ATTACHMENT C: TESTING AND MONITORING PLAN

Introduction and Facility Information

Facility name:	Wellington Field Small Scale Carbon Capture and Storage Project KSS191GS0001
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Well location:	Sumner County, Kansas Latitude 37.319485, Longitude -97.4334588

This Testing and Monitoring Plan describes how Berexco, LLC (Berexco) will monitor the Wellington Oil Field Small Scale Carbon Capture and Storage Project site pursuant to 40 CFR 146.90 during the injection phase of this project. In addition to demonstrating that the well is operating as planned, the CO_2 plume and pressure front are moving as predicted, and that there is no endangerment to USDWs, the monitoring data will be used to validate and adjust the modeling information used to predict the migration of the CO_2 injected and the pressure evolution due to injection, to support AoR reevaluations and a non-endangerment demonstration.

Appendix A to this Testing and Monitoring Plan contains a generalized schedule of testing and monitoring activities to be conducted throughout the life of the project, for reference purposes. Injection-phase activities described in this plan are enforceable pursuant to 40 CFR 146.90.

Results of the testing and monitoring activities described in this plan may trigger action according to the AoR and Corrective Action Plan (Attachment B to this permit), Emergency and Remedial Response Plan (Attachment F to this permit), or other permit conditions.

Quality Assurance Procedures

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

Reporting Procedures

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

Carbon Dioxide Stream Analysis

The CO_2 stream will be analyzed 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). Samples will be collected and analyzed quarterly during the injection phase, on the following schedule: once 12 weeks after injection begins (± 1 week) and once 24 weeks after injection begins (± 1 week).

Berexco will notify EPA prior to switching CO_2 sources, at which time EPA will re-evaluate the relevant sampling procedures and target analytes.

Any changes to the physical, chemical, and other relevant characteristics of the CO_2 stream from the established operating data (as specified in the permit) or a demonstration that these characteristics have not changed since the previous reporting period shall be described in a semi-annual report and submitted to EPA in compliance with 40 CFR 146.91(a)(1).

Analytical Parameters

KGS/Berexco will contract with Linde Industrial Gases to analyze the CO_2 stream for the constituents identified in Table 1 using the methods listed below.

Table 1. Summary of analytical parameters for CO_2 gas stream.

Parameters	Analytical Methods(1)	Detection/ISBT Limit(2)	Typical Precisions	Quality Control (QC) Requirements
Oxygen	ISBT 4.0 (GC/DID)	1 uL/L to 30 uL/L (ppm v/v)	± 10% reading	Daily standard within 10% of calibration, secondary standard after calibration
Nitrogen	ISBT 4.0 (GC/DID)	1+ uL/L (ppm v/v)	± 10% reading	Daily standard within 10% of calibration, secondary standard after calibration
Carbon monoxide	ISBT 5.0 (GC/DID)	1 to 10 uL/L (ppm v/v)	± 10% reading	Daily standard within 10% of calibration, secondary standard after calibration
Oxides of nitrogen	ISBT 7.0 (DT)	0.5 to 5 uL/L (ppm v/v)	± 20% reading	Duplicate analysis
Total hydrocarbons	ISBT 10.0	1 uL/L to 50 uL/L (ppm v/v)	5–10% of reading	Daily standard within 10% of calibration, secondary standard after calibration
Methane	ISBT 10.1 (GC)	0.1 uL/L to 50 uL/L (ppm v/v)	5–10% of reading	Daily standard within 10% of calibration, secondary standard after calibration
Acetaldehyde	ISBT 11.0 (GC)	0.05 uL/L to 0.2 uL/L (ppm by v/v)	5–10% of reading	Daily standard within 10% of calibration, secondary standard after calibration
Sulfur dioxide	ISBT 14.0 (GC)	0.05 uL/L to 1.0 uL/L (ppm by v/v)	5–10% of reading	Daily standard within 10% of calibration, secondary standard after calibration
Hydrogen sulfide	ISBT 14.0	0.01 uL/L to 0.1 uL/L (ppm v/v)	5–10% of reading	Daily standard within 10% of calibration, secondary standard after calibration

Parameters	Analytical Methods(1)	Detection/ISBT Limit(2)	Typical Precisions	Quality Control (QC) Requirements
CO_2 purity	ISBT 2.0	5.0% to 99.9%	± 10 % of reading	Calibration per manufacturer recommendation

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

(2) International Society of Beverage Technologist (ISBT) codes govern CO_2 production and testing at the source plants.

Sampling methods

CO_2 stream sampling will use the following equipment and procedures, as described in Attachment C to the QASP:

- Container material and volume: 2 – 2L sampling bags, 1 – 75 cc mini-cylinder.
- Preservation technique: storage cabinets.
- Maximum sample holding time: 5 business days.

A chain of custody form will be filled out for each set of samples collected. The form will include the following:

- Sampling date.
- Analytical detection limit.
- Sample location.
- Type of container.
- Sampler name and signature.
- Shipping information.
- Other comments and notes.
- Signature of others involved in the chain of custody.

CO_2 stream samples will be collected either at the Wellington injection site or at Linde's plants in Woodward and Enid, Oklahoma, and Praxair's plant in Dodge City, Kansas. If an alternate vendor or plant to those listed is selected, then EPA will be notified in advance of the change. In the event that CO_2 from an ethanol plant is available in the future, then Berexco may elect to use such a source for the CO_2 but will notify EPA prior to switching the source to allow time for EPA to re-evaluate the relevant sampling procedures and target analytes.

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

Berexco will install and use continuous recording devices in KGS 1-28 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 to meet the requirements of 40 CFR 146.90(b).

Deviations in operating parameters may trigger automatic shutdown of the well, as described in the Emergency and Remedial Response Plan (Attachment F to this permit).

Berexco will perform the activities identified in Table 2, at the locations specified in the table, to verify internal mechanical integrity of the injection well and monitor injection pressure, rate, and volume, annular pressure, and annular fluid added as required at 40 CFR 146.88, 146.89, and 146.90(b).

Table 2. Measurement locations for continuous monitoring.

Test Description	Location
Annular Pressure Monitoring	Surface
Injection Pressure Monitoring	Surface
Injection Rate Monitoring	Surface
Injection Volume Monitoring	Surface
Temperature Monitoring	Surface and within the perforations
Annulus Fluid Volume Added	Surface (fluid addition to be undertaken manually)

All monitoring will be continuous for the duration of the injection period, and collection and recording of monitoring data will occur at the frequencies described in Table 3.

Table 3. Sampling and recording frequencies for continuous monitoring.

Well Condition	Minimum sampling frequency(1) Once every:	Minimum recording frequency(2) Once every:
For continuous monitoring of the injection well when operating:	30 seconds	30 seconds
For the injection well when shut-in:	30 seconds	30 seconds

(1) Sampling frequency refers to how often the monitoring device obtains data from the well for a particular parameter. For example, a recording device might sample a pressure transducer monitoring injection pressure once every two seconds and save this value in memory.

(2) Recording frequency refers to how often the sampled information gets recorded to digital format (such as a computer hard drive). For example, the data from the injection pressure transducer might be recorded to a hard drive once every minute.

The injection well will have pressure and temperature transducers located at the surface and downhole within the perforations. Pressure and temperature gauges will be calibrated as shown in Table 4.

Table 4. Summary of measurement parameters for field gauges.

Parameters	Methods	Detection Limit (Range)	Typical Precisions	QC Requirements
Wellhead pressure	ANSI Z540-1-1994	0.01 psi (0 to 3,000 psi)	± 2 psi	Calibration per manufacturer's recommendation
Arbuckle downhole temperature	ANSI Z540-1-1994	± 0.01°F (-40°F to 392°F)	± 0.010F	Annual calibration
Arbuckle downhole pressure	ANSI Z540-1-1994	± 0.01 psi (0 to 5,000 psi)	± 0.01 psi	Annual calibration
Injection flow rate (NUFLO Liquid Turbine Flow Meter)	No specific method	12 lb/min (12 to 325 lb/min)	± 1%	Annual calibration

The results of these monitoring activities will be submitted to EPA in a semi-annual report as specified in the permit. Specifically, Berexco will report:

- Monthly average, maximum, and minimum values for injection pressure, flow rate, and volume, in compliance with 40 CFR 146.91(a)(2).
- Monthly average, maximum, and minimum values for annulus pressure, in compliance with 40 CFR 146.91(a)(2).
- A description of any event that exceeds operating parameters for annular pressure or injection pressure specified in the permit, in compliance with 40 CFR 146.91(a)(3).
- The monthly volume and/or mass of the CO_2 stream injected over the reporting period and volume injected cumulatively over the life of the project, in compliance with 40 CFR 146.91(a)(5).
- Monthly annulus fluid volume added, in compliance with 40 CFR 146.91(a)(6).

Injection Rate and Pressure Monitoring

Berexco will receive CO_2 in 20-ton tanker trucks at the site and store it in storage vessel(s) until the time of injection. Mass of CO_2 injected will be determined by measuring the weight of the CO_2 as it is delivered by trucks. Flow rate will be monitored by using a NUFLO Liquid Turbine Flow Meter. All data will be recorded by a PLC at the well site and sent to Berexco's SCADA system, which will in turn manipulate the flow control valves.

Calculation of Injection Volumes

Injection volumes will be calculated using Bernoulli's equation and the density of CO_2 as determined by equations of state and the measured pressure and temperature. Berexco will use the Massachusetts Institute of Technology's CO_2 Thermophysical Property Calculator (https://sequestration.mit.edu/tools/index.html) to determine the CO_2 density.

Continuous Monitoring of Annular Pressure

The annulus will be filled with a non-corrosive fluid (CRW37 fluid supplied by Baker Petrolite) and monitored for pressure. The annulus will be maintained under hydrostatic conditions with the fluid filled close to the surface and the annular pressure will be monitored using a pressure gauge at the surface. Please refer to “Annulus Fluid Volume Added” below for an explanation of how the annulus fluid level will be maintained. Approximately 430 ft^3 or 3,230 gallons of fluid will be used in the annulus.

Pressure will be monitored continuously, with readings taken every 30 seconds during the injection period. Any deviations from expected changes due to temperature will indicate an integrity problem and will initiate a well shut-down and investigation into the cause of loss of integrity according to the procedures described in the Emergency and Remedial Response Plan (Attachment F to this permit).

Casing-Tubing Pressure Monitoring

During the injection timeframe of the project, the casing-tubing pressure will be monitored and recorded in real time. Surface pressure of the casing-tubing annulus is anticipated to be from 0 to 800 psi. Significant changes in the casing-tubing annular pressure attributed to well mechanical integrity will be investigated as described in the Emergency and Remedial Response Plan (Attachment F to this permit).

