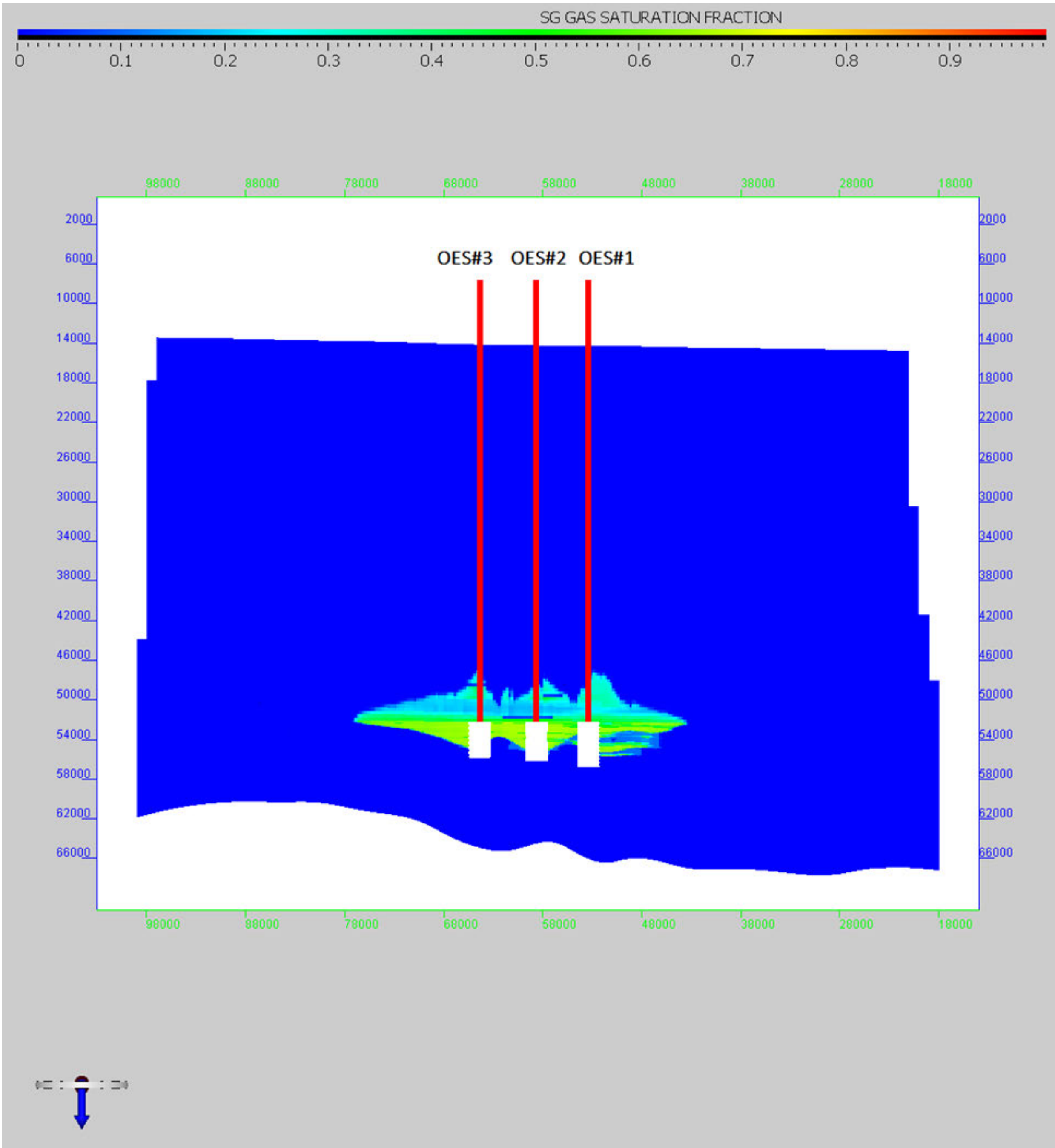

Figure 2*. Cross section of Area of Review pressure front and CO_2 plume at the end of injection.*

The Testing and Monitoring Plan will utilize direct and indirect monitoring technologies that will monitor:

- Injectate composition to demonstrate that it is consistent with the permit 40 CFR 146.90(a)
- Corrosion of well materials and components (40 CFR 146.90(c))
- Determine whether CO_2 or brine has migrated above the Confining Zone (ACZ) (40 CFR 146.90(d))
- USDW groundwater quality (40 CFR 146.95(f)(3)(i))
- Well integrity over the injection phase of the project (40 CFR 146.89(c) and 146.90)
- Near well-bore environment using pressure fall-off testing (40 CFR 146.90(f))
- Development of the CO_2 plume and pressure front in the storage formation over time (40 CFR 146.90(g))

Injection operations will be monitored using a range of techniques and methods as required by 40 CFR 146.88(e) and 146.90(b). Injection operations are discussed in more detail in Narrative Section: Well Operation. Continuous recording devices will monitor wellhead injection pressure, temperature, and flow rate (40 CFR 146.90 (b)). A Coriolis flow meter, which measures mass flow rate directly, or an orifice meter which measures flow volume with a calculated mass flow rate, will be installed on the injection line at surface.

The annular pressure between the tubing and the injection casing strings and the annular fluid volumes also will be monitored on a continuous basis (40 CFR 146.90 (b)). These data will be linked into a supervisory control and data acquisition (SCADA) system to record the operations data, control injection rates, or initiate system shutdown, if needed. The SCADA system can also be used to adjust the volume of annular fluid, and thereby pressure, in the annular space to meet the operational and regulatory objectives. Pressure and temperature will be measured continuously using pressure gauges to establish a wellhead-to-packer pressure correlation. This correlation can be used to calculate the injection pressure at the reservoir (perforated interval) at any time using the wellhead and downhole pressure data. The reservoir pressures and temperatures will also be used to calculate the injection rate at the reservoir, and the injection volumes will be used to update the computational models at regular intervals throughout the injection phase of the project (AoR and Corrective Action Plan).

Pre-operational logging and testing (See Narrative) will establish baseline mechanical integrity of the injection wells. External mechanical integrity will be monitored continuously using distributed temperature sensors (DTS) mounted to the exterior of the injection well casing and cemented into place. External mechanical integrity will be confirmed through annual logging and compared back to baseline logging data to identify deflections from that could indicate fluid flow behind the casing (40 CFR 146.90 (e)). Annual testing will include oxygen activation logging, temperature logging (wireline or DTS), or noise logging.

Monitoring wells will be used to evaluate the plume and pressure front development in the injection zone, and to assure containment and protection of USDWs. The injection wells and IZM wells will be used for wireline logging and will be equipped with gauges and instrumentation to measure pressure (downhole gauge), temperature (DTS) and acoustics (DAS). These wells will provide DTS and DAS data along the length of the well from above the perforated interval to above the lowermost USDW. The IZM wells will be utilized for fluid sampling (fluid sampling will be discontinued once there is CO_2 breakthrough at the well). Above confining zone (ACZ) monitoring wells will include a well set in the brine-saturated zone above the primary confining unit and a well in the lowermost USDW. These wells will be used for fluid sampling and will be equipped with pressure gauges.

A summary of the monitoring well type and well ID is shown in Table 1. Proposed well locations are shown in **Figure 1**.

Table 1. *One Earth CCS well summary.*

Well Type	Well ID	Notes
Injection	OES #1	Sensitive, Confidential, or Privileged Information [redacted]
	OES #2	
	OES #3	
IZM	IZM #1	
	IZM #2	
ACZ	OES USDW #1	
	OES ACZ #1	
Geophysical Monitoring Wells	TBD	

All monitoring locations are either on One Earth CCS property or will be accessible through property access agreements with the landowner. Other monitoring will include annular pressure monitoring for the injection wells and corrosion monitoring.

To date, One Earth Sequestration, LLC (OWNER) has successfully negotiated surface land access for purposes of drilling the stratigraphic well, and pre-injection (baseline) monitoring activities such as 2D and 3D seismic testing. The OWNER's proven ability to work with local landowners and public entities to obtain access to surface and subsurface areas for activities related to the project should be sufficient to demonstrate the OWNER's ability to obtain access for monitoring, and corrective actions (if they are necessary) in the future. The OWNER may acquire, by lease or purchase, additional land parcel areas and surface entry rights for the injection, monitoring, and surface and sub-surface infrastructure. Monitoring well locations could change slightly but only to the extent that they retain their monitoring intent as described in the Testing and Monitoring Plan (QASP). Monitoring locations will also consider access routes that minimize property damage, crop loss, and property owner inconvenience. And to assure safe access to each location.

The Testing and Monitoring Plan will be adaptive over time in that the plan can be adjusted to respond:

- As project risks evolve over the course of the project
- If significant differences between the monitoring data and dynamic simulation predictions are identified
- If monitoring indicates anomalous results related to well integrity or the loss of containment.

