ATTACHMENT E: POST-INJECTION SITE CARE AND SITE CLOSURE PLAN

Facility Information

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KSS191GS0001

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This Post-Injection Site Care (PISC) and Site Closure Plan describes the activities that Berexco, LLC (Berexco) will perform to meet the requirements of 40 CFR 146.93. Berexco will monitor ground water quality and track the position of the carbon dioxide plume and pressure front for 4 years following the cessation of injection. This alternative post-injection site care timeframe was approved by EPA, but Berexco may not cease post-injection monitoring until a demonstration of non-endangerment of USDWs has been approved by the UIC Program Director pursuant to 40 CFR 146.93(b)(3). Following approval for site closure, Berexco will plug all monitoring wells, restore the site to its original condition, and submit a site closure report and associated documentation.

Pursuant to 40 CFR 146.93(a)(3), Berexco will either submit an amended PISC and Site Closure Plan upon cessation of injection or demonstrate to the UIC Program Director (based on monitoring data and modeling results) that no amendment to the Plan is needed.

Pre- and Post-Injection Pressure Differential

Based on the modeling of the pressure front as part of the AoR delineation, bottomhole pressure is expected to decrease to 2,093 psi, pre-injection level, within 3 months of cessation of injection. The highest pressure increase (at the end of the injection phase) is predicted by the model to be 2,485 psi. Additional information on the projected post-injection pressure declines and differentials is presented in the Area of Review and Corrective Action Plan (Attachment B to this permit).

Predicted Position of the CO_2 Plume and Associated Pressure Front at Site Closure

Figure 1 shows the predicted extent of the plume and pressure front at the end of the 4-year PISC timeframe. This map is based on the final AoR delineation modeling results submitted per 40 CFR 146.84, assuming that 26,000 metric tons of CO_2 are injected. If Berexco injects more CO_2 during the injection phase (i.e., between 26,000 metric tons and the permitted amount of 40,000 metric tons), Berexco will update this figure and other applicable figures in the plan to reflect the actual injected amount and submit the amended plan upon cessation of injection as required by 40 CFR 146.93(a)(3).