Annulus Fluid Volume Added

The pressure in the annulus will be recorded continuously with a pressure transducer. Due to the fact that surface pressure in the tubing will be below 1,200 psi, a positive pressure at the surface will not be maintained in the annulus. The water level in the annulus is expected to vary due to temperature variations associated with CO_2 injection. The temperature in the tubing could drop below 40°F on commencement of injection, which will result in a corresponding drop in the annulus water level. The annulus will be filled 5 feet below the surface prior to commencement of injection and then the water levels will be monitored to determine the drop in water level due to reduction of fluid density. Once water levels have stabilized, then water levels will be maintained 5 feet below the surface. As documented in the Wellington Operating Plan for Safe and Efficient Injection, if there is a 25% or greater drop of pressure within a 5 minute period, then the response procedures in the Emergency and Remedial Response Plan (Attachment F) and the “Monitoring Based Rapid Response Plan” (included as an appendix to the Emergency and Remedial Response Plan) will be executed as a response to a potential leakage from well or caprock.

Corrosion Monitoring

To meet the requirements of 40 CFR 146.90(c), Berexco 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. Berexco will monitor corrosion using corrosion coupons and collect samples according to the description below.

Monitoring will be done quarterly during the injection period, on the following schedule: 12 weeks after injection begins (± 1 week) and 24 weeks after injection begins (± 1 week).

The results of this monitoring will be described in a semi-annual report and submitted to EPA in compliance with 40 CFR 146.91(a)(7).

Sample Description

Two pre-weighed, photographed, and measured coupons will be used made of representative well construction materials. The coupons will be composed of J55 steel (or equivalent) and will be clamped in the line between the CO_2 storage tank and the injection well. Table 5 lists the methods to be used for analyzing the corrosion coupons.

Table 5. Summary of analytical parameters for corrosion coupons.

Parameters	Analytical Methods	Detection Limit	Typical Precisions	QC Requirements
Mass	NACE RP0775-2005 (or equivalent)	0.05 mg	± 3%	Manufacturer recommended calibration
Thickness	NACE RP0775-2005 (or equivalent)	0.01 mm	± 0.05 mm	Manufacturer recommended calibration

Sample Exposure

The corrosion coupons will be clamped in the line between the CO_2 storage tank and the injection well in order to ensure that there is no mass loss (and hence compromise of mechanical integrity). The coupons will be sent quarterly to SGS Laboratory for analysis in accordance with NACE Standard RP-0775 (or equivalent).

Sample Handling and Monitoring

Samples will be removed on a quarterly basis and cleaned, weighed, and visually inspected for loss of mass, thickness, pitting, cracking, and other signs of corrosion. Weights will be measured to within 0.1 mg and used to calculate a loss rate in mils per year. A corrosion rate of greater than 0.3 mils/year will initiate more frequent sampling and corrective action in consultation with the UIC Program Director.

Ground Water Quality Monitoring and Other Monitoring Above the Confining Zone

Berexco will monitor ground water quality and geochemical changes above the confining zone during the operation period to meet the requirements of 40 CFR 146.90(d).

Monitoring will occur in the following formations above the confining zone:

- Upper Wellington Formation.
- Mississippian Formation.

Table 6 shows the planned monitoring methods, locations, and frequencies for ground water quality monitoring above the confining zone. All of the monitoring sites are located on Berexco property. Figure 1 and Figure 2 show the project area with the planned locations for monitoring above the confining zone.

Table 7 identifies the parameters to be monitored and the analytical methods to be employed by the testing laboratory. Sampling will be conducted using the methods and procedures as described in the QASP.

If dissolved CO_2 is detected in samples from the Mississippian Formation (see "Analytical Parameters" below), Berexco will investigate to determine whether the detected CO_2 is from the Class VI injection well or from nearby enhanced recovery operations. The CO_2 that is to be injected in the Arbuckle will contain SF_6 as a tracer, to assist in identifying the CO_2 source. SF_6 is a (trace) anthropogenic gas found in the atmosphere at 7-8 parts per trillion (ppt). Therefore, the testing equipment is designed to measure minute quantities of this gas. SF_6 is a conservative gas which does not sorb onto the matrix or react/decompose into daughter products. SF_6 will be added at the Wellington site in the supply line between the CO_2 storage tank and the wellhead. Twenty (20) kilograms of SF_6 will be added to the CO_2 during the injection phase at a continuous rate of approximately 75 grams per day for 9 months.

Berexco will also monitor for changes in the Mississippian Formation using 2D seismic surveying, approximately halfway through the injection period.

The results of this monitoring will be described in a semi-annual report and submitted to EPA in compliance with 40 CFR 146.91(a)(7).

Table 6. Direct and indirect monitoring of ground water quality and geochemical changes above the confining zone.

Target Formation	Monitoring Activity	Monitoring Location(s)	Injection Phase Frequency
Upper Wellington	Geochemical monitoring (fluid sampling and analysis)	3 shallow monitoring wells, as shown in Figure 1: • SW-1: 37°19'10.50"N, 97°25'59.52"W (50 ft. below ground surface) • SW-2: 37°19'8.42"N, 97°26'1.09"W (100 ft below ground surface) • SW-3: 37°19'5.08"N, 97°26'7.50"W (200 ft below ground surface)	Quarterly: • 12 weeks after injection begins (± 1 week) • 24 weeks after injection begins (± 1 week)
Mississippian	Geochemical monitoring (fluid sampling and analysis)	Wellington Unit Wells 24 and 32, as shown in Figure 1: • MS-24: 37.3206917, -97.4346848; open hole interval 3660–3707 ft • MS-32: 37.3188077, -97.431280; open hole interval 3634–3678 ft	Every 2 months: • 8 weeks after injection begins (± 1 week) • 16 weeks after injection begins (± 1 week) • 24 weeks after injection begins (± 1 week)

Target Formation	Monitoring Activity	Monitoring Location(s)	Injection Phase Frequency
Multiple (primarily the Mississippian)	2D seismic surveying	Surface stations, along lines shown in Figure 2	Once, approximately halfway through the injection period (approximately 12 weeks after the start of injection)

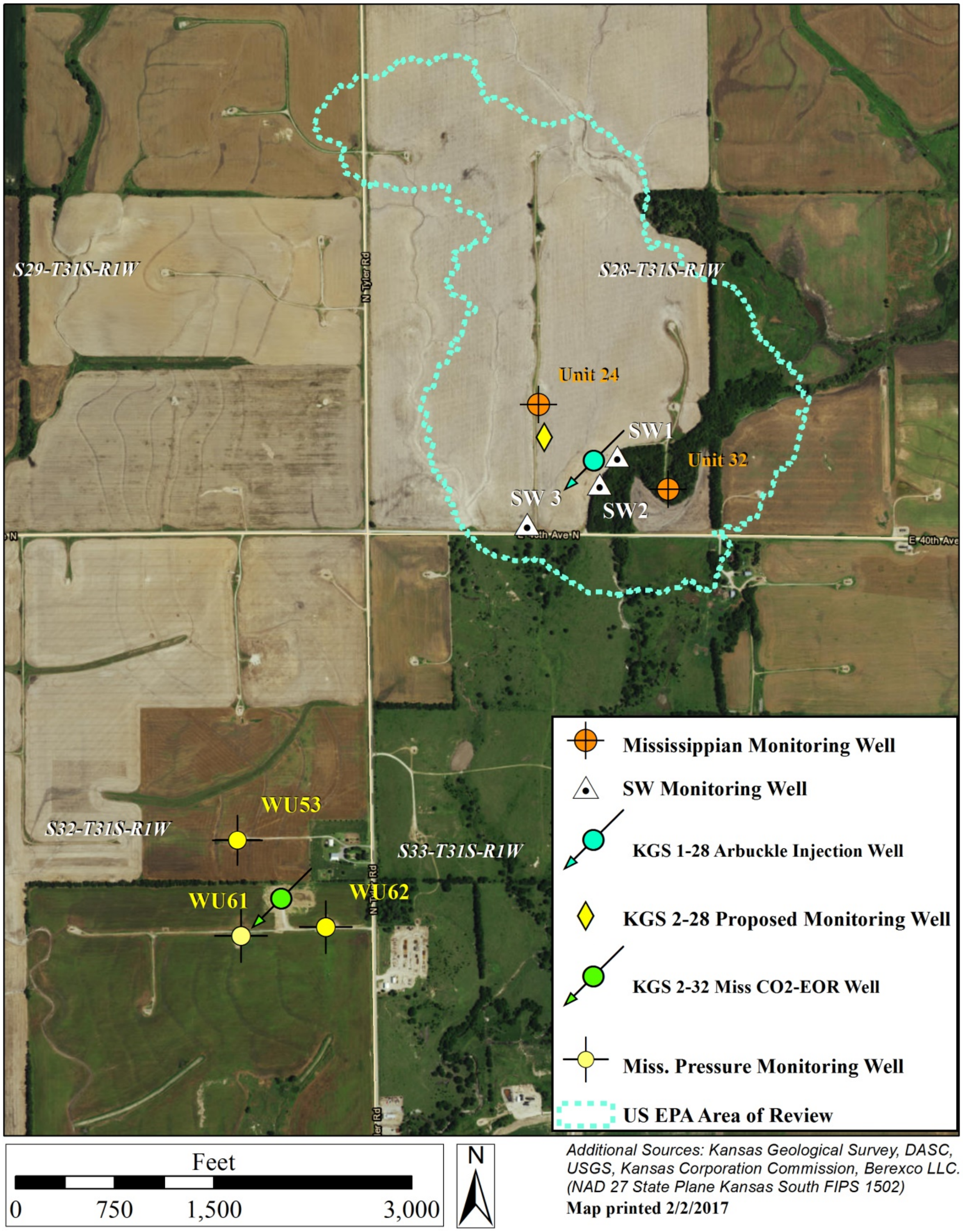


Figure 1. Monitoring well locations.