Table 2 presents the general schedule and spatial extent for the monitoring activities in the baseline and injection phases of the project based on the current understanding of the site. The monitoring program will follow the Testing and Monitoring plan to establish that CO_2 injection is occurring in a stable and predictable manner. If, however, anomalous results are identified in the monitoring data, changes to the monitoring schedule or methods may be required. Changes to the Testing and Monitoring Plan will be made in consultation with the UIC Program Director (40 CFR 146.90 (j)).

***Table 2**. Testing and monitoring activities summary for the One Earth CCS project.*

Monitoring Activity	**Baseline Data Frequency**	**Injection Phase Frequency**	**Location**
		Operational Monitoring	
CO_2 Injectate Compositional and Isotopic Analysis	Once	Quarterly	CO_2 Delivery Pipeline
Corrosion Coupon Analysis	NA	Quarterly years 1 and 2; annually thereafter	CO_2 Delivery Pipeline
		Injection Monitoring	
Injection Pressure	NA	Continuous	Injection Wellheads
Mass Injection Rate	NA	Continuous	Injection Wellheads
Injection Volume (calculated)	NA	Continuous	Reservoir
Annular Pressure	NA	Continuous	Injection Wellheads
Annular Fluid Volume	NA	Continuous	Injection Wellheads
Temperature and acoustics (DTS and DAS)	Continuous	Continuous	Injection and IZM wells. Downhole, above perforations
		Mechanical Integrity Testing	
Temperature or Noise or Oxygen Activation Log	Once	Annually	Injection Wells
PFO Tests	Once	Every five years and at end of injection period	Injection Wells
DTS	Continuous	Continuous	Injection wells. Downhole, above perforations
		Verification Monitoring (Fluid Sampling)	
St. Peter sandstone	Once	Annually	ACZ USDW well

Monitoring Activity	Baseline Data Frequency	Injection Phase Frequency	Location
Ironton Galesville formations	Once	Annually	ACZ Well
Mt. Simon	Once	Annually*	IZM Wells
Isotope Analysis	Once	Annually	ACZ and IZM wells
	Verification Monitoring (Pressure, DTS, DAS)		
St. Peter Sandstone	Continuous	Continuous	ACZ USDW well
Ironton and Galesville formations	Continuous	Continuous	ACZ well
IZM Mt. Simon Sandstone	Continuous	Continuous	IZM wells
Pulsed Neutron Logging	Once	Annually for the first 5 years of injection then every 2 years thereafter	Injection Wells ACZ and IZM Wells
Time-lapse 2D Surface Seismic Data	Once	1st after 4 years of injection 2nd after 9 years of injection Every 10 years thereafter	Surface

*In-zone fluid sampling will be discontinued once CO_2 breakthrough occurs at the well.

Sampling frequencies during the injection period, for the One Earth Sequestration LLC Testing and Monitoring plan, are defined as follows:

- Quarterly sampling and testing will take place by the following dates each year: 3 months after the date of authorization of injection, 6 months after the date of authorization of injection, 9 months after the date of authorization of injection, and 12 months after the date of authorization of injection and every 3 months thereafter, unless otherwise noted.
- Semi-annual sampling will take place by the following dates each year: 6 months after the date of authorization of injection and 12 months after the date of authorization of injection and every 6 months thereafter, unless otherwise noted.
- Annual sampling will occur up to 45 days before the anniversary date of authorization of injection each year and every year thereafter, unless otherwise noted. Annual logging will take place up to 45 days before the anniversary date of authorization of injection each year and every year thereafter, unless otherwise noted.

Quality assurance procedures

A quality assurance and surveillance plan (QASP) for all testing and monitoring activities, required pursuant to 146.90(k), is provided as an Appendix to this Testing and Monitoring Plan.

Reporting procedures

One Earth Sequestration LLC will report the results of all testing and monitoring activities to the EPA in compliance with the requirements under 40 CFR 146.91.

Carbon Dioxide Stream Analysis [40 CFR 146.90(a)]

Pre-injection (baseline) samples will be collected and analyzed to demonstrate that the CO_2 stream and as required by 40 CFR 146.82(a)(7), (9), (10), and 146.88, meets permit requirements. One Earth Sequestration LLC will analyze the CO_2 stream during the operation period to yield data representative of its chemical and physical characteristics and to meet the requirements of 40 CFR 146.90(a). The current sampling and analytical program is based on the CO_2 stream captured at the One Earth Energy, LLC ethanol production facility.

The detection of carbon isotopes ($\delta^{13}C$) in the injected CO_2 is useful in tracing the movement of CO_2 in the injection reservoir. The $\delta^{13}C$ composition of CO_2 ($\delta^{13}C_{(CO2)}$) in the gas samples is dependent on the type of plant (corn) used to produce the alcohol. Ethanol production plants that utilize different photosynthetic cycles produce different carbon isotopic compositions.

Additional sampling and analysis may be required if other sources of CO_2 are delivered to the injection site. The Director will be notified 60 days in advance of any such changes. The sampling and analytical program will be modified as needed to meet the requirements of 40 CFR 146.90(a). One Earth Sequestration LLC will sample and analyze the CO_2 stream as described below:

Sampling location and frequency

CO_2 stream sampling will occur in the compressor building after the last stage of compression. If other sources of CO_2 are delivered to the injection site, those will also be sampled at a location to be determined. Sampling will take place quarterly, beginning within 3 months after the date of authorization of injection, then every three months thereafter.

Analytical parameters

One Earth Sequestration LLC will analyze the CO_2 for the constituents identified in **Table 3** using the methods listed. Additional constituents may be included if other sources of CO_2 are delivered to the site. The Director will be notified 60 days in advance of any such changes.

***Table 3**. Summary of analytical parameters for CO_2 stream.*

Parameter	Analytical Method(s)[1]
Oxygen (O_2)	ISBT 4.0 (GC/DID) GC/TCD
Nitrogen (N_2)	ISBT 4.0 (GC/DID) GC/TCD
Carbon Monoxide	ISBT 5.0 Colorimetric ISBT 4.0 (GC/DID)
Oxides of Nitrogen	ISBT 7.0 Colorimetric
Total Hydrocarbons	ISBT 10.0 THA (FID)
Methane	ISBT 10.1 GC/FID)
Acetaldehyde	ISBT 11.0 (GC/FID)
Sulfur Dioxide	ISBT 14.0 (GC/SCD)
Hydrogen Sulfide	ISBT 14.0 (GC/SCD)
Ethanol	ISBT 11.0 (GC/FID)
Carbon Isotope	Isotope ratio mass spectrometry
CO_2 Purity	ISBT 2.0 Caustic absorption Zahm-Nagel ALI method SAM 4.1 subtraction method (GC/DID) GC/TCD

Note 1: An equivalent method may be employed with the prior approval of the UIC Program Director.

Sampling methods

CO_2 stream sampling will occur in the compressor building after the last stage of compression. If other CO_2 is delivered to the site, that CO_2 will be sampled at the point of delivery or along the pipeline. A sampling station will be installed with the ability to purge and collect samples into a container that will be sealed and sent to the authorized laboratory.

All sample containers will be labeled with durable labels and indelible markings. A unique sample identification number and sampling date will be recorded on the sample containers.

Laboratory to be used/chain of custody and analysis procedures

Samples will be analyzed by a third-party laboratory using standardized procedures for gas chromatography, mass spectrometry, detector tubes, and photoionization. The sample chain-of-custody procedures described in Section B.3 of the QASP will be employed. The sample integrity and security will be documented through maintenance of a field sampling record and by use of the Chain of Custody form. The laboratory will provide, upon request, documentation of instrument calibration. The laboratory report will include the analytical results as well as reporting detection limits established for each method. The laboratory report will also include a copy of the completed Chain of Custody form.

Corrosion Monitoring

To meet the requirements of 40 CFR 146.90(c), One Earth Sequestration LLC will monitor well materials during the operation period for loss of mass, thickness, cracking, pitting, and other signs of corrosion to ensure that the well components meet the minimum standards for material strength and performance.

One Earth Sequestration LLC will monitor corrosion using the corrosion coupon method and will collect samples according to the description below.

Monitoring location and frequency

For the first two years of injection operations, corrosion monitoring will occur quarterly, by the following dates each year: 3 months after the date of authorization of injection, and then every three months thereafter. For the remainder of injection operations, monitoring will occur annually. There are no plans to monitor the coupons based on injection volumes. If the coupons show evidence of corrosion, the injection well can be assessed for signs of corrosion using well logging techniques such as multi-finger caliper logging or an ultrasonic casing evaluation tool.

Additional monitoring location(s) may be required if other sources of CO_2 are delivered to the injection wells via additional pipeline(s). The Director will be notified 60 days in advance of any such changes. The sampling and analytical program will be modified as needed to meet the requirements of 40 CFR 146.90(c).