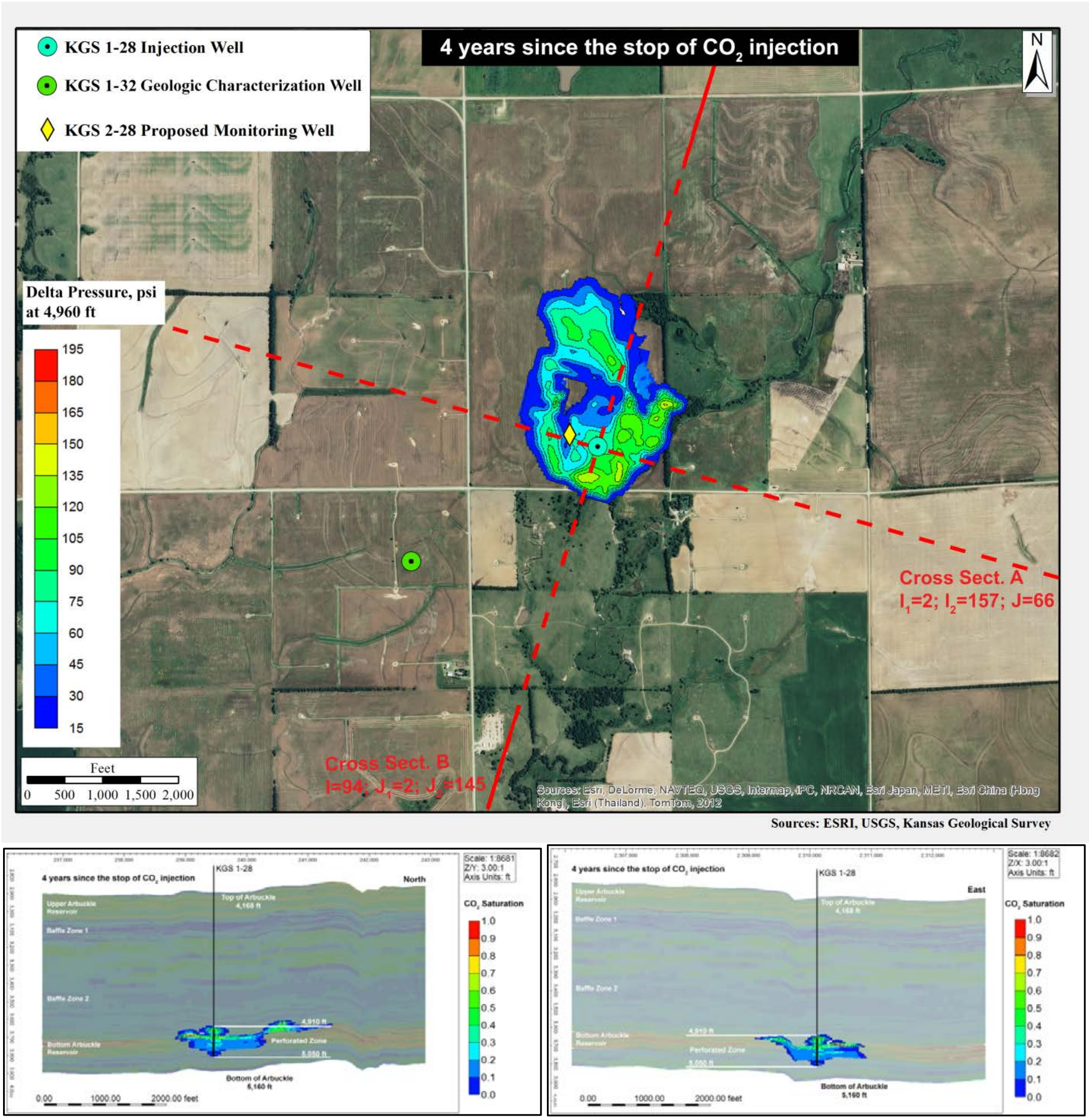


Figure 1. Map and cross-sections of the predicted extent of the separate-phase CO_2 plume at site closure (assuming 26,000 metric tons of CO_2 injected).