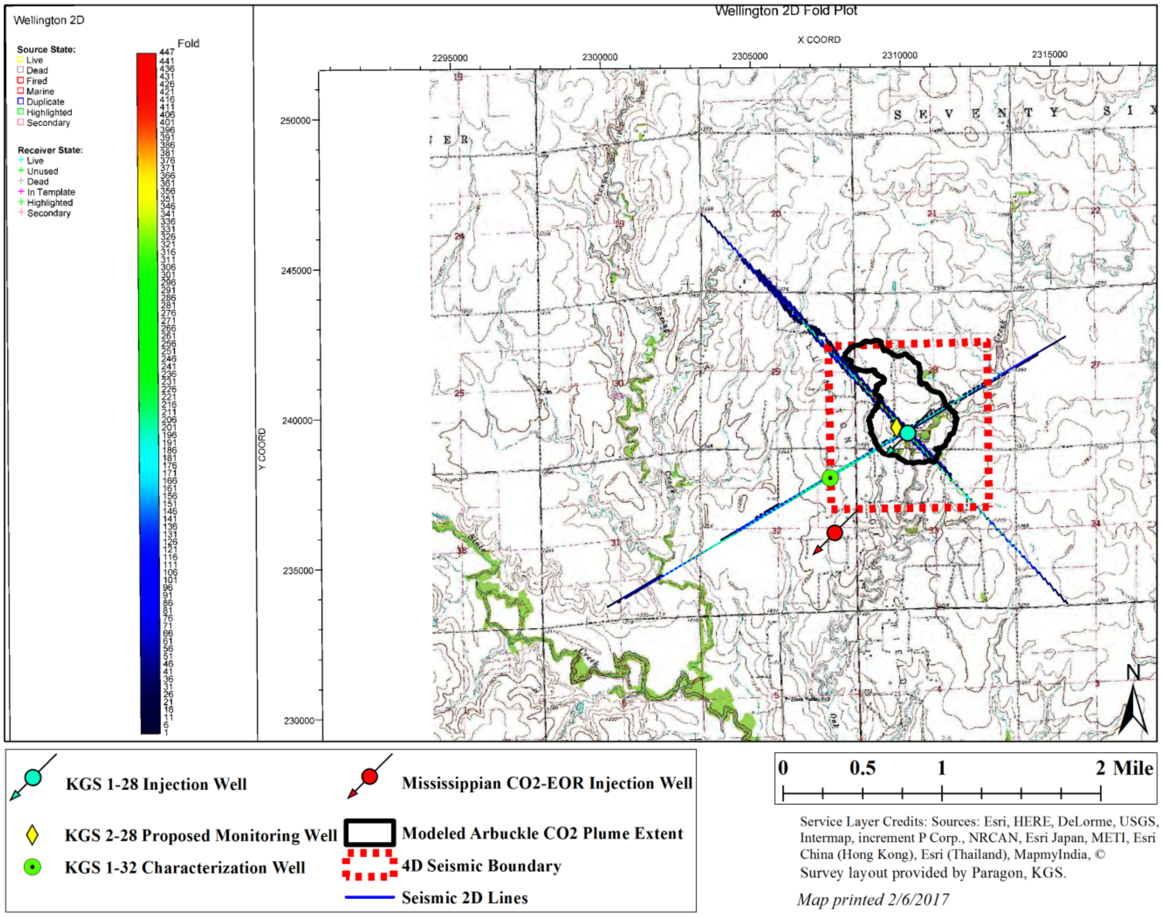


Figure 2. Area of planned 3-D seismic survey and 2-D seismic lines.

Table 7. Summary of parameters for ground water samples.

Parameters	**Analytical Methods(1)**
Upper Wellington	
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and Tl	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO_3, SO_4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Total dissolved solids	Gravimetry; APHA 2540C
Alkalinity	APHA 2320B
pH (field)	SM 2450

Parameters	Analytical Methods[1]
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple
Oxidation-reduction potential (field)	SESDPROC-113-R1
Sulfur hexafluoride	Busenberg and Plummer, 2000 (http://water.usgs.gov/lab/sf6/)
Hydrogen sulfide	SM4500-S2D
Acetaldehyde	EPA Method 8315A
Turbidity	Method 180.1
Mississippian	
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and Tl	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO_3, SO_4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Total dissolved solids	Gravimetry; APHA 2540C
Alkalinity	APHA 2320B
pH (field)	SM 2450
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple
Oxidation-reduction potential (ORP) (field)	SESDPROC-113-R1
Hydrogen sulfide	SM4500-S2D
Acetaldehyde	EPA Method 8315A
Turbidity	Method 180.1
Sulfur hexafluoride	Busenberg and Plummer, 2000 (http://water.usgs.gov/lab/sf6/)

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

Sampling Methods

Samples will be collected using the following procedures:

- Static water levels will be measured in the Upper Wellington wells prior to sampling.
- The shallow (50-ft) Upper Wellington well will be purged of 3 wellbore volumes before sampling. The deeper (100-ft and 200-ft) Upper Wellington wells will be purged of 1 wellbore volume before sampling.
- All equipment lowered downhole will be rinsed with deionized water.
- All equipment will be calibrated according to manufacturer instructions.

- Exposure of samples to ambient air will be minimized.
- pH, temperature, specific conductance, and dissolved oxygen will be measured in field.
- Each sampling event will include two duplicates, an equipment rinsate, a matrix spike, and a trip blank.
- When necessary samples will be packaged and shipped according to ASTM D6911-03.

Samples will be sent to a certified laboratory for analysis. All sampling will be conducted by a KGS contractor pursuant to the EPA-approved QASP, and all geochemical analyses will take place at the Pace Laboratory in Salina, Kansas, or a state-certified laboratory.

Chain of Custody Procedures

All bottles will be labeled using indelible markers. Each sample will be labeled with a unique sample ID number, date, and analyte. A chain of custody form will accompany each set of samples. The form will include the following information:

- Sampling date.
- Analytical detection limit.
- Location.
- Type of container.
- Sampler name and signature.
- Other comments.
- Shipping information.
- Signature of others involved in the chain of custody.

External Mechanical Integrity Testing

Berexco will conduct at least one mechanical integrity test (MIT) in the injection well (KGS 1-28) during the injection phase to verify external mechanical integrity as required at 40 CFR 146.89(c) and 146.90. Berexco will also perform one external MIT in the Arbuckle monitoring well (KGS 2-28). This MIT will be a temperature log performed via wireline well log, as described under "Description of MIT(s) that may be employed" below. If Berexco wishes to conduct a different approved MIT as listed at 40 CFR 146.89(c), Berexco will notify EPA and submit a description of the planned test procedures, to be approved by EPA before the test is conducted.

The results of this testing will be reported to EPA within 30 days of the test, in compliance with 40 CFR 146.91(b)(1). The results will also be included in a semi-annual report and submitted to EPA in compliance with 40 CFR 146.91(a)(7).

Description of MIT(s) that may be employed

As suggested in EPA guidance, the well will be shut during the injection phase for a period of 36 hours before obtaining the temperature log. During the shut-in period, the temperature within the wellbore will typically migrate towards ambient geothermal conditions but will not fully equilibrate to ambient conditions. If there has been a leak of fluid out of the well, the temperature within the wellbore at this location will change to a lesser extent and be measured as an anomaly because the temperature of the surrounding formation will have been modified by the leaking fluid.

Leaks will be identified from injection and post-injection logs by noting relative differences between the collected temperature log and the baseline (and previous) logs. Since lithology and injectate characteristics will be similar, the thermal effects along the wellbore are expected to be very similar. After the temperature effects caused by injection, casing joints, packers, well diameter, casing string differences, and cement have dissipated, the temperature profiles are expected to be similar, although not identical. The log and associated report will be submitted to the EPA within 30 days of test completion as required in 40 CFR 146.91(b). If interpretation of the data indicates a noncompliance, a report will be submitted to EPA within 24 hours of testing as required by 40 CFR 146.91(c). If necessary, radioactive tracer, noise, oxygen activation, or other logs approved by the UIC Program Director may be used to further define the nature of the fluid movement.

Pressure Fall-Off Testing

Berexco will perform one pressure fall-off test during the injection phase to meet the requirements of 40 CFR 146.90(f).

Berexco will conduct pressure fall-off testing according to the procedures below.

The results of this test will be included in a semi-annual report and submitted to EPA in compliance with 40 CFR 146.91(a)(7).

Pressure Fall-Off Test Procedure

Water will be injected into the well at a steady rate for 12 hours followed by a 12-hour shut-in period. Bottom-hole pressure will be monitored during the shut-in period.

1. General Operational Concerns
    a. Adequate storage for the waste should be ensured for the duration of the test
    b. Offset wells completed in the same formation as the test well should be shut-in, or at a minimum, provisions should be made to maintain a constant injection rate prior to and during the test.
    c. Install a crown valve on the well prior to starting the test so the well does not have to be shut-in to install a pressure gauge.

d. The location of the shut-in valve on the well should be at or near the wellhead to minimize the wellbore storage period.

e. The condition of the well, junk in the hole, wellbore fill or the degree of wellbore damage (as measured by skin) may impact the length of time the well must be shut-in for a valid falloff test. This is especially critical for wells completed in relatively low transmissibility reservoirs or wells that have large skin factors.

f. Cleaning out the well and acidizing may reduce the wellbore storage period and therefore the shut-in time of the well.

g. Accurate recordkeeping of injection rates is critical including a mechanism to synchronize times reported for injection rate and pressure data. The elapsed time format usually reported for pressure data does not allow an easy synchronization with real time rate information. Time synchronization of the data is especially critical when the analysis includes the consideration of injection from more than one well.

h. Any significant changes to the testing procedure, or any testing of a well with known or anticipated problems, should be discussed with EPA staff prior to performing the test.

2. <u>Site Specific Pretest Planning</u>

a. Determine the time needed to reach radial flow during the injectivity and falloff portions of the test:

i. Review previous well tests, if available.

ii. Simulate the test using measured or estimated reservoir and well completion parameters

iii. Calculate the time to the beginning of radial flow using the empirically-based equations. The equations are different for the injectivity and falloff portions of the test with the skin factor influencing the falloff more than the injection period.

iv. Allow adequate time beyond the beginning of radial flow to observe radial flow so that a well-developed semilog straight line occurs. A good rule of thumb is 3 to 5 times the time to reach radial flow to provide adequate radial flow data for analysis.

b. Adequate and consistent injection fluid should be available so that the injection rate into the test well can be held constant prior to the falloff. This rate should be high enough to produce a measurable falloff at the test well given the resolution of the pressure gauge selected. The viscosity of the fluid should be consistent. Any mobility issues (k/μ) should be identified and addressed in the analysis if necessary.

c. Bottomhole pressure measurements are usually superior to surface pressure measurements because bottomhole measurements tend to be less noisy. Surface pressure measurements can be used if positive pressure is maintained at the surface throughout the falloff portion of the test. The surface pressure gauge should be located at the wellhead. A surface pressure gauge may also serve as a backup to a downhole gauge and provide a monitoring tool for tracking the test progress. Surface gauge data can be plotted during the falloff in a log-log plot format with the pressure derivative function to determine if the test has reached radial flow and can be terminated. Note: Surface pressure measurements are not adequate if the well goes on a vacuum during the test.

d. Use two pressure gauges during the test with one gauge serving as a backup, or for verification in cases of questionable data quality. The two gauges do not need to be the same type.

3. Conducting the Fall-Off Test
   a. Tag and record the depth to any fill in the test well.
   b. Simplify the pressure transients in the reservoir
      i. Maintain a constant injection rate in the test well prior to shut-in. This injection rate should be high enough and maintained for a sufficient duration to produce a measurable pressure transient that will result in a valid falloff test.
      ii. Offset wells should be shut-in prior to and during the test. If shut-in is not feasible, a constant injection rate should be recorded and maintained during the test and then accounted for in the analysis.
      iii. Do not shut-in two wells simultaneously or change the rate in an offset well during the test.
   c. The test well should be shut-in at the wellhead in order to minimize wellbore storage and afterflow.
   d. Maintain accurate rate records for the test well and any offset wells completed in the same injection interval.
   e. Measure and record the viscosity of the injectate periodically during the injectivity portion of the test to confirm the consistency of the test fluid.