Sample description

Samples of material used in the construction of the compression equipment, pipeline, and injection well, which come into contact with the CO_2 stream, will be included in the corrosion monitoring program either by using actual material and/or conventional corrosion coupons. Samples will consist of those items listed in Table 4. Each coupon will be weighed, measured,and photographed prior to initial exposure (see "Sample Handling and Monitoring" below).

Table 4. *List of equipment coupon with material of construction.*

Equipment Coupon	Material of Construction
Pipeline(s)	e.g., CS A106B; Design is TBD
Long String Casing (Upper casing type)	Carbon Steel
Long String Casing (Deep casing type)	Chrome Alloy
Injection tubing	Chrome Alloy
Wellhead	Chrome Alloy
Packers	Chrome Alloy

Monitoring details

Sample Exposure

Each sample will be attached to an individual holder and then inserted in a flow- through pipe arrangement (**Figure 3**). The corrosion monitoring system will be located downstream of all process compression/dehydration/pumping equipment (i.e., at the beginning ofthe pipeline to the wellhead). To accomplish this, a parallel stream of high-pressure CO_2 will be routed from the pipeline through the corrosion monitoring system and then back into a lower pressure point upstream in the compression system. This loop will operate any time injection is occurring. No other equipment will act on the CO_2 past this point; therefore, this location will provide representative exposure of the samples to the CO_2 composition, temperature, and pressures that will be seen at the wellhead and injection tubing. The holders and location of the system will be included in the pipeline design and will allow for continuation of injection during sample removal.

Figure 3. *Coupon holder (top). Flow-through pipe arrangement (bottom).*

Sample Handling and Monitoring

The coupons will be handled and assessed for corrosion using the American Society for Testing and Materials (ASTM) G1-03, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens (ASTM 2011). The coupons will be photographed, visually inspected with a minimum of 10x power, dimensionally measured (to within 0.0001 inch), and weighed (to within 0.0001 gm).

Above Confining Zone Monitoring

One Earth Sequestration LLC will monitor groundwater quality and geochemical changes above the confining zone during the operation period to meet the requirements of 40 CFR 146.90(d). One

ACZ monitoring well will be used to monitor the Ironton/Galesville, the aquifer immediately above the confining layer. The purpose is to monitor whether there is CO_2 or brine migration out of the storage formation. The well will be utilized for pressure and temperature monitoring as well as periodic fluid sampling. If monitoring data indicates that CO_2 has migrated out of the primary storage formation, it will trigger external well integrity testing of the injection well and the deep in zone monitor wells and may trigger an emergency response action described in the Emergency and Remedial Response Plan.

To meet the requirements at 40 CFR 146.95(f)(3)(i), One Earth Sequestration LLC will also monitor groundwater quality, geochemical changes, and pressure in the St. Peter sandstone, the lowermost USDW above the injection zone. The USDW monitoring program will meet the requirements of 40 CFR 146.90 (d) and will include baseline groundwater samples to characterize variations in water quality within the AoR prior to the start of CO_2 injection. Once the injection phase of the project begins, the analytical results will be compared to the baseline conditions for indication of CO_2 or brine migration into the USDW. If indications of CO_2 or brine are found in the USDW, it will trigger the emergency response actions found in the Emergency and Remedial Response Plan.

Monitoring location and frequency

Table 5a shows the planned monitoring methods, locations, and frequencies for ground water quality and geochemical monitoring above the confining zone. Table 5b shows the planned wireline logging program.

The groundwater monitoring plan focuses on the following zones:

- The St. Peter Sandstone – the lowermost USDW.
- The Ironton-Galesville Formation – the zone above the Eau Claire Formation confining zone.

Table 5a. *ACZ monitoring of groundwater quality and geochemical changes.*

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
St. Peter Formation (Lowermost ACZ USDW)	Fluid sampling	Lowermost USDW monitoring well	1 interval. Depth TBD based on site conditions	Baseline (quarterly). Annually thereafter through post-injection operations.
	Pressure/ temperature monitoring	Lowermost USDW monitoring well	1 interval. Depth TBD based on site conditions	Continuous
Ironton-Galesville (Above Confining Zone)	Fluid sampling	ACZ well	1 interval. Depth TBD based on site conditions	One baseline. Annually thereafter through post-injection operations
	Pressure/ temperature monitoring	ACZ well	1 interval. Depth TBD based on site conditions	Continuous

Table 5b. *ACZ indirect monitoring*

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
St. Peter	Pulse Neutron Logging/RST	Lowermost USDW ACZ monitoring well	Continuous to full well depth	Baseline (Once) Annually thereafter
Ironton-Galesville	Pulse Neutron Logging/RST	ACZ Well	Continuous to full well depth	Baseline (Once) Annually thereafter

Note: Baseline sampling and analysis will be completed before injection is authorized.

Analytical parameters

Table 6 identifies the parameters to be monitored and the analytical methods One Earth Sequestration LLC will use for ground water samples.

Table 6. *ACZ summary of analytical and field parameters for ground water samples.*

Parameters	**Analytical Methods [1]**
	Lowermost USDW
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and Tl	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO_3, and SO_4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Isotopes: $\delta^{13}C$ of Dissolved Inorganic Carbon (DIC)	Isotope ratio mass spectrometry
Total Dissolved Solids	Gravimetry; APHA 2540C
Water Density (field)	Oscillating body method
Alkalinity	APHA 2320B
pH (field)	EPA 150.1
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple
	Above Confining Zone
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and Tl	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO_3, and SO_4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Isotopes: $\delta^{13}C$ of DIC	Isotope ratio mass spectrometry
Total Dissolved Solids	Gravimetry; APHA 2540C
Water Density(field)	Oscillating body method
Alkalinity	APHA 2320B
pH (field)	EPA 150.1
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple

Note 1: ICP = inductively coupled plasma; MS = mass spectrometry; OES = optical emission spectrometry; GC-P = gas chromatography - pyrolysis. An equivalent method may be employed with the prior approval of the UIC Program Director.

Sampling methods

Sampling will be performed as described in Section B.2 of the QASP; this section of the QASP describes the groundwater sampling methods to be employed, including sampling standard operating procedures (SOPs) (Section B.2 a/b), and sample preservation (Section B.2.f).

Laboratory to be used/chain of custody procedures

A qualified, commercial laboratory will be selected to provide analytical services in accordance with the methods and standards included here and in the QASP. Sample handling and custody will be performed as described in Section B.3 of the QASP. Quality control will be ensured using the methods described in Section B.5 of the QASP.

External Mechanical Integrity Testing

One Earth Sequestration, LLC will conduct at least one of the tests presented in **Table 7** periodically during the injection phase to verify external MI as required at 146.89(c) and 146.90. MITs will be performed annually, up to 45 days before the anniversary date of authorization of injection each year or alternatively scheduled with the prior approval of the UIC Program Director.

Table 7. *Mechanical integrity tests.*

Test Description	Location
Temperature Log	Along wellbore using DTS or wireline well log
Noise Log	Wireline Well Log
Oxygen Activation Log	Wireline Well Log

Description of MIT(s) That May be Employed

Temperature Logging

Temperature logging detects leaks by measuring temperature anomalies due to fluid movement adjacent to the well bore. Fluid leaks from the wellbore are typically a different temperature compared to native fluids. Temperature logs are run after the well has been shut-in long enough for temperature effects to dissipate, leaving a relatively simple temperature profile (typically ~36 hours). While the absolute gradients may differ due to injection history, the relative profiles should be consistent. If there has been a leak of fluid out of the well, there may be an anomalous heating or cooling effect as compared to the baseline or another log. Gradient variation due to lithologic changes are expected. Distributed fiber sensing or electric wireline deployed temperature measurement devices can be used and should be of sufficient resolution and sufficiently calibrated to detect changes.

Temperature Logging Using Wireline

To ensure the mechanical integrity of the casing of the injection well, temperature data will be recorded across the wellbore from surface down to primary caprock. Bottom hole pressure data near the packer will also be provided. The following procedures, will be employed for temperature logging:

The well should be in a state of injection for at least 6 hours prior to commencing operations to cool injection zones.

1. Move in and rig up an electrical logging unit with lubricator.
2. Run a temperature survey from the top of the confining formation (or higher) to the deepest point reachable in the injection well while injecting at a rate that allows for safe operations. Should operational constraints or safety concerns not allow for a logging pass while injecting, an acceptable, alternate plan is to stop injecting immediately prior to the first logging pass
3. Stop injection, pull tool back to shallow depth, wait 1 hour.
4. Run a temperature survey over the same interval as step 2.
5. Pull tool back to shallow depth, and wait 2 hours.
6. Run a temperature survey over the same interval as step 2.
7. Pull tool back to shallow depth, and wait 2 hours.
8. Run a temperature survey over the same interval as step 2.
9. Evaluate data to determine if additional passes are needed for interpretation. Should CO_2 migration be interpreted in the topmost section of the log, additional logging runs over a higher interval will be required to find the top of migration.
10. If additional passes are needed, repeat temperature surveys every 2 hours until 12 hours, over the same interval as step 2.
11. Rig down the logging equipment.
12. Data interpretation involves comparing the time-lapse well temperature profiles and looking for temperature anomalies that may indicate a failure of well integrity, i.e., tubing leak or movement of fluid behind the casing. As the well cools down the temperature profile along the length of the tubing string is compared to the baseline profile. Fluid movement into the annulus or outside the casing creates a temperature anomaly when compared to the baseline cooling profile.