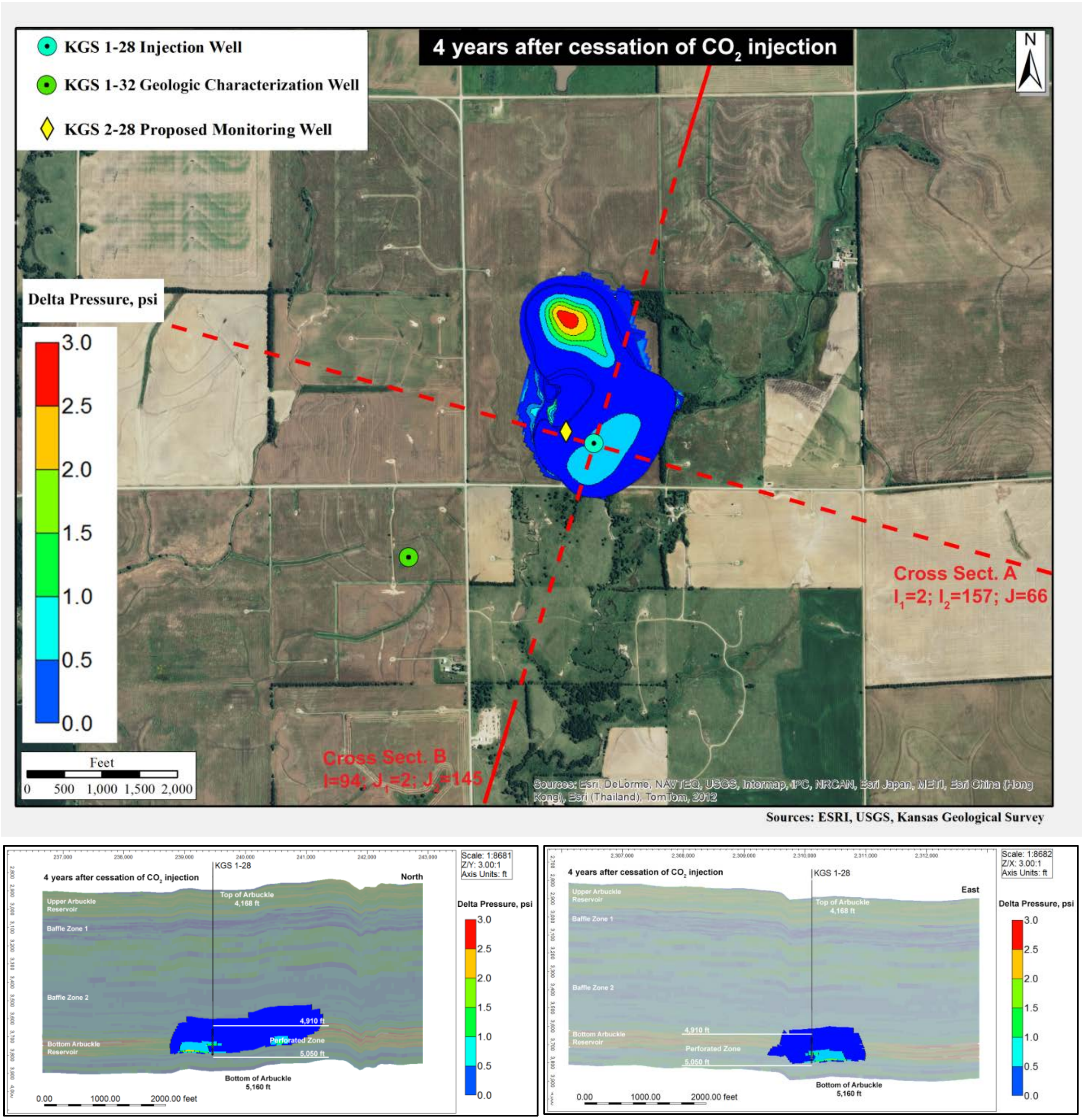


Figure 2. Map and cross-sections of the predicted extent of elevated pressure at site closure (assuming 26,000 metric tons of CO_2 injected).

Post-Injection Monitoring Plan

Berexco will perform the following activities, as described in the subsections below, to meet the requirements of 40 CFR 146.93(b)(1): continuous monitoring at the injection well, ground water quality monitoring and other monitoring above the confining zone, carbon dioxide plume and pressure-front tracking, and seismicity and fault monitoring.

All PISC monitoring data and monitoring results (i.e., resulting from the testing and monitoring activities described below) will be submitted to EPA in annual reports. The annual reports will contain information and data generated during the reporting period, including well-based monitoring data, sample analysis results, geophysical monitoring results, and comparisons between monitoring data and predictions from computational modeling.

A quality assurance and surveillance plan (QASP) for all testing and monitoring activities during the injection and post-injection phases is provided in the Appendix to the Testing and Monitoring Plan (Attachment C to this permit).

The Appendix of this Post-Injection and Site Closure Plan contains a generalized schedule of testing and monitoring activities to be conducted throughout the life of the project, for reference purposes. Post-injection phase activities described in this plan are enforceable pursuant to 40 CFR 146.93(a).

Continuous Monitoring

Berexco will perform the continuous monitoring activities listed in Table 1. Collection and recording of monitoring data will occur at the frequencies described in Table 2.

Table 1. Continuous monitoring activities.

Activity	Location	Frequency
Annular pressure	KGS 1-28 wellhead pressure gauge	Continuous

Table 2. Sampling and recording frequencies for continuous monitoring.

Well Condition	Minimum sampling frequency: once every(1)	Minimum recording frequency: once every(2)
For continuous monitoring of the injection well:	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). Following the same example above, the data from the injection pressure transducer might be recorded to a hard drive once every minute.

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 post-injection phase. Monitoring will occur in the following formations above the confining zone:

- Upper Wellington Formation.
- Mississippian Formation.

Table 3 presents the planned monitoring methods, locations, and frequencies for ground water quality monitoring above the confining zone. Berexco will also monitor for changes in the Mississippian Formation using 2D seismic surveying. The post-injection phase 2D seismic survey will take place approximately halfway through the PISC period, with the specific timing to be scheduled per discussion with the UIC Program Director based on early PISC monitoring results and/or suspicion of any CO_2 leaks or endangerment to USDWs.

All of the monitoring sites are located on Berexco property. Figure 3 and Figure 4 show the project area with the planned monitoring locations.

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.

Table 3. Direct and indirect monitoring of ground water quality and geochemical changes above the confining zone.