Carbon Dioxide Plume and Pressure-Front Tracking

Berexco will employ direct and indirect methods to track the extent of the CO_2 plume and the presence or absence of elevated pressure during the operation period to meet the requirements of 40 CFR 146.90(g).

The results of this monitoring will be reported to EPA in a semi-annual report, in compliance with 40 CFR 146.91(a)(7).

Plume Monitoring

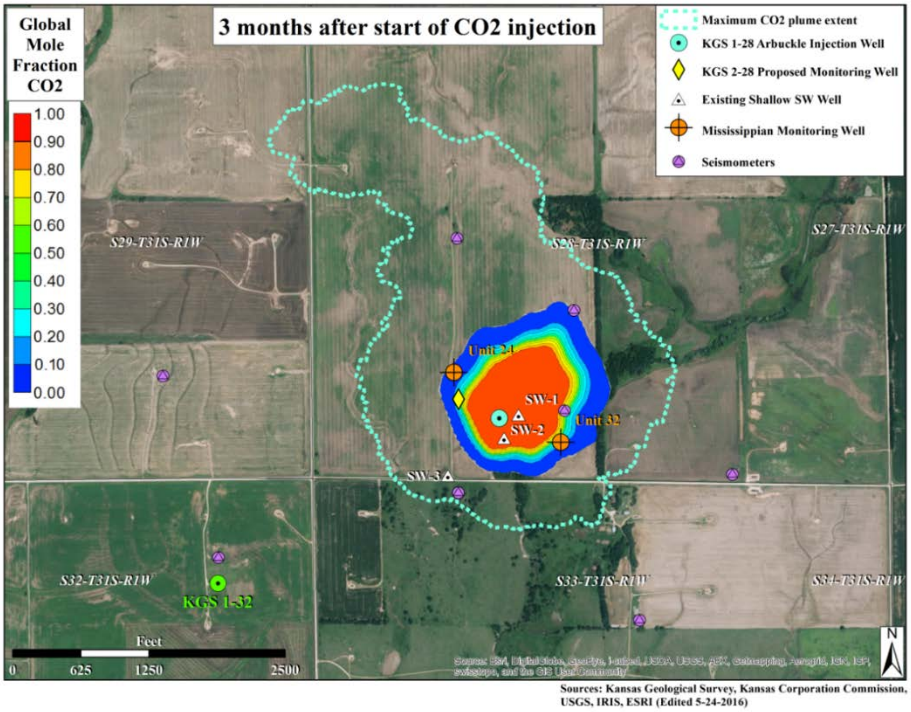
Fluid sampling will be conducted for direct measurement of the plume. Tracer injection and measurement will be part of the fluid sampling. Samples will be collected using a U-tube sampler. Indirect measurements will include surface seismic surveys combined with cross-well seismic surveys and continuous active source seismic monitoring (CASSM). A baseline surface seismic and cross-well seismic survey will be performed prior to commencement of injection. Two cross-well seismic surveys will be conducted during the injection phase. CASSM data will be recorded every 24 hours until the CO_2 plume arrives at KGS 2-28.

Any potential interference between CASSM and downhole pressure monitoring is not expected to be problematic. This is because the CASSM surveys will be acquired every 24 hours. The bottom hole pressure in the injection well is expected to change rapidly only during the first 24 hours. Thereafter, the pressure will increase but not as rapidly, and therefore any loss of pressure accuracy during CASSM acquisition is not expected to be consequential.

Berexco will primarily rely on CASSM and pH measurements to detect breakthrough of CO_2 at the KGS 2-28 monitoring well. The CASSM reading will be graphed continuously, so any uptick in the delay time will be readily apparent and indicate breakthrough. In particular, a delay time of 0.02 ms at any sensor will be indicative of breakthrough and will be confirmed by other sensors above and below the sensor that initially records a delay time. Based on data at the Wellington EOR site and other CO_2 sequestration sites such as the Bozeman in Montana (Kharaka et al., 2010), the pH level is expected to drop quite precipitously on arrival of CO_2. Berexco expects to see a drop in pH of up to 1.0 pH units within 10 days of plume arrival. They will consider a drop in pH from background levels of 0.25 pH units as possible breakthrough (the CASSM information is, however, expected to contain more reliable breakthrough data). The pH will be measured using SM 2540 every two weeks after initial detection of plume by CASSM. The typical precision is +- 0.2 pH unit. The pH will continue to be measured every two weeks until stabilization of the plume. (Preliminary samples collected prior to breakthrough will only be checked for pH at the site as a proxy for CO_2. If CO_2 is suspected in the samples, then the sample will be sent to the laboratory to be tested for a complete suite of parameters listed in Table 9.)

If the delay time for three consecutive CASSM readings are within 0.05 ms, then stabilization will be assumed. Additionally, Berexco will consider stabilization to have occurred if the pH from three consecutive (biweekly) measurements following breakthrough are within 0.4 pH units or varying within a range of 10%. Stabilization will also be assumed/verified if alkalinity (HCO_3) remains within a range of 50 mg/L for three consecutive (biweekly) measurements.

Table 8 presents the direct and indirect methods that Berexco will use to monitor the position of the CO_2 plume, including the activities, locations, and frequencies Berexco will employ. Monitoring locations relative to the predicted location of the CO_2 plume at three and six months after the start of injection are shown in



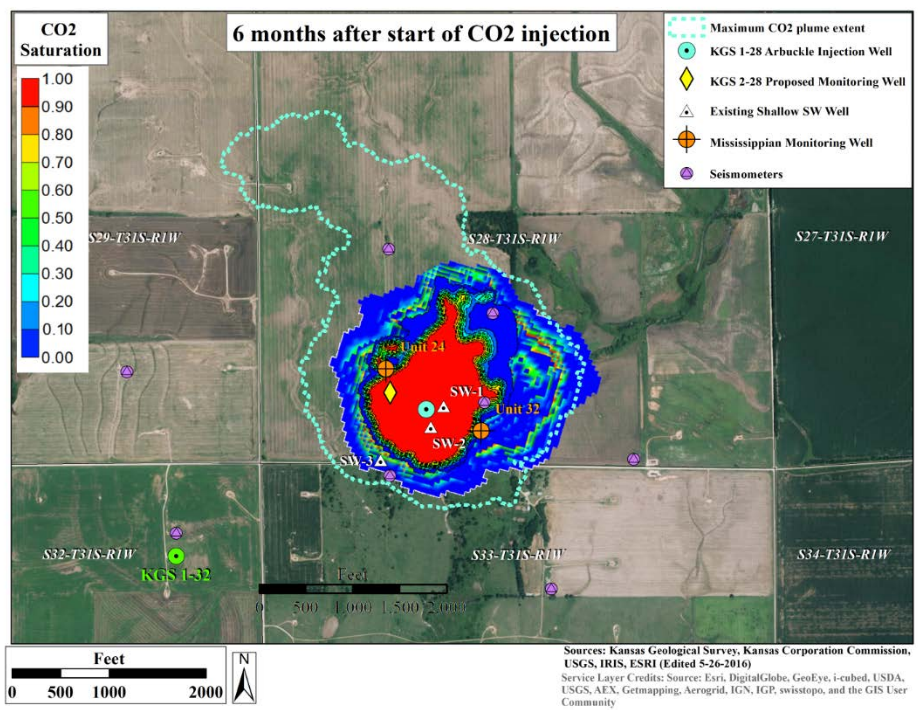
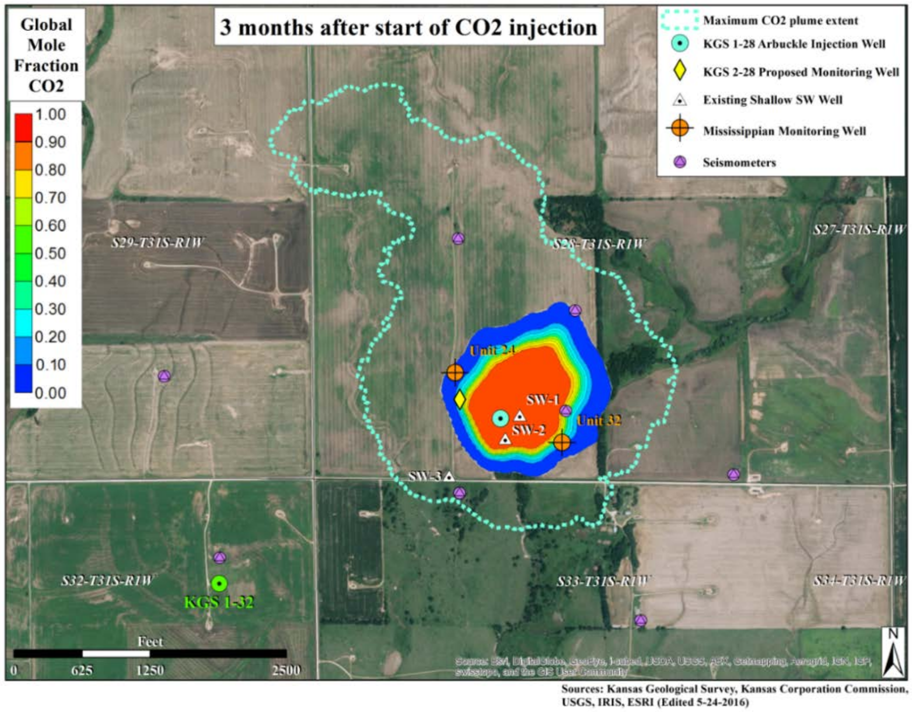


Figure 3 and

Figure 4, respectively. The area to be covered by the 3D seismic survey is shown in Figure 2 above. The parameters to be analyzed as part of fluid sampling in the injection zone and associated analytical methods are presented in Table 9.

These images are included in this Plan for comparison with monitoring results during injection



period. The images in

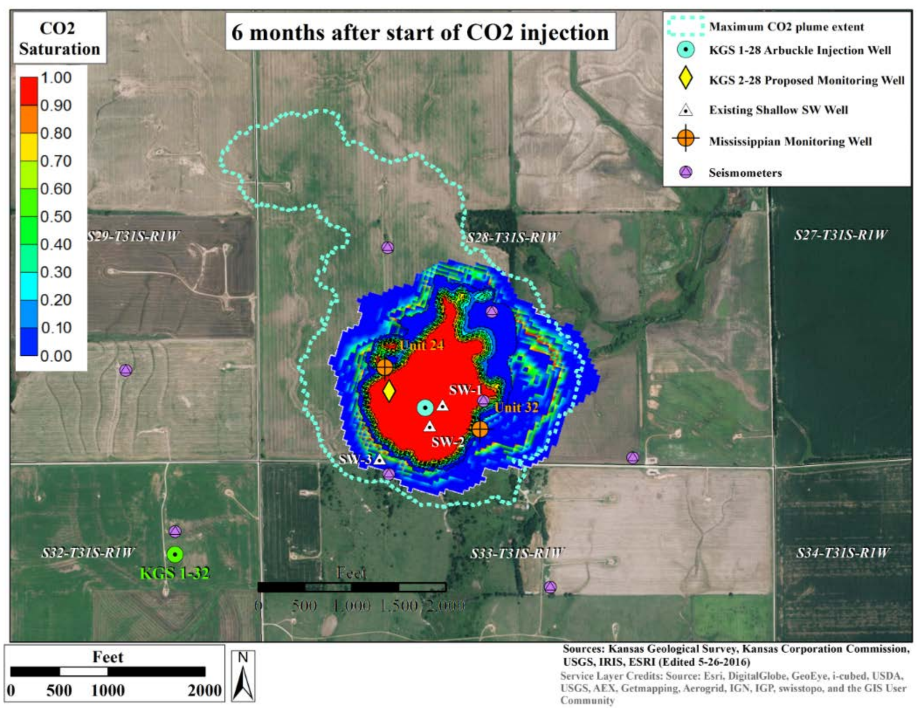


Figure 3 and

Figure 4 reflect the modeling scenario with conditions that resulted in the greatest plume migration (referred to as the "worst-case" scenario by Berexco). Accordingly, actual plume extent may not be as extensive as shown in these images. The procedures that Berexco will use to compare the modeled predictions with the monitoring results are described in Attachment B to this permit.