Temperature Logging Using DTS Fiber Optic Line

The injection well will be equipped with a DTS fiber optic temperature monitoring system that can monitor the injection well's annular temperature along the length of the tubing string. The DTS line is used for real-time temperature monitoring and, like a conventional temperature log, can be used for early detection of temperature changes that may indicate a loss of well mechanical integrity. The procedure for using the DTS for well mechanical integrity is asfollows:

1. After the well is completed and prior to injection, a baseline temperature profile will be established. This profile represents the natural temperature gradient for each stratigraphic zone.
2. During injection operation, record the temperature profile for 6 hours prior to shutting in the well.
3. Stop injection and record temperature profile for 6 hours.
4. Evaluate data to determine if additional cooling time is needed for interpretation.
5. Start injection and record temperature profile for 6 hours.
6. Data interpretation involves comparing the time-lapse well temperature profiles and looking for temperature anomalies that may indicate a failure of well integrity, i.e., tubing leak or movement of fluid behind the casing. The DTS system monitors and records the

well's temperature profiles at a pre-set frequency in real-time. As the well cools down the temperature profile along the length of the tubing string is compared to the baseline. Fluid movement into the annulus or outside the casing creates a temperature anomaly when compared to the baseline profile. This data can be continuously monitored to provide real-time MIT surveillance making this technology superior to wireline temperature logging.

Noise Logging

A wireline tool is deployed which uses sensitive microphones to detect noise due to flow behind the casing. The sounds are recorded in different frequency ranges at ~100' depth intervals for approximately three to five minutes. If anomalies are detected the depth intervals are shortened to better locate the anomaly. When the level of sound is low, a linear scale is used for reporting noise logs, and, when there are intervals with higher sound, a logarithmic scale is used. Departures from baseline noise levels in the log indicate an anomaly. Ambient noise while injecting that produces a signal greater than 10 millivolts (mV) may indicate leakage or require further investigation.

To ensure the mechanical integrity of the casing of the injection well, logging data will be recorded across the wellbore from surface down to the primary caprock. Bottom hole pressure data near the packer will also be provided. Noise logging will be carried out while injection is occurring. If ambient noise is greater than 10 mv, injection will be halted. The following procedures will be employed:

1. Move in and rig up an electrical logging unit with lubricator.
2. Run a noise survey from the top of the confining formation (or higher) to the deepestpoint reachable in the injection well while injecting at a rate that allows for safe operations.
3. Make noise measurements at intervals of 100 feet to create a log on a coarse grid.
4. If anomalies are evident on the coarse log, construct a finer grid by making noise measurements at intervals of 20 feet within the coarse intervals containing high noiselevels.
5. Make noise measurements at intervals of 10 feet through the first 50 feet above the injection interval and at intervals of 20 feet within the 100-foot intervals containing:
6. The base of the lowermost bleed-off zone above the injection interval and
7. The base of the lowermost USDW.
8. Additional measurements may be made to pinpoint depths at which noise is produced.
9. Use a vertical scale of 1 or 2 inches per 100 feet.
10. Rig down the logging equipment.
11. Interpret the data as follows: Determine the base noise level in the well (dead well level). Identify departures from this level. An increase in noise near the surface due to equipment operating at the surface is to be expected in many situations. Determine the extent of fluid movement; flow into or between USDWs indicates a lack of mechanical integrity; flow from the injection zone into or above the confining zone indicates a failure ofcontainment.

Oxygen Activation (OA) Logging

A wireline tool is deployed to activate oxygen by emitting high-energy neutrons from a neutron source. The activated isotopes emit gamma radiation which is measured by the wireline tool. Gamma-ray measurements are used to calculate water flow direction and velocity. If water flow outside of the casing is detected it could indicate the potential loss of external mechanical integrity.

To minimize false positives, a calibration will be performed, and measurements will be confirmed at several nearby depths and/or under a minimum of three varying injection rates.

To ensure the mechanical integrity of the casing of the injection well, logging data will be recorded across the wellbore from surface down to primary caprock. Bottom hole pressure data near the packer will also be provided. OA logging will be carried out while injection is occurring. The following procedures will be employed:

1. Move in and rig up an electrical logging unit with lubricator.
2. Conduct a baseline Gamma-Ray Log and casing collar locator log from the top of the injection zone to the surface prior to taking the stationary readings with the OA tool. (Gamma-Ray Log is necessary to evaluate the contribution of naturally occurring background radiation to the total gamma radiation count detected by the OA tool. There are different types of natural radiation emitted from various geologic formations or zones and the natural radiation may change over time.
3. The OA log shall be used only for casing diameters of greater than 1-11/16 inches andless than 13- 3/8 inches.
4. All stationary readings should be taken with the well injecting fluid at the normal ratewith minimal rate and pressure fluctuations.
5. Prior to taking the stationary readings, the OA tool must be properly calibrated in a “no vertical flow behind the casing” section of the well to ensure accurate, repeatable tool response and for measuring background counts.
6. Take, at a minimum, a 15-minute stationary reading adjacent to the confining interval located immediately above the injection interval. This must be at least 10 feet above the injection interval so that turbulence does not affect the readings.
7. Take, at a minimum, a 15-minute stationary reading at a location approximately midway between the base of the lowermost USDW and the confining interval located immediately above the injection interval.
8. Take, at a minimum, a 15-minute stationary reading adjacent to the top of the confining zone.
9. Take, at a minimum, a 15-minute stationary reading at the base of the lowermost USDW.
10. If flow is indicated by the OA log at a location, move uphole or downhole as necessary at no more than 50-foot intervals and take stationary readings to determine the area of fluid migration.
11. Interpret the data: Identification of differences in the activated water’s measured gamma ray count-rate profile versus the expected count-rate profile for a static environment. Differences between the measured and expected may indicate flow in the annulus or behind the casing. The flow velocity is determined by measuring the time that the activated water passes a detector.

Pressure Fall-Off Testing

One Earth Sequestration LLC will perform pressure fall-off tests during the injection phase as described below to meet the requirements of 40 CFR 146.90(f). Pressure Fall-Off tests are required to demonstrate to measure formation properties in the vicinity of the injection well (e.g., transmissivity).

Baseline pressure fall-off tests (PFO) will be conducted as described in the Pre-Operational Testing Plan (See Narrative). During the injection phase of the project, a PFO will be conducted in the injection wells every five years and at end of the injection period. The objective of the PFO testing is to periodically monitor for changes in the near wellbore environment that would impact injectivity or cause injection pressures to increase (US EPA, 2013). The formation characteristics obtained through the PFO testing will be compared to the results from previous tests to identify changes over time, and they will be used to calibrate the computational models. Finally, if an anomalous pressure drop occurs during the PFO, it may indicate an issue with well integrity (US EPA, 2013).

Testing location and frequency

Pressure fall-off testing will be performed in each well:

- As part of pre-operational testing (baseline)
- During Injection Operations:
    - Every five years and,
    - At end of the injection period

Testing details

Pressure Fall-off Test Procedure

A pressure falloff test has a period of injection followed by a period of no-injection or shut-in. Normal injection will be used during the injection period preceding the shut-in portion of the falloff tests. However, if the rate causes relatively large changes in bottomhole pressure, the rate may be decreased. A minimum, one week of relatively continuous injection will precede the shut-in portion of the falloff test. The pressure Fall-Off data will be measured using a downhole gauge sampling at 5-second intervals. The gauges may be those used for day-to-day data acquisition, or a pressure gauge conveyed via wireline. Surface or downhole gauges will be used to inform test duration. To reduce the wellbore storage effects attributable to the pipeline and surface equipment, the well will be shut-in at the wellhead nearly instantaneously with direct coordination with the injection compression facility operator. The shut-in period of the falloff test will be adequate to assure that enough pressure transient data are collected to calculate the average pressure. Quantitative analysis of the measured data is used to estimate formation characteristics, including transmissivity, permeability, and a skin factor. The measured parameters will be compared to those used in site computational modeling and AoR delineation.

Carbon Dioxide Plume and Pressure Front Tracking

One Earth Sequestration LLC will employ direct and indirect methods to track the extent of the carbon dioxide plume and the presence or absence of elevated pressure during the operation period to meet the requirements of 40 CFR 146.90(g).

Evolution of the threshold pressure gradient in the injection zone, and through injection operations, is summarized in **Figure 4**, Predicted pressure profiles of the bottom-hole pressure at the injection wells are shown in **Figure 5**.