Target Formation	Monitoring Activity	Monitoring Location(s)	Frequency
Upper Wellington	Geochemical monitoring (parameters and analytical methods given in Table 4)	3 shallow monitoring wells (as shown in Figure 3): • 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)	Every 6 months (beginning 6 months after the date of cessation of injection)
Mississippian	Geochemical monitoring (parameters and analytical methods given in Table 4)	Wellington Unit Wells 24 and 32 (as shown in Figure 3): • 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 6 months (beginning 6 months after the date of cessation of injection)
Multiple (primarily the Mississippian)	2D seismic surveying	Surface stations, as shown in Figure 4	Once during the post-injection phase, 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)

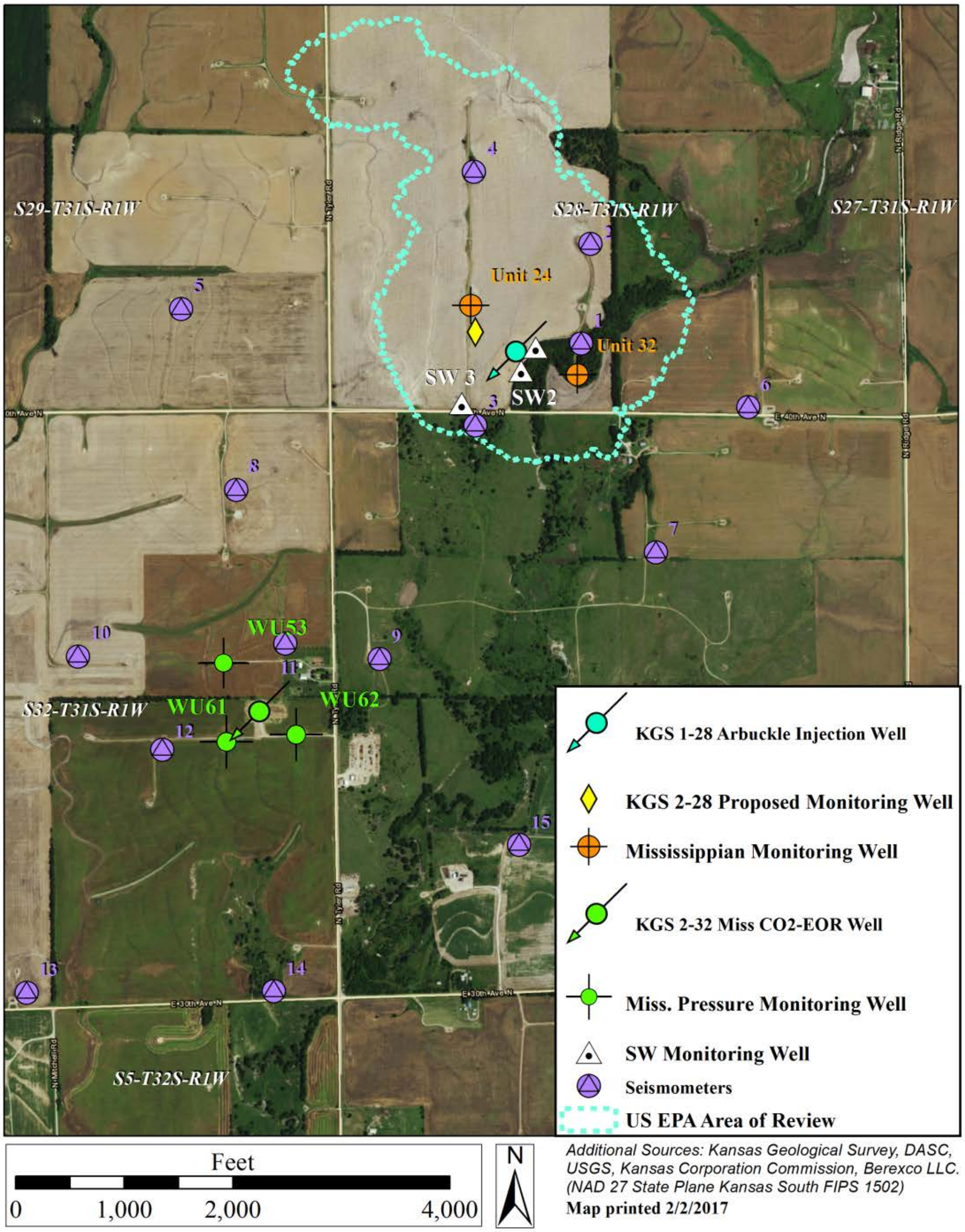


Figure 3. Monitoring locations at the injection well site. The locations of wells associated with the KGS 2-32 project (wells KGS 2-32, WU53, WU 61, and WU 62) are shown for informational purposes only.