Table 8. Plume monitoring activities.

Target Formation	Monitoring Activity	Monitoring Location(s)	Injection Phase Frequency
Direct Plume Monitoring			
Arbuckle	Geochemical monitoring (U-tube fluid sampling)	KGS 2-28 (sampling interval approx. 4,910 – 5,100 ft below ground surface)	CASSM will inform about plume arrival at KGS 2-28, and will trigger immediate collection of U-tube sample. Thereafter, samples will be collected every two weeks until stabilization of CO_2 concentrations.(1) As an independent check, U-tube samples will be collected once every two weeks after commencement of injection. Following breakthrough and subsequent stabilization of CO_2 concentrations, U-tube samples will be collected monthly.
Indirect Plume Monitoring			
Multiple	3D seismic survey	As shown in Figure 2, covering an area of at least 1 square mile around the injection well. In the event that the diameter of the plume is estimated to extend further than the 1 square mile area, the 3D seismic survey area will be extended in consultation with the UIC Program Director. Vertical coverage from base of Arbuckle to land surface,	None (initial survey performed before injection; additional survey to be performed prior to site closure)
Arbuckle	CASSM	KGS 1-28 and KGS 2-28; 10 sensors at 50 ft spacing from 4,750 ft to 5,200 ft depth	Continuous (approx. 24 hour temporal resolution), until the plume arrives at KGS 2-28
	Cross-well tomography	Plane between KGS 1-28 and KGS 2-28 (at 4,750 to 5,200 ft depth)	Two injection-phase surveys: one timed to provide information on plume arrival at KGS 2-28 and one at the end of injection (in addition to a baseline survey conducted prior to commencement of injection)

(1) Preliminary samples collected prior to breakthrough will only be checked for pH at the site as a proxy for CO_2. If CO_2 is suspected in the samples, then the sample will be sent to the laboratory to be tested for a complete suite of parameters listed in Table 9.

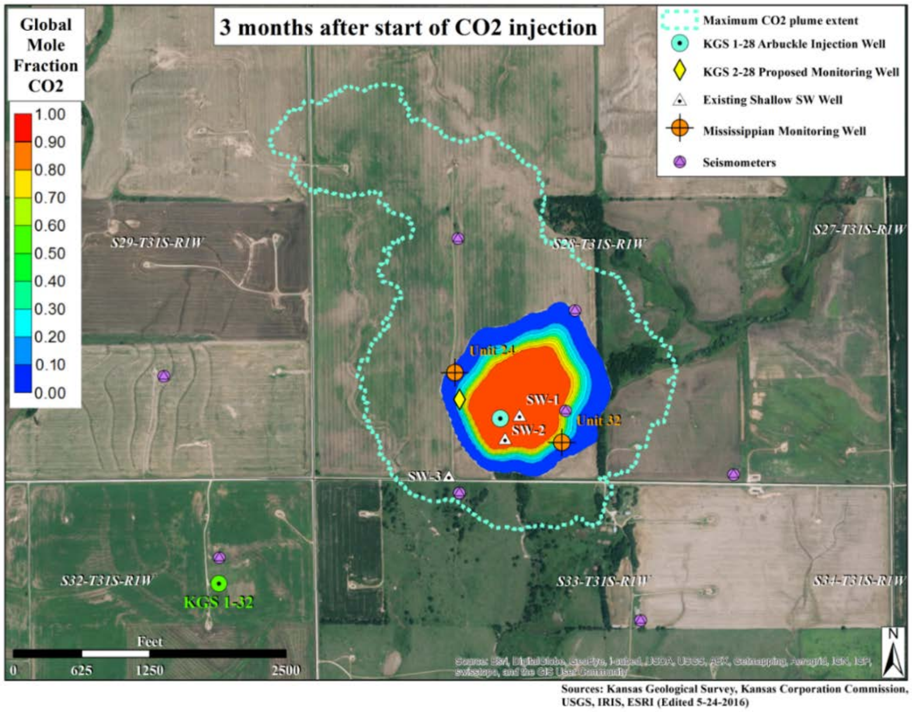


Figure 3. Location of monitoring wells and simulated plume boundary (dissolved plus free-phase CO_2) at the end of three months from commencement of injection for the 26,000 MT injection case. The dashed blue line shows the maximum extent of the free-phase plume only (the delineated AoR).

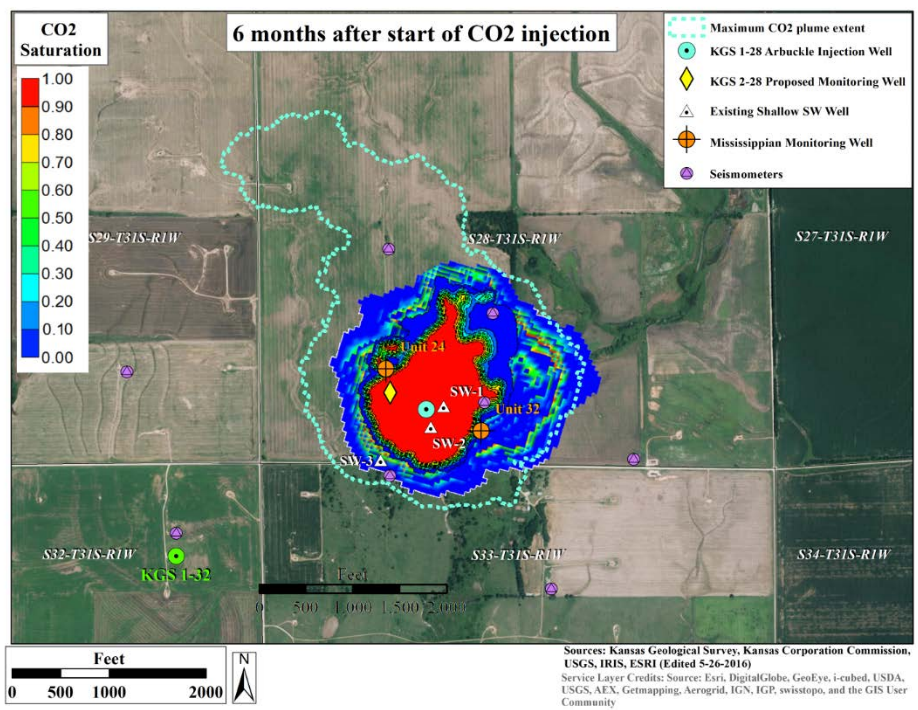


Figure 4. Location of monitoring wells and simulated plume boundary (dissolved plus free-phase CO_2) at the end of six months from commencement of injection for the 26,000 MT injection case. The blue dashed line shows the maximum extent of the free-phase plume only (the delineated AoR).

Table 9. Summary of analytical parameters for fluid sampling in the injection zone.

Parameters	Analytical Methods
Arbuckle	
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and Tl	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO_3, SO_4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Total dissolved solids	Gravimetry; APHA 2540C
Alkalinity	APHA 2320B
pH (field)	EPA 150.1
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple
Oxidation-reduction potential (field)	SESDPROC-113-R1
Hydrogen sulfide	SM4500-S2D
Turbidity	Method 180.1
Acetaldehyde	EPA Method 8315A

Pressure-Front Monitoring and Other Related Monitoring

Pressure front monitoring will be conducted directly, using pressure and temperature gauges installed downhole in the injection and monitoring wells. Indirect pressure front monitoring will be conducted using passive seismic monitoring. The same seismometer array will also be used to monitor seismicity, including natural and induced seismic activity. Additional data will be collected using Interferometric Synthetic Aperture Radar (InSAR) supplemented with continuous GPS (CGPS) measurements.

Table 10 presents the direct and indirect methods that Berexco will use to monitor the position of the pressure front, including the activities, locations, and frequencies Berexco will employ.

Table 10. Pressure-front monitoring and other related monitoring activities.

Target Formation	Monitoring Activity	Monitoring Location(s)	Injection Phase Frequency
Direct Pressure-Front Monitoring			
Arbuckle	Pressure/temperature monitoring	KGS 1-28 (pressure transducer within the perforations)	Continuous (every 30 sec.)
		KGS 2-28 (pressure transducer within the perforations)	Continuous (every 30 sec.)
Mississippian	Pressure monitoring	Unit 24 (Echometer)	Once a month
Indirect Pressure-Front Monitoring			
Multiple	Passive seismic monitoring	Seismometer network, as shown in Figure 5a and b	Continuous (downloaded monthly)
Other Related Monitoring			
Arbuckle	Interferometric synthetic aperture radar (InSAR) with continuous GPS (CGPS)	Radar data acquired in the imaging mode: StripMap - up to 3 m resolution, scene size 30 km (width) x 50 km (length) GPS station: adjacent to injection site (sampling frequency of 15 sec. averaged into a daily location)	GPS: daily InSAR: monthly

For purposes of identifying the area where a pressure increase is predicted to occur due to injection, and to support the strategy for monitoring pressure increase/evolution in the subsurface, Berexco will use a monitoring cutoff value of 15 psi. This value is used for monitoring/model validation purposes only; it is not equal to the critical pressure value calculated to delineate the pressure front. The simulated increase in pressure through the injection phase is shown in Figure 5: at 1 and 3 months after the start of injection in Figure 5a, at 6 months after the start of injection in Figure 5b, and at 9 months after the start of injection (i.e., the end of the injection phase) in Figure 5c. The pressure profiles (over time) at the Arbuckle injection and monitoring wells (KGS 1-28 and KGS 2-28) are presented in Figure 6.