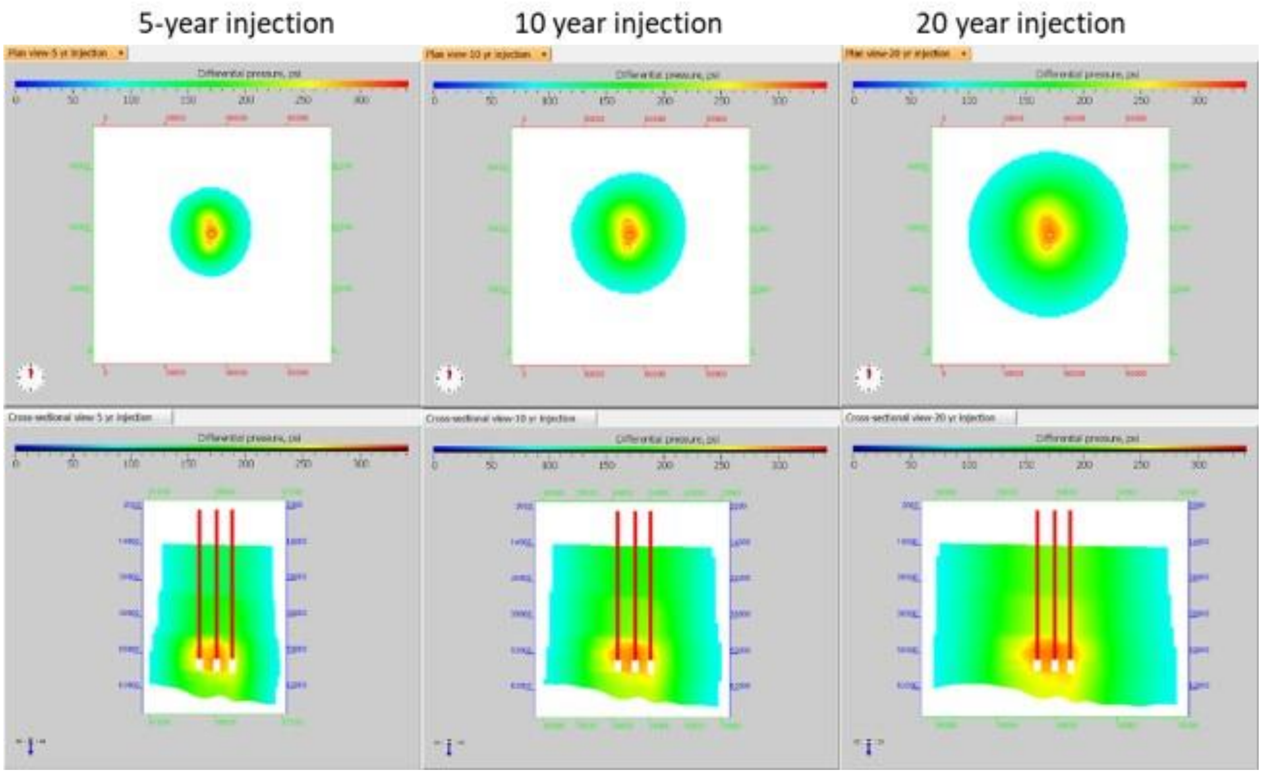

Figure 4. *Threshold pressure front evolution.*

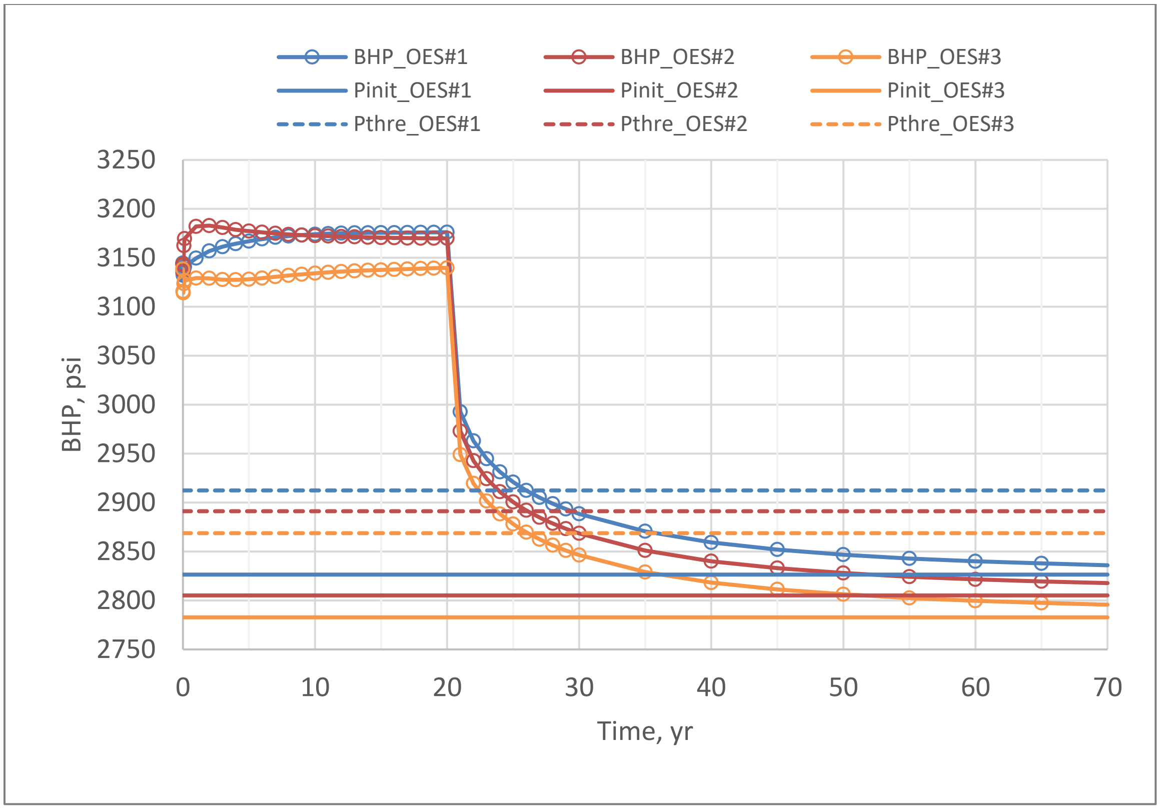

Figure 5. *Bottomhole pressure profiles of injection wells.*

Monitoring locations relative to the predicted location of the CO_2 plume and pressure front at 5-year intervals throughout the injection phase are shown in Figures 6 through 9.

Two in-zone monitoring (IZM) wells are proposed for the site. OEE #1, the stratigraphic test well drilled for the purpose of site characterization, but constructed for the purpose of monitoring, will provide the initial in-zone monitoring location. A second IZM well, location to be determined (TBD), is also planned for installation. The location of the second IZM will be identified after 5 years of injection operations, or after 10 million tonnes of CO_2 injection, whichever occurs first. The location will be based on data from OEE #1 and, if available, the results of the first time-lapse 2D survey. As shown in **Figure 6**, the CO_2 plume is not projected to reach IZM #1 through the first five years of injection. The second in-zone monitoring well location will be proposed to the director following completion of the updated dynamic model. Based on concurrence from the Director, the well then will be installed.