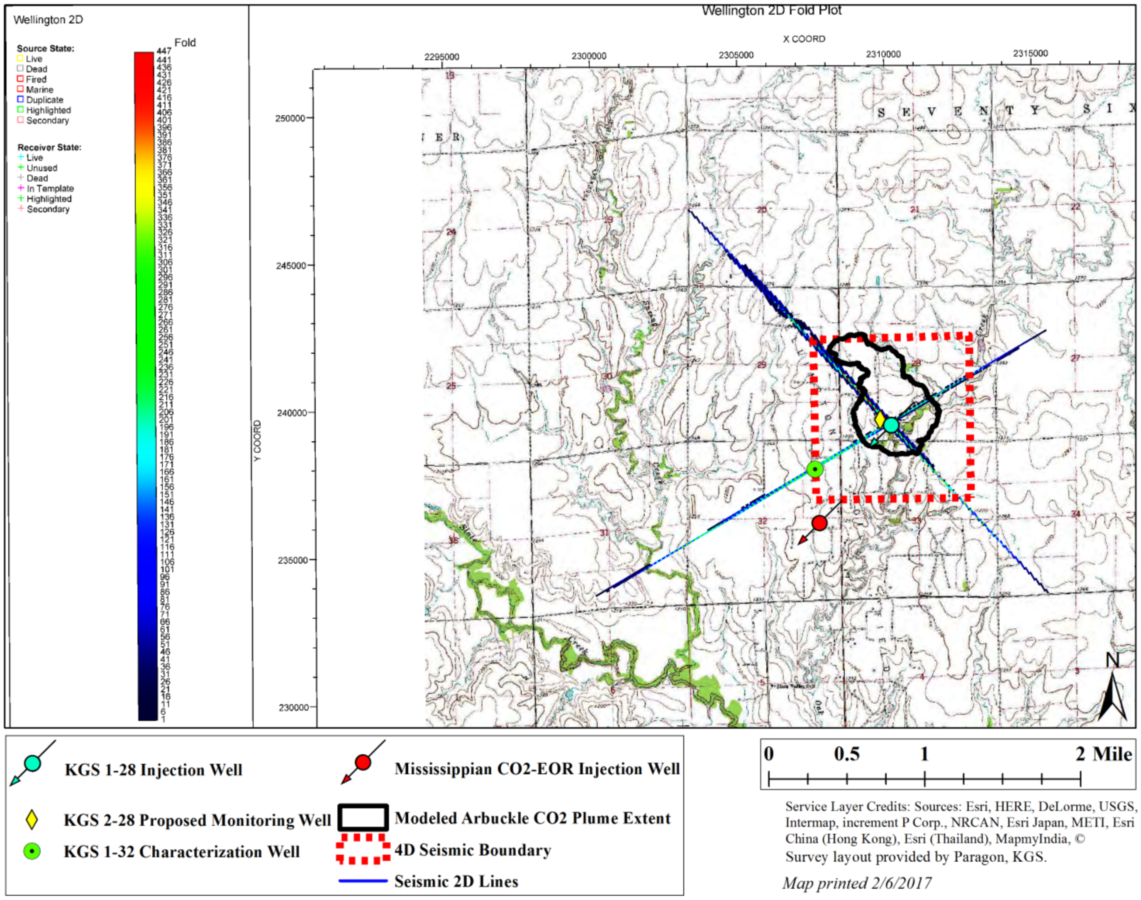


Figure 4. Area of time-lapse 3D seismic data collection and location of 2D seismic line.

Analytical Parameters

Table 4 identifies the parameters to be monitored and the analytical methods Berexco will employ. Sampling will be conducted using the methods and procedures as described in the QASP.

Table 4. 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

Parameters	Analytical Methods(1)
pH (field)	SM 2450
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
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
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.

Carbon Dioxide Plume and Pressure-Front Tracking

Berexco will employ direct and indirect methods to track the extent of the carbon dioxide plume and the presence or absence of elevated pressure.

Plume Monitoring

Fluid sampling will be conducted for direct measurement of the plume. Samples will be collected using a U-tube sampler. Indirect measurements will include a 3D surface seismic survey that will be conducted before the end of the post-injection phase.

Table 5 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. Direct plume monitoring will occur in the Arbuckle through monitoring at KGS 2-28. Indirect plume monitoring will be performed using a surface seismic survey (see Figure 4) at the end of the PISC monitoring period.

Table 5. Post-injection phase plume monitoring.