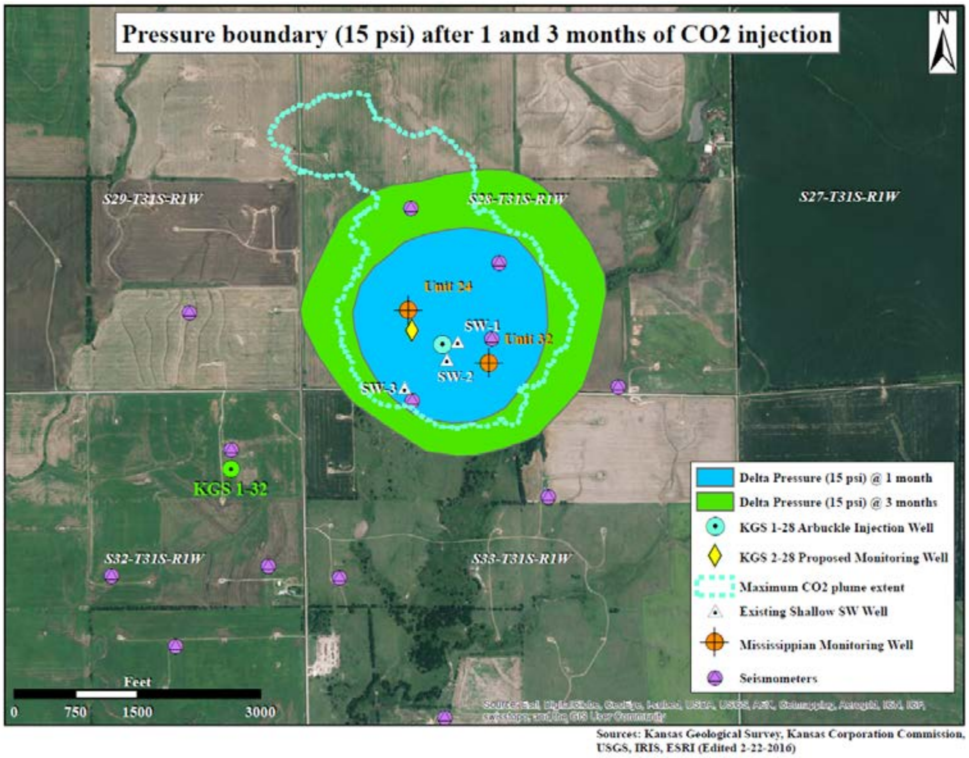


Figure 5a. Location of monitoring wells and simulated pressure increase at the end of 1 and 3 months from commencement of injection.

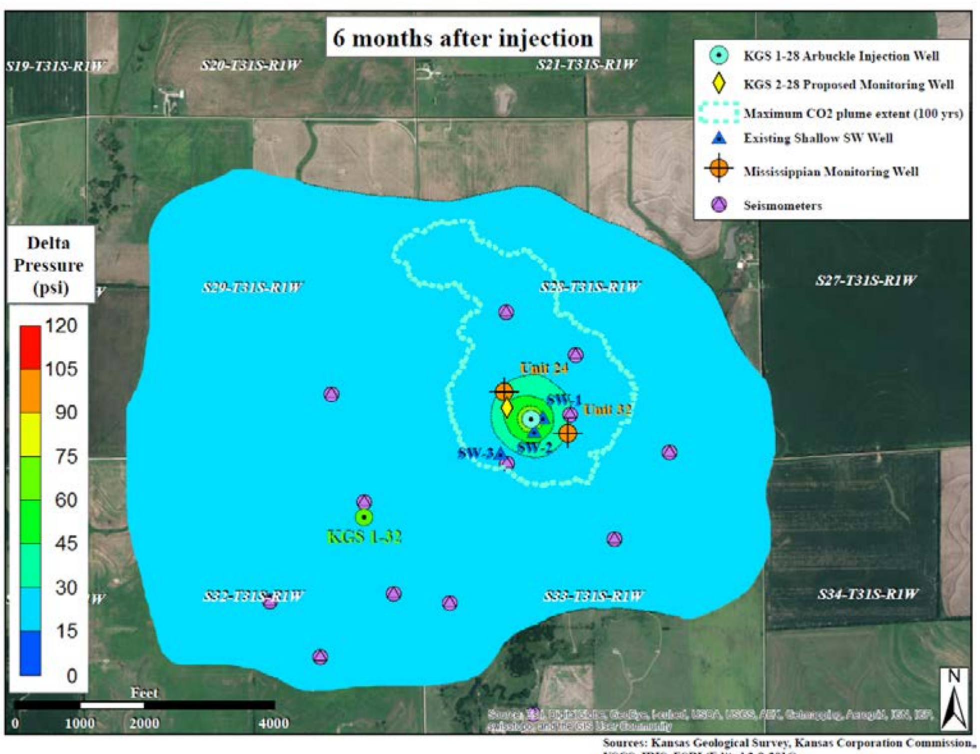


Figure 5b. Location of monitoring wells and simulated pressure increase (15 psi delta-pressure boundary) at the end of 6 months from commencement of injection.

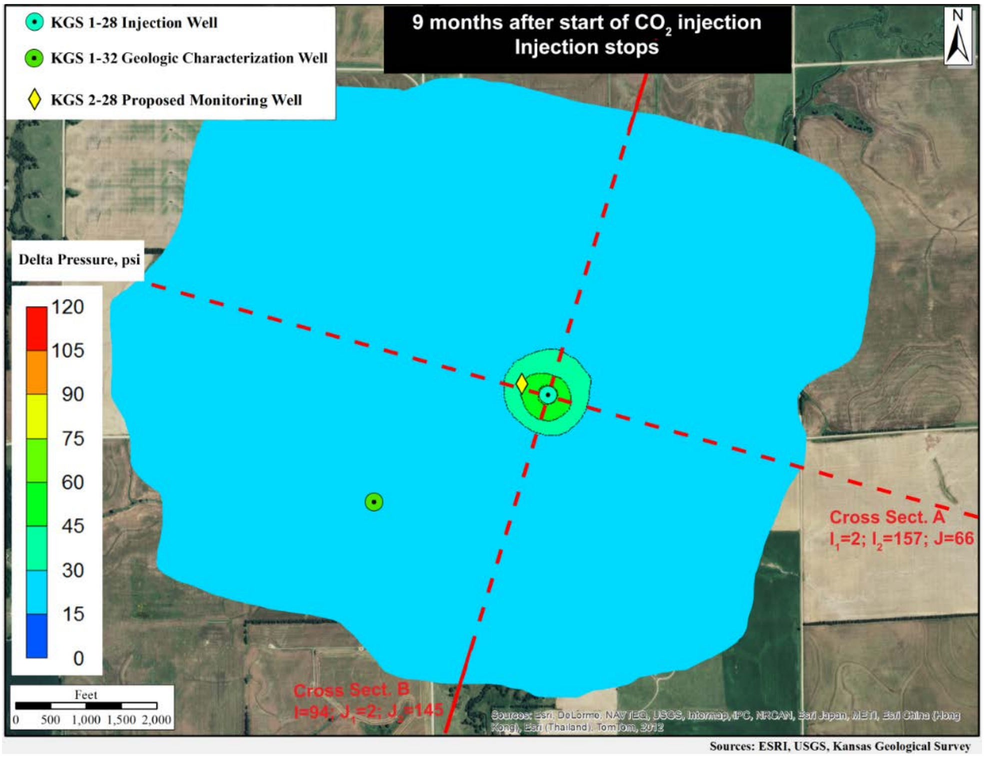


Figure 5c. Location of monitoring wells and simulated pressure increase (15 psi delta-pressure boundary) at the end of 9 months from commencement of injection (the end of the injection phase).

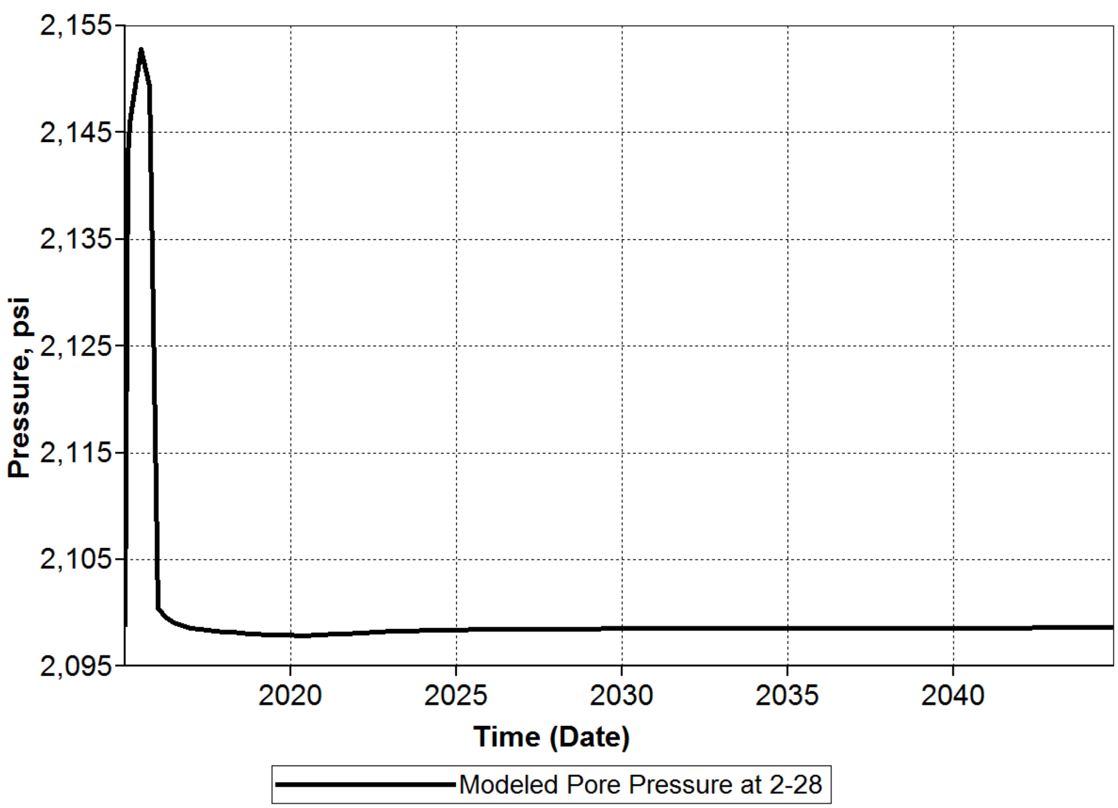


Figure 6a. Pressure profile in the Arbuckle monitoring well (KGS 2-28) for the 100-year simulation period.