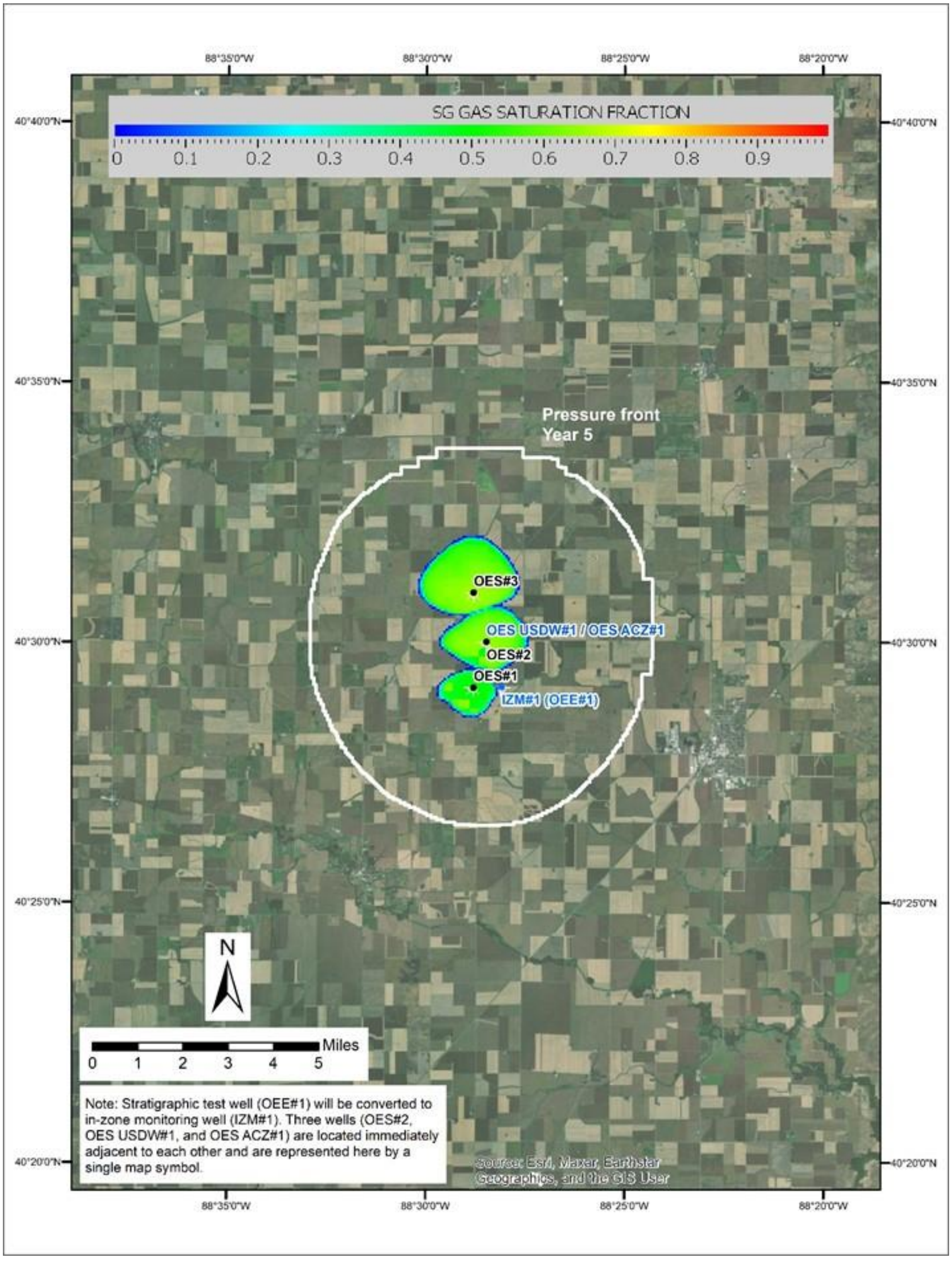

***Figure 6**. Modeled CO_2 plume location and pressure front (white line) after 5 years of injection.*

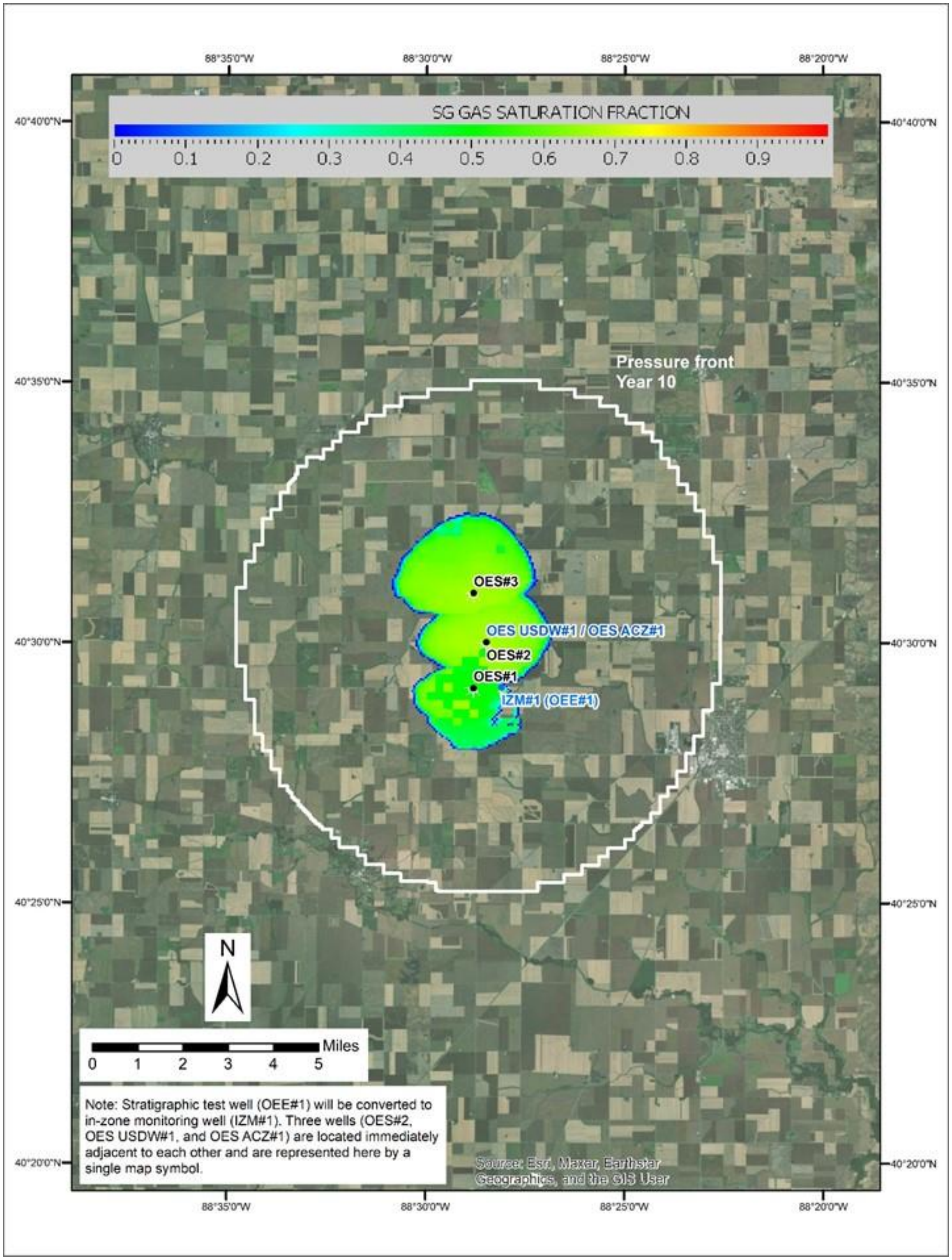

Figure 7. *Modeled CO_2 plume location and pressure front (white line) after 10 years of injection.*

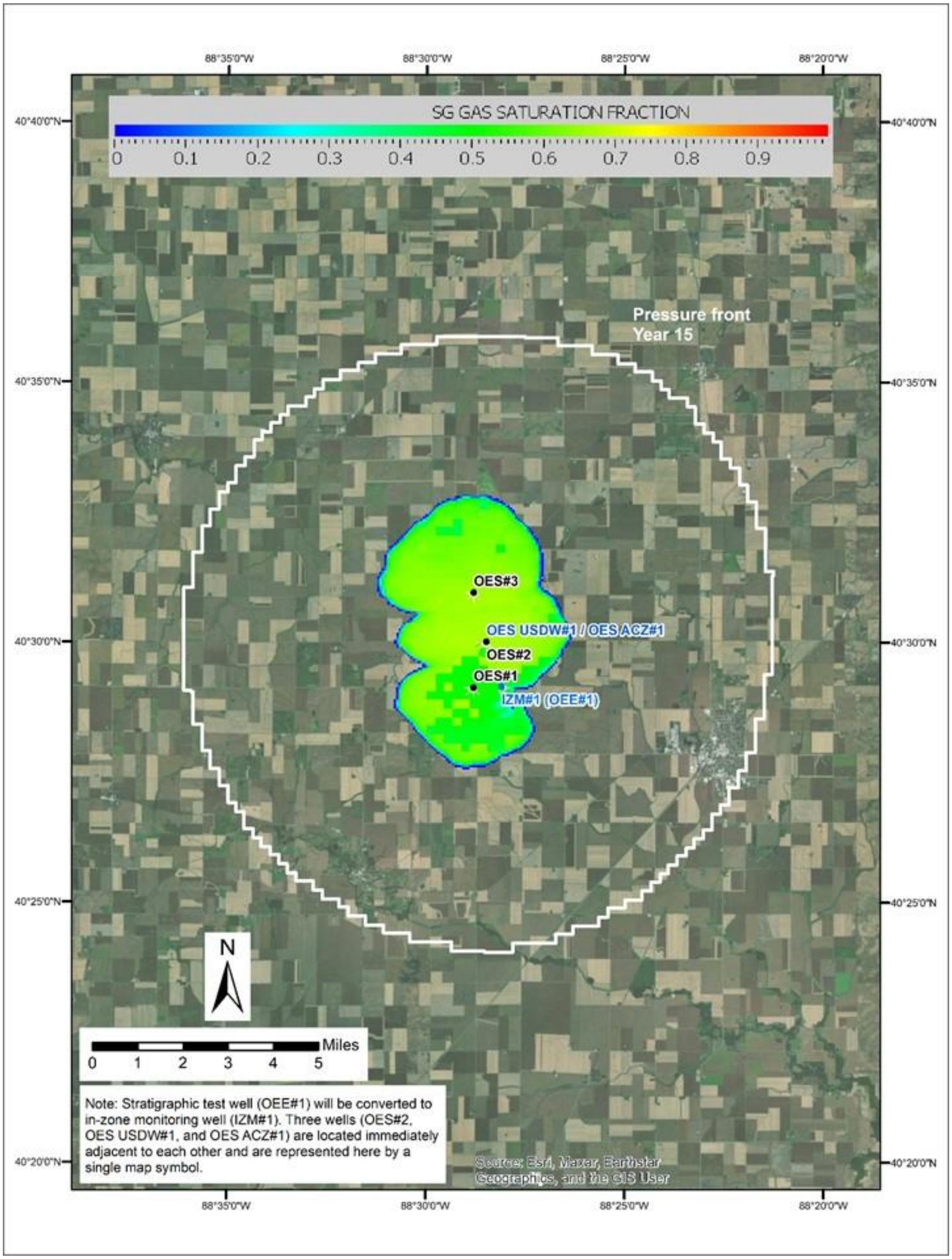

Figure 8. *Modeled CO_2 plume location and pressure front (white line) after 15 years of injection.*