Target Formation	Monitoring Activity	Monitoring Location(s)	Frequency
Direct Plume Monitoring			
Arbuckle	Geochemical monitoring (U-tube fluid sampling)	KGS 2-28 (sampling interval approx. 4910 – 5050 ft below ground surface)	Quarterly
Indirect Plume Monitoring			
Multiple	3D seismic survey	As shown in Figure 4, 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,	Once

Monitoring locations relative to the predicted location of the free-phase CO_2 plume at the beginning of the post-injection phase and annually through the end of the 4-year PISC period are shown in Figure 5 through Figure 9.

These images are included in this Plan for comparison with monitoring results during the post-injection period. The images in Figure 5 through Figure 9 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 migration 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.

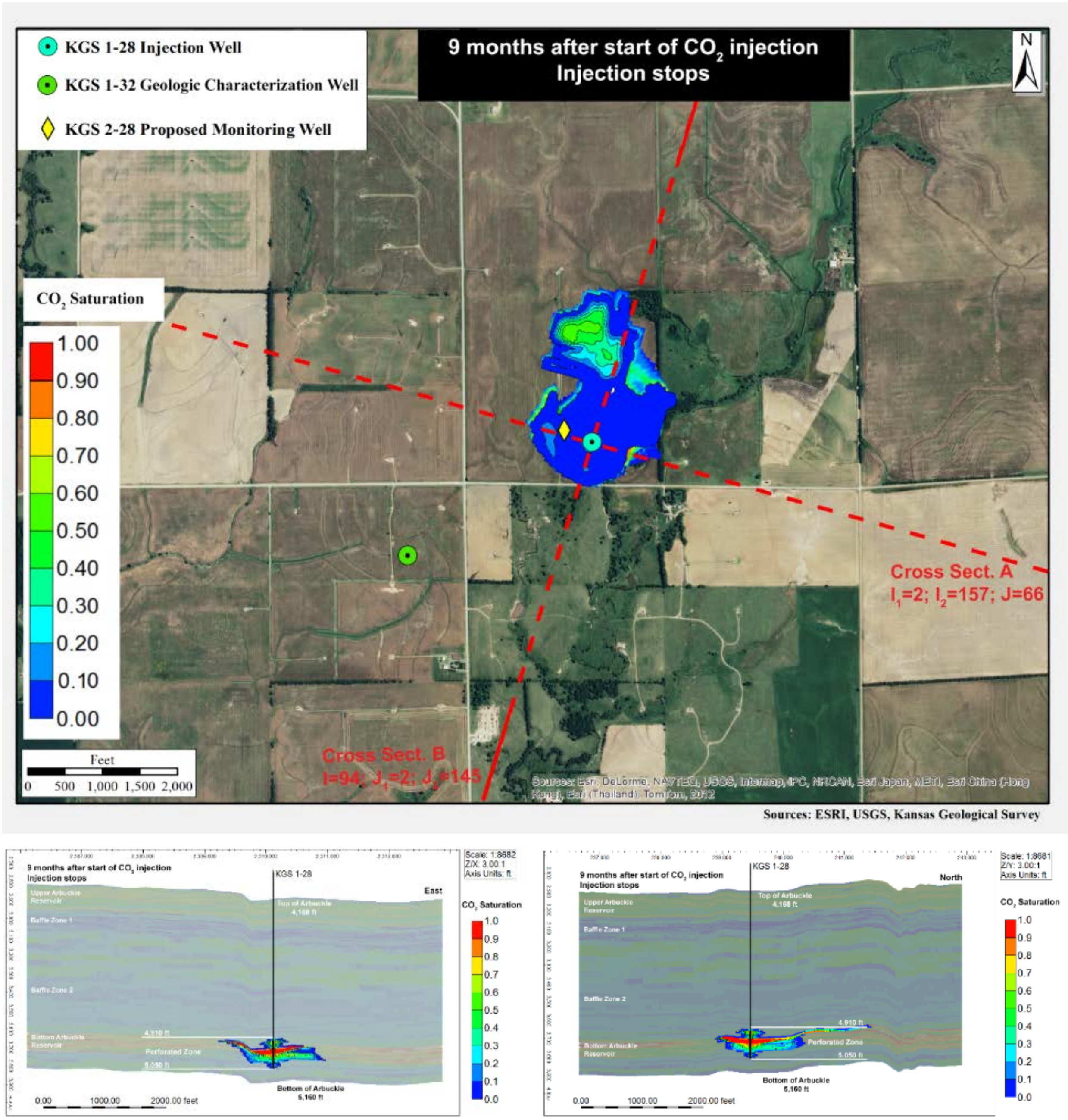


Figure 5. Location of monitoring wells and simulated plume boundary (free-phase CO_2) at the beginning of the post-injection phase (assuming 26,000 metric tons of CO_2 injected).