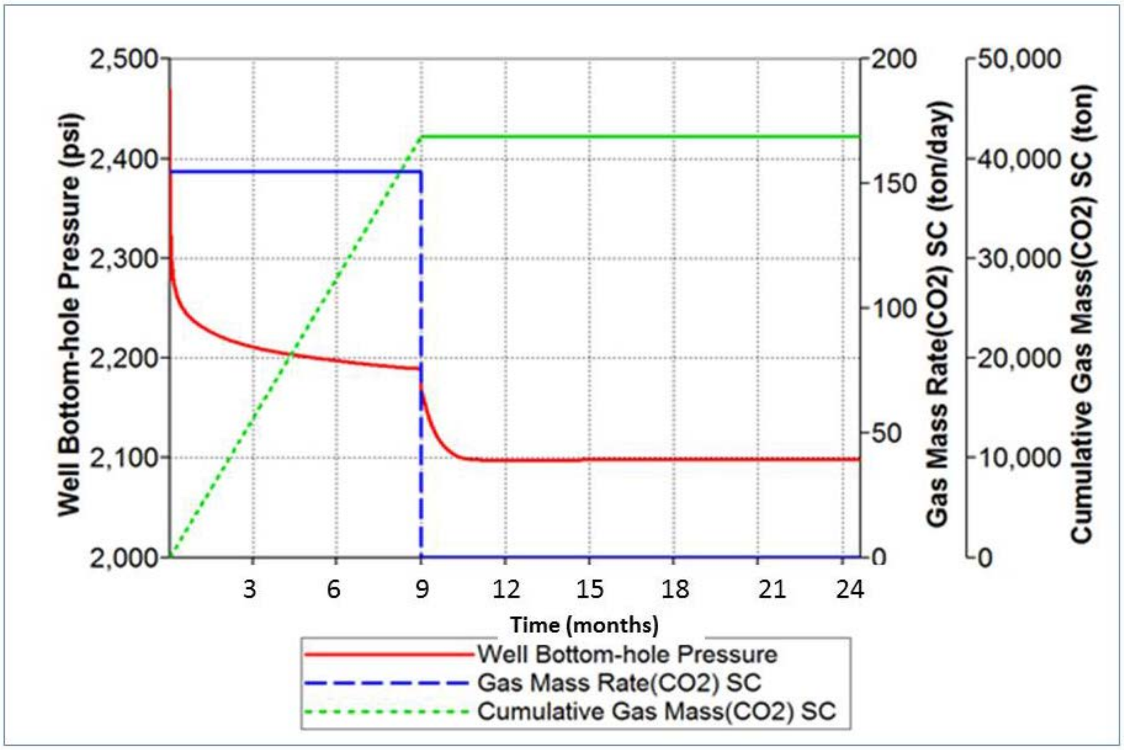


Figure 6b. Pressure profile in the Arbuckle injection well (KGS 1-28) for the 100-year simulation period.

These images above, in Figure 5 and Figure 6, are included in this Plan for comparison with monitoring results during the injection period. These images reflect the modeling scenario with conditions that resulted in the greatest plume migration (referred to the "worst-case" scenario by Berexco). Accordingly, actual pressure-front behavior may not be as extensive as shown in these images. The procedures that Berexco will use to compare the modeled predictions with the monitoring results are described in Attachment B to this permit.

Seismicity and Fault Monitoring

Seismicity monitoring and fault-related monitoring are required by the UIC Program Director pursuant to 40 CFR 146.90(i). The locations and frequencies for seismicity and fault monitoring are given in Table 11. The results of this monitoring will be described in a semi-annual report and submitted to EPA in compliance with 40 CFR 146.91(a)(7).

Table 11. Seismicity and fault monitoring.

Target Formation	Monitoring Activity	Monitoring Location(s)	Injection Phase Frequency
Multiple	Passive seismic monitoring	Seismometer network, as shown in Figure 5a and b	Continuous (downloaded monthly)

Target Formation	Monitoring Activity	Monitoring Location(s)	Injection Phase Frequency
Mississippian	Direct pressure monitoring	Mississippian monitoring well identified as Unit 24 in Figure 1	Once monthly and within 12 hours of a felt earthquake of magnitude 2.5 or larger. As explained Appendix B, if induced pressures in the Mississippian exceed 800 psi over background levels, then the monitoring frequency will change to weekly from monthly.

The same passive seismic monitoring described above under "Carbon Dioxide Plume and Pressure-Front Tracking" will be used to monitor seismic activity near the project site.

Direct pressure monitoring conducted in the Mississippian will be used in conjunction with the passive seismic monitoring to demonstrate that the fault interpreted to be located on the western end of the AoR is not affecting CO_2 containment. As explained in the Appendix B (Rationale and Methodology for Mississippian Pressure Monitoring to Support Induced Seismicity Evaluations), if an earthquake of magnitude 2.5 or larger is felt, then the relevant Mississippian pressure data will be used in conjunction with other monitoring data in an attempt to ascertain the origin of the earthquake as outlined in the Wellington Rapid Response Plan.

The Wellington seismometer network is able to detect magnitude 2.5 and larger earthquakes from the site to central Oklahoma without any depth limitation (as almost all recorded earthquakes in the area occur at depths shallower than 15 km). The seismometer network is quite sensitive and capable of detecting earthquakes of magnitude 1 to a distance (and depth) of 5 km from the injection well.

The results of this seismicity monitoring may also trigger additional action as described in the Emergency and Remedial Response Plan (Attachment F to this permit).

References

Busenberg E., and Plummer, L.N., 2000, Dating young ground water with sulfur hexafluoride: Natural and anthropogenic sources of sulfur hexafluoride. Water Resources Research, v. 36(10), 3011-3030.

Kharaka et al., 2010. Changes in the chemistry of shallow groundwater related to the 2008 injection of CO2 at the ZERT field site, Bozeman, Montana, Environmental Earth Science, 60:273-284, Springer.

Massachusetts Institute of Technology (MIT), 2016. CO_2 thermophysical property calculator. Accessed January 10, 2017. https://sequestration.mit.edu/tools/index.html

Appendix A: Testing and Monitoring Schedule for all Project Phases

The following is a generalized schedule of testing and monitoring activities to be conducted throughout the life of the project. Pre-injection (baseline) and post-injection activities are included for reference purposes only. Injection phase activities described in this plan are enforceable pursuant to 40 CFR 146.90.

Class VI Rule Requirement	Activity	Location	Frequency - Pre-Injection Phase	Frequency - Injection Phase	Frequency - Post-Injection Phase
CO_2 stream analysis *[40 CFR 146.90(a)]*	Direct CO_2 stream sampling	Supply plant	One sample at each supply plant	Quarterly: • 12 weeks after injection begins (± 1 week) • 24 weeks after injection begins (± 1 week)	N/A
Continuous recording of injection pressure/rate/volume and annular pressure *[40 CFR 146.90(b)]*	Injection rate and volume (via flow meter)	KGS 1-28 wellhead	N/A	Continuous	N/A
	Wellhead injection pressure (via pressure gauge)	KGS 1-28 wellhead	N/A	Continuous	N/A
	Annular pressure (via pressure gauge)	KGS 1-28 wellhead	Continuous	Continuous	Continuous
	Annulus fluid volume added	KGS 1-28 wellhead	N/A	Continuous	N/A
Corrosion monitoring *[40 CFR 146.90(c)]*	Corrosion coupons	Flow line to KGS 1-28 wellhead	N/A	Quarterly: • 12 weeks after injection begins (± 1 week) • 24 weeks after injection begins (± 1 week)	N/A

Class VI Rule Requirement	Activity	Location	Frequency - Pre-Injection Phase	Frequency - Injection Phase	Frequency - Post-Injection Phase
Ground water monitoring above the confining zone *[40 CFR 146.90(d)]*	Direct monitoring - Upper Wellington fluid sampling	SW-1, SW-2, and SW-3	A minimum of 2 samplings at different dates	Quarterly: • 12 weeks after injection begins (± 1 week) • 24 weeks after injection begins (± 1 week)	Every 6 months (beginning 6 months after the cessation of injection)
	Direct monitoring - Mississippian fluid sampling	MS-24 and MS-32	A minimum of 2 samplings at different dates	Every 2 months: • 8 weeks after injection begins (± 1 week) • 16 weeks after injection begins (± 1 week) • 24 weeks after injection begins (± 1 week)	Every 6 months (beginning 6 months after the cessation of injection)
	Indirect monitoring - 2D seismic survey	As shown in Figure 2	One survey	One survey, approximately halfway through the injection period (approximately 12 weeks after injection begins)	One survey, approximately halfway through the post-injection period (specific timing to be determined per discussion with the Director, based on early monitoring results and/or any potential USDW endangerment)
External mechanical integrity testing *[40 CFR 146.87(a)(4);146.90(e)]*	Temperature log	KGS 1-28 and KGS 2-28	One test	One test	One test (before each well is plugged or converted)
Internal mechanical integrity testing, in addition to continuous monitoring *[40 CFR 146.87(a)(4)]*	Annular pressure test (via pressure gauge)	KGS 1-28	One test	One test	N/A

Class VI Rule Requirement	Activity	Location	Frequency - Pre-Injection Phase	Frequency - Injection Phase	Frequency - Post-Injection Phase
Pressure fall-off testing *[40 CFR 146.87(e)(1); 146.90(f)]*	Pressure fall-off test (via pressure gauge)	KGS 1-28	One test	One test	N/A
Plume monitoring *[40 CFR 146.90(g)]*	Direct monitoring - Arbuckle	KGS 2-28	A minimum of one sampling event.	Every 2 weeks after commencement of injection.[1] On break-through, samples will be collected once every two weeks until stabilization of CO_2 concentrations. Thereafter, U-tube samples will be collected monthly. See Table 8 and the "Plume Monitoring" section for further details.	Quarterly
	Indirect monitoring - 3D seismic survey	As shown in Figure 2	Already acquired (April 2010)	None	One survey
	Indirect monitoring - CASSM	KGS 1-28 and KGS 2-28	A minimum of 1 week of reading	Continuous (approx. 24-hr temporal resolution), until plume arrives at KGS 2-28	None

[1] Preliminary samples collected prior to breakthrough will only be checked for pH at the site as a proxy for CO_2. If CO_2 is suspected in the samples, then the sample will be sent to the laboratory to be tested for a complete suite of parameters listed in Table 9.