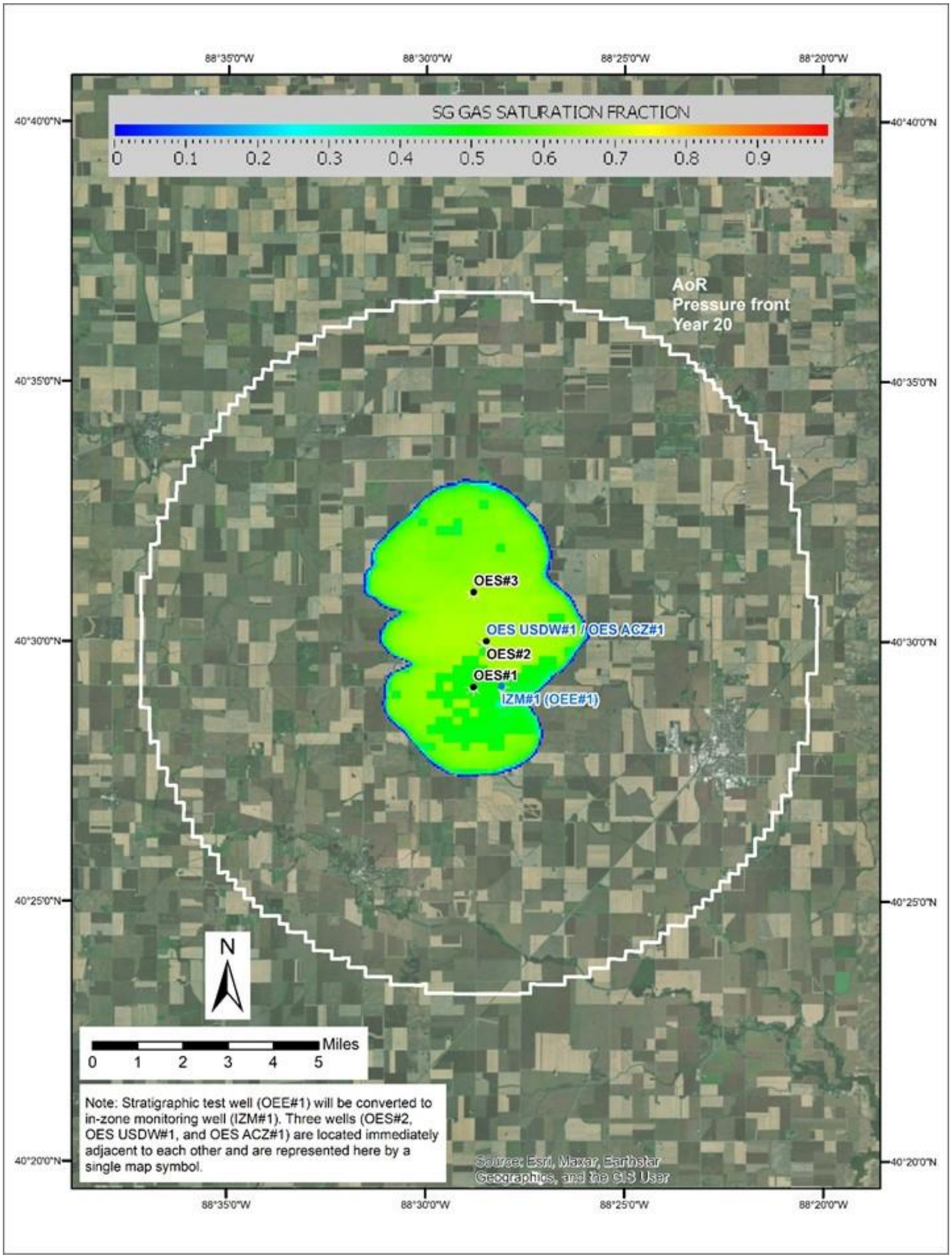

***Figure 9**. Modeled CO_2 plume location and pressure front (white line) after 20 years of injection.*

Pressure and temperature sensors in the IZM wells will be used to measure pressure and temperature variations in the storage formation in the pre-operational, injection, and post-injection phases of the project (40 CFR 146.90 (g)). Note that the second IZM wells will begin continuous pressure and temperature monitoring upon completion. The gauges will record the data that will be retrieved and reviewed monthly Additional detail regarding the gauges is included in the QASP. The IZM wells also will be used to collect fluid samples from the storage formation to monitor for changes in the water chemistry over time and verify when the leading edge of the CO_2 plume reaches the IZM well. Once there is CO_2 breakthrough, fluid sampling will be discontinued in that IZM well.

Pulsed neutron logging detects leaks by measuring changes in the capture cross-section of the fluids and gasses in the pore space of the rock using a wireline tool that emits neutrons which are slowed to a thermal velocity through elastic and inelastic collisions with the nuclei of the environment's elements and ultimately captured. These interactions are sensitive to fluid type and saturation changes in the formation and in the casing-formation annulus. Therefore, pulsed neutron measurements can be used to monitor the formation fluids as well as identify mechanical integrity problems. The pulsed neutron Sigma (Σ) is the thermal neutron capture cross-section or the rate at which thermal neutrons are captured by the formation matrix and fluids. The capture cross-section can be used to detect fluid changes behind the casing over time to verify the well external mechanical integrity. Open hole wireline logs for lithologic definition and baseline pulsed neutron logs are key inputs to this type of monitoring.

Pulsed neutron (sigma mode)/RST logs will be acquired in the injection and IZM wells to identify the saturation of CO_2 close to the well bores and the stratigraphic intervals that may contain CO_2. This monitoring activity also will be used to examine for the presence of CO_2 above the confining zone. The pressure and pulsed neutron log data will be used to calibrate the dynamic simulation during the injection and post-injection phases of the project.

Indirect techniques will be used to monitor the development of the CO_2 plume and the associated pressure front through the injection and post injection project phases (40 CFR 146.90 (g)). Time-lapse 2D surface seismic data will be used to qualitatively monitor the CO_2 plume distribution and calibrate the computational modeling results over time. The time-lapse 2D surface seismic data will also be used to verify CO_2 containment within the storage formation.

Plume monitoring location and frequency

One Earth Sequestration LLC will conduct fluid sampling and analysis to detect changes in groundwater to directly monitor the carbon dioxide plume. The parameters to be analyzed as part of fluid sampling in the injection zone and analytical methods are described above in the monitoring section. One Earth Sequestration LLC will additionally deploy pressure/temperature sensors coupled with DTS to directly monitor the position of the pressure front and temperature changes in and above the primary confining unit.

Indirect plume monitoring will include pulsed neutron capture RST logs to monitor CO_2 saturation in the injection and IZM wells. In addition, time-lapse 2D seismic will be used to assess the extent

and position of the CO_2 plume. **Figure 10** shows the location of the 2D lines acquired as part of site characterization. The repeat 2D seismic will follow Line 1 and the 2019 Gibson line.