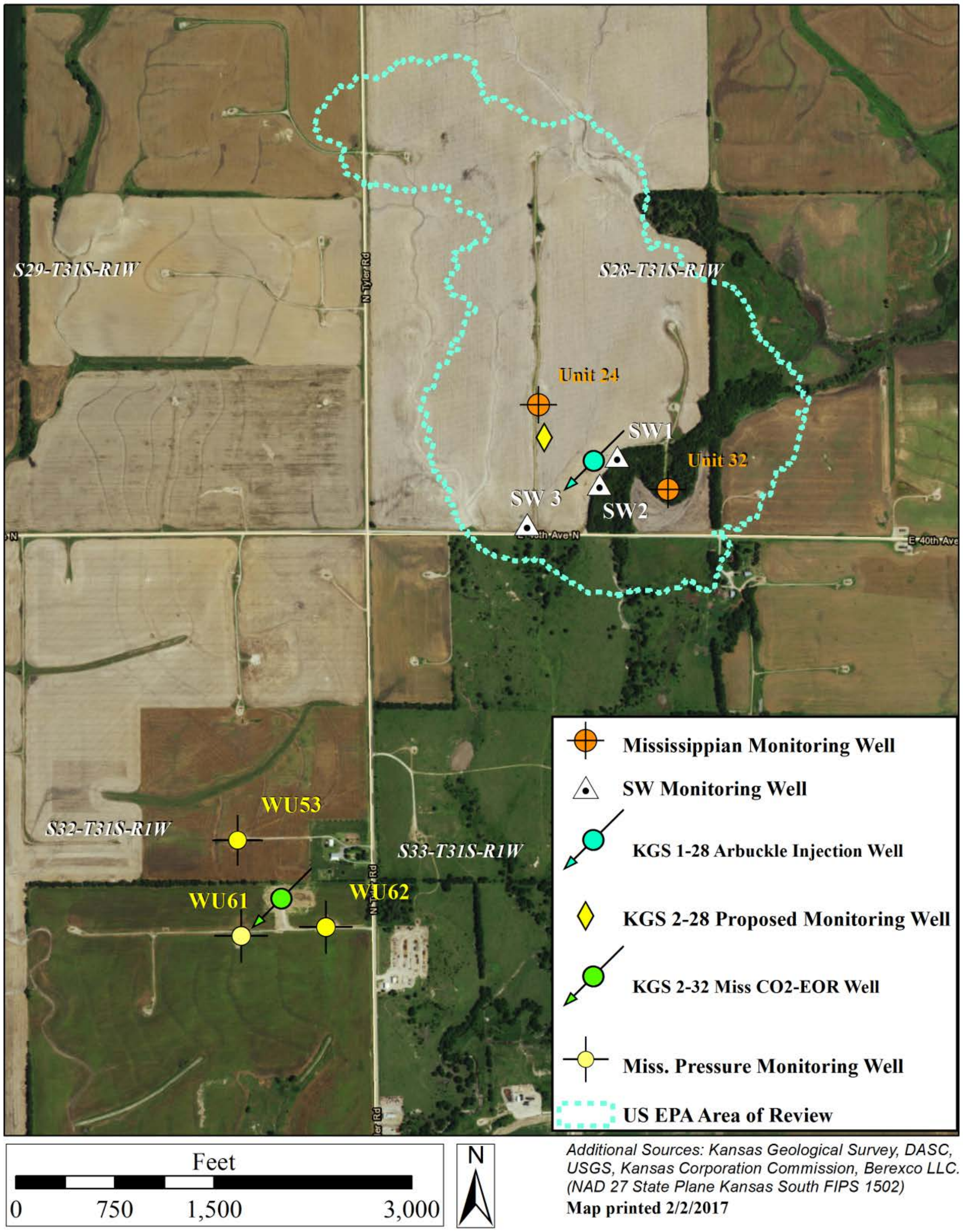
Class VI Rule Requirement	Activity	Location	Frequency - Pre-Injection Phase	Frequency - Injection Phase	Frequency - Post-Injection Phase
Plume monitoring, cont. *[40 CFR 146.90(g)]*	Indirect monitoring - crosswell seismic	KGS 1-28 and KGS 2-28	One survey	Two surveys, one timed to provide information on plume arrival at KGS 2-28 and one at the end of injection	None
Pressure-front monitoring *[40 CFR 146.90(g)]*	Direct monitoring - downhole pressure/ temperature gauge	KGS 1-28 and KGS 2-28	A minimum of 1 week of reading	Continuous (every 30 seconds)	Continuous (every 30 seconds, then every 30 minutes when bottomhole pressure has decreased to within 5% of pre-injection levels)
	Indirect monitoring - passive seismic (also used for seismicity monitoring)	As shown in Figure 5a and b	Continuous	Continuous (downloaded monthly)	Continuous (downloaded monthly)
Other monitoring *[40 CFR 146.90(i)]*	InSAR with cGPS	As described in Table 10	InSAR - monthly, cGPS - daily	InSAR - monthly, cGPS - daily	InSAR - monthly, cGPS - daily
	Seismicity monitoring - passive seismic (also used for indirect pressure-front monitoring)	As shown in Figure 5a and b	Continuous	Continuous (downloaded monthly)	Continuous (downloaded monthly)

Appendix B: Rationale and Methodology for Mississippian Pressure Monitoring to Support Induced Seismicity Evaluations

At the request of EPA, the water levels in the Mississippian reservoir at the injection site will be monitored in order to assist in identifying the cause of an earthquake of magnitude 2.5 or larger with an epicenter within a mile of the KGS 1-28 injection well. It should be emphasized that the site is within an active wellfield, and therefore the fluctuating pressures will not be used to ascertain if any CO_2 has escaped from the Arbuckle injection zone. As agreed upon with the EPA, the groundwater quality, along with additional monitoring information such as pressures in the Arbuckle, seismic analyses, Mechanical Integrity Tests, Hall Plot analysis, InSAR data, etc. will be relied upon to determine breach of the confining zone or leakage from the injection well. The rationale and methodology for the proposed Mississippian pressure monitoring is explained below.

During the recent Enhanced Oil Recovery (EOR) initiative in the southern portions of the Wellington field (Figure B-1), the pore pressures have increased by up to 600 psi in monitoring wells in the Mississippian reservoirs (Figure B-2). These pressures have built up over a period of nearly four months since commencement of injection in October 2015. During this period, there has not been any earthquake of magnitude 2.5 or larger in the Wellington field as detected in either the Wellington, Kansas, or USGS seismometer networks. We anticipate that pressures will increase to over 800 psi by the end of injection in July 2016. We do not anticipate any seismic events of magnitude 2.5 (or larger) within the Wellington wellfield associated with CO_2 injection during the entire EOR period. As documented in Section 4.6.3 and shown in Figure 4.29 of the permit application, the ambient pressure in the Mississippian is approximately 800 psi lower than hydrostatic conditions and this depleted condition is attributed to oil and gas production from the reservoir over the past eight decades. Therefore, the Mississippian reservoir has a large capacity to absorb injected fluids for EOR operations.

Based on the above pressure information recorded during the EOR operations, it would be safe to assume that a pressure increase of 800 psi in the Mississippian reservoir at the Class VI injection site will not induce an earthquake. For monitoring purposes during injection at the sequestration site, water level in the Mississippian observation well Unit marked Unit 24 (Figure B-1) well will be recorded on a monthly basis with an Echometer in order to monitor pressure trends. Three water level measurements over a period of one month will be acquired in this well prior to commencement of injection in the Arbuckle in order to establish “background condition.” During CO_2 injection in the Arbuckle, no action will be taken as long as the induced pressures in the Mississippian remain below 800 psi. If induced pressures increase over the threshold value of 800 psi, then the monitoring frequency will be increased to weekly from monthly. However, in the event of an earthquake with felt magnitude of 2.5 or greater, the water level in the Mississippian monitoring well will be recorded within 12 hours of the event regardless of the pressure in the Mississippian reservoir. This information, along with previously recorded pressure data will be analyzed along with the monitoring data to assist in the seismic analysis and corrective action as documented in the Wellington Seismic Action Plan and the Emergency and Remedial Response Plan (Attachment F to the permit).



Additional Sources: Kansas Geological Survey, DASC, USGS, Kansas Corporation Commission, Berexco LLC. (NAD 27 State Plane Kansas South FIPS 1502)

Map printed 2/2/2017

Figure B-1. Location of observation wells at the Wellington Enhanced Oil Recovery (EOR) and geologic sequestration sites.

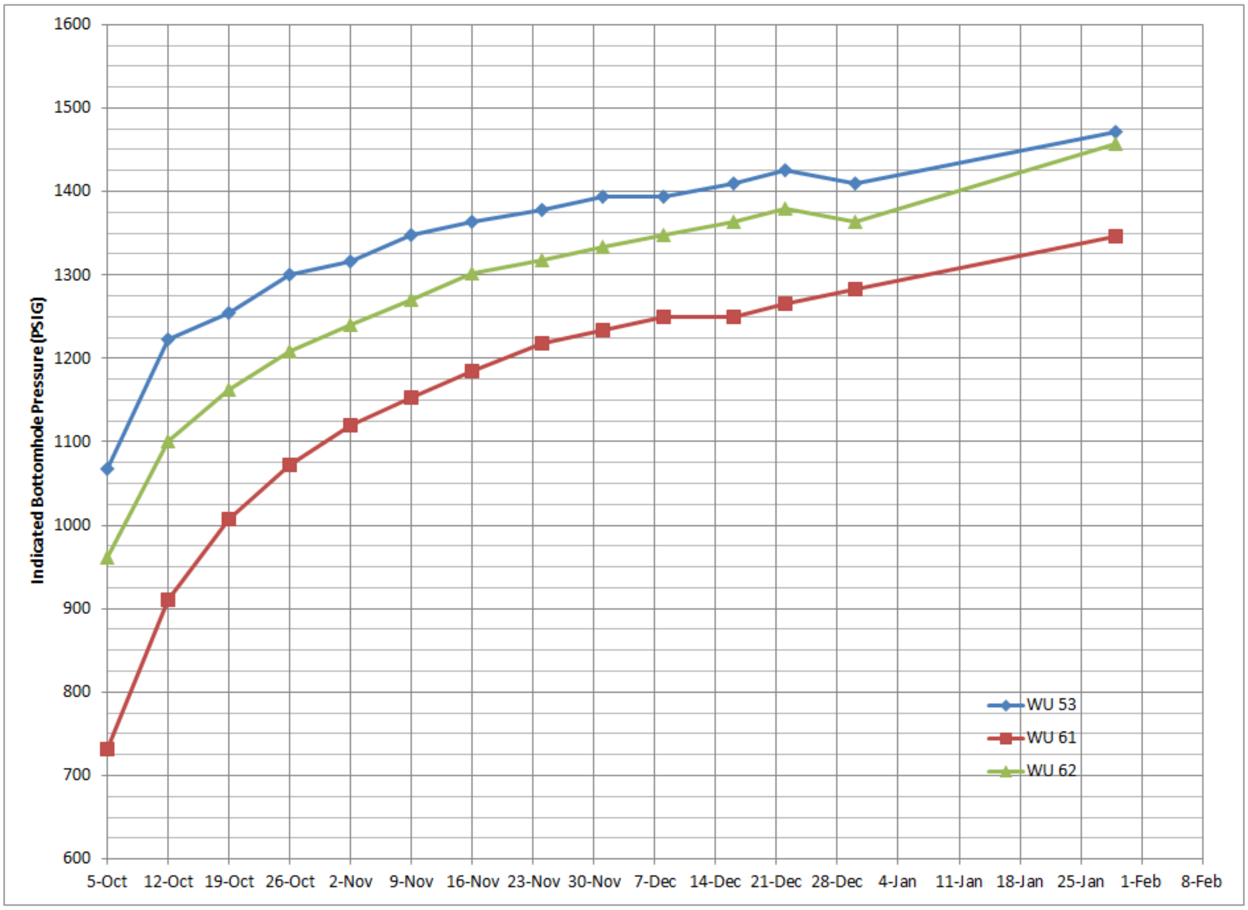


Figure B-2. Pore pressures (psi) in the Mississippian monitoring wells surrounding the EOR injection well. Refer to Figure B-1 for location of the monitoring wells.

Appendix C: Quality Assurance and Surveillance Plan

[final QASP to be attached by EPA]