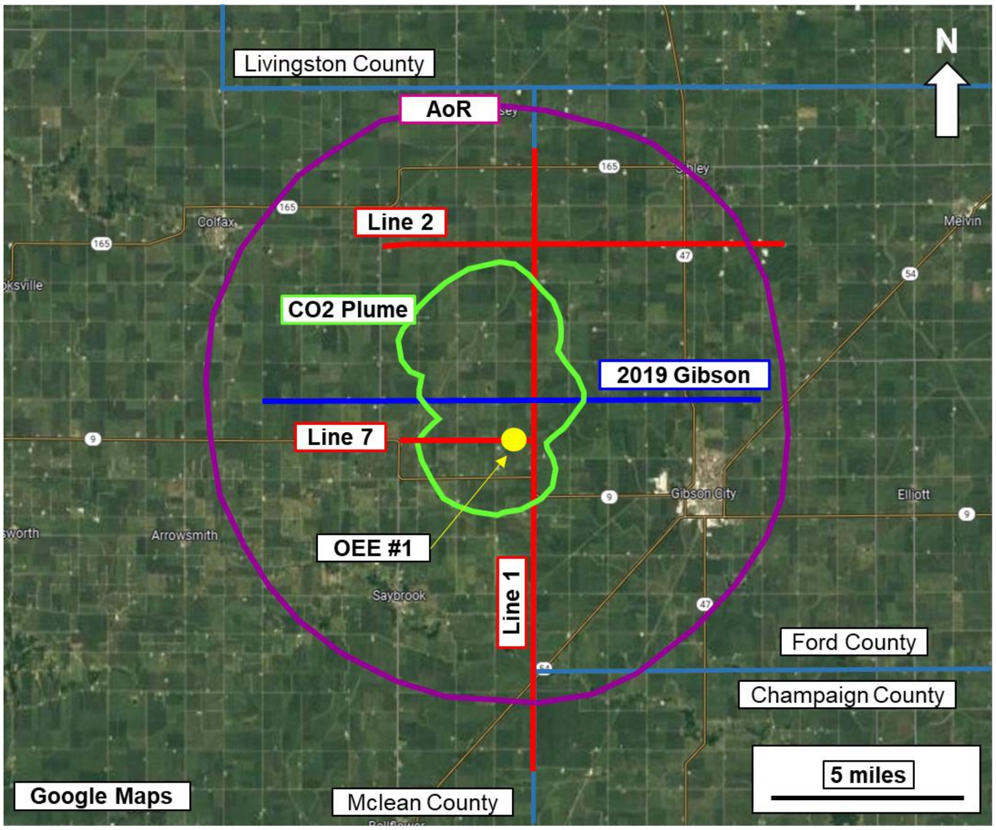

Figure 10*. 2D seismic lines acquired during site characterization. Note CO2 plume (in green) and AoR (purple) outlines have been generalized.*

Quality assurance procedures for seismic monitoring methods are presented in Section B.9 of the QASP.

Plume monitoring details

Table 8 presents the methods that One Earth Sequestration LLC will use to monitor the position of the CO_2 plume, including the activities, locations, and frequencies One Earth Sequestration LLC will employ. The parameters to be analyzed as part of fluid sampling in the injection zone and associated analytical methods are presented in **Table 9**. Quality assurance procedures for these methods are presented in the QASP.

***Table 8**. Plume monitoring activities.*

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
Direct Plume Monitoring				
Injection Zone	Fluid sampling	IZM wells	1 interval. Depth TBD based on site conditions	Baseline (Once); Annual starting at end of first year of injection. (Fluid sampling will be discontinued at each respective IZM well once the monitoring zone is saturated with CO_2)
Indirect Plume Monitoring				
Injection Zone	Pulse Neutron Logging/RST	Deep monitoring wells	Continuous to full well depth	Baseline (once), Annually thereafter
		Injection Well	Continuous to full well depth	Baseline (once), Annually thereafter through injection operations (and PISC until P&A)
	2D surface seismic survey	Cross-sectional coverage	Fold Image Coverage approximately 40 miles	Baseline (once) 1st after 4 years of injection 2nd after 9 years of injection Every 10 years thereafter

***Table 9.** IZM summary of analytical and field parameters for fluid sampling.*

Parameters	Analytical Methods
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and Tl	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO_3, and SO_4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Isotopes: $\delta^{13}C$ of DIC	Isotope ratio mass spectrometry
Total Dissolved Solids	Gravimetry; APHA 2540C
Water Density (field)	Oscillating body method
Alkalinity	APHA 2320B
pH (field)	EPA 150.1
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple

Pressure-front monitoring location and frequency

Table 10 presents the methods that One Earth Sequestration LLC will use to monitor the position of the pressure front, including the activities, locations, and frequencies.

***Table 10**. Pressure front monitoring.*

Target Formation	**Monitoring Activity**	**Monitoring Location(s)**	**Spatial Coverage**	**Frequency**
Direct Pressure-Front Monitoring				
Mt. Simon	Pressure/ temperature monitoring	IZM #1	Sensitive, Confidential, or Privileged Information [redacted]	Continuous
		IZM #2	[redacted]	Continuous
		Injection Wells	[redacted]	Continuous

Quality assurance procedures for these methods are presented in Section A.4 of the QASP.

Continuous Recording of Injection Pressure, Rate, and Volume; Annulus Pressure

One Earth Sequestration LLC will install and use continuous recording devices to monitor injection pressure, rate, and volume, the pressure on the annulus between the tubing and the long string casing, and the annulus fluid volume added.

One Earth Sequestration LLC will perform the activities identified in Table 11 to verify internal mechanical integrity of the injection well and monitor injection pressure, rate, volume, and annular pressure as required at 40 CFR 146.88, 146.89, and 146.90(b). All monitoring will be continuous for the duration of the operation period, and at the locations shown in the table. The injection wells will have pressure/temperature gauges at the surface and in the tubing at the packer. In addition, there will be DTS and DAS fibers in the injection wells.

***Table 11**. Locations for continuous monitoring in injection wells.*

Test Description	**Location**
Annular Pressure Monitoring	Surface
Injection Pressure Monitoring	Surface
Injection Pressure Monitoring	Reservoir - Proximate to packer
Injection Rate Monitoring	Surface
Injection Volume Monitoring	Surface
Temperature Monitoring	Surface
Temperature Monitoring	Reservoir - Proximate to packer
Temperature Monitoring	Along wellbore to packer using DTS
Acoustic Monitoring	Along wellbore to packer using DAS

Above-ground pressure and temperature instruments shall be calibrated over the full operational range at least annually using ANSI or other recognized standards. In lieu of removing the injection tubing, downhole gauges will demonstrate accuracy by using a second pressure gauge, with current certified calibration, that will be lowered into the well to the same depth as the permanent downhole gauge. Pressure transducers shall have a drift stability of less than 1 psi over the operational period of the instrument and an accuracy of ± 5 psi. Sampling rates will be at least once per 5 seconds. Temperature sensors will be accurate to within one degree Celsius. DTS sampling rate will be once per 10 seconds.

Flow will be monitored with a mass flowmeter at the wellhead. The flow meter will be either an orifice meter with flow computer or a Coriolis meter. The meter will be calibrated using accepted standards and be accurate to within ± 0.1 percent. The meter will be calibrated for the entire expected range of flow rates.

Injection Rate and Pressure Monitoring

One Earth Sequestration LLC will monitor injection operations using a process control system, as presented below. For remote instrumentation installed at the wellhead, data will be transmitted back to the process control system via a secure data transmission system that allows for continuous monitoring and alarming to the operator. Loss of communication with the remote monitoring equipment will be alarmed to the operator as well.

The Surface Facility Equipment & Control System will limit maximum flow to 4,225 MT/day per well, and/or limit the well head pressure to 2,498 psia, 2,480 psia, and 2,462 psia for injection wells OES #1, OES #2, and OES #3, respectively, which corresponds to the regulatory requirement to not exceed 90% of the injection zone’s fracture pressure. All injection operations will be continuously monitored and controlled by the One Earth Sequestration LLC operations staff using the distributed process control system. This system will continuously monitor, control, record, and will alarm and shutdown if specified control parameters exceed their normal operating range.

More specifically, all critical system parameters, e.g., pressure, temperature, and flow rate will have continuous electronic monitoring with signals transmitted back to a master control system. One Earth Sequestration LLC supervisors and operators will have the capability to monitor the status of the entire system from the distributed control center.

Calculation of Injection Volumes

Flow rate is measured at ground surface. Actual density is computed from pressure and temperature measurements at the flow meter location. The downhole pressure and temperature data will be used to perform the injectate density calculation.

The volume of CO_2 injected will be calculated from the mass flow rate obtained from the mass flow meter installed on the injection line. The mass flow rate will be divided by density and multiplied by injection time to determine the volume injected.

Density will be calculated using an industry standard correlation. The Standard Annulus Pressure Test (SAPT) is used to demonstrate the absence of significant leaks in tubing, casing, and packer. This test is based on the principle that a pressure applied to fluids filling a sealed vessel will persist. A well's annulus system, though closed to transfer of matter, is not closed to energy transfer because it is not isolated from transfer of heat from its surroundings, therefore an allowance for small pressure changes is necessary. The test provides an immediate demonstration of whether leaks, detectable by these means, exist.

The interpretation and confirmation of the SAPT included: Comparison of the pressure change through the test period to 3% of the test pressure (0.03 X test pressure). If the annulus test pressure changes by this amount or more (gain or loss), the well has failed to demonstrate mechanical integrity, and operation may constitute a violation of the UIC regulations. If the annulus test pressure changes by less than 3 percent (gain or loss) over the test period, the well has demonstrated mechanical integrity, pursuant to 40 C.F.R. § 146.8(a)(1).

Appendix: Quality Assurance and Surveillance Plan

(Submitted as separate files)