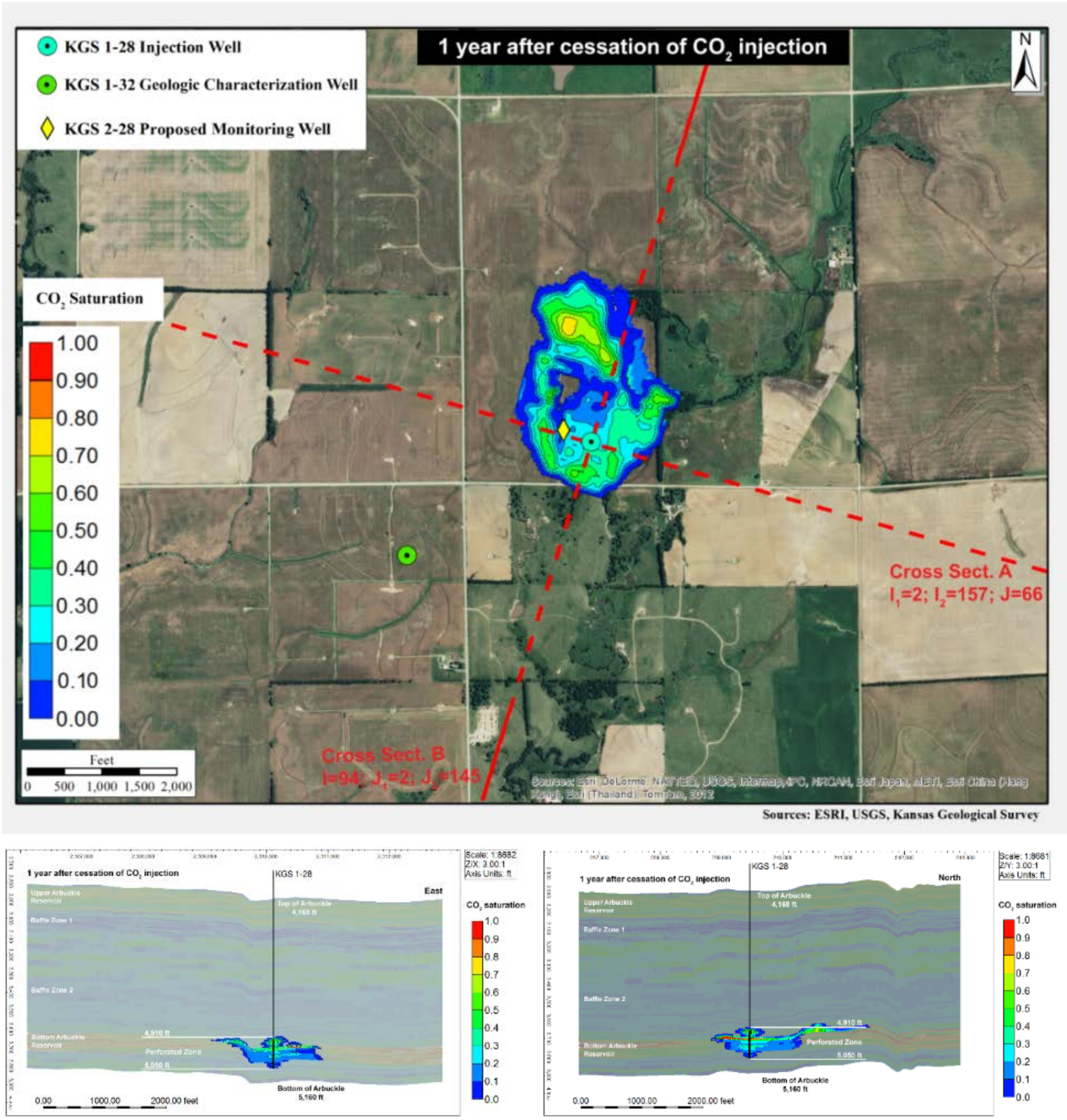


Figure 6. Location of monitoring wells and simulated plume boundary (free-phase CO_2) at the end of 1 year after the cessation of injection (assuming 26,000 metric tons of CO_2 injected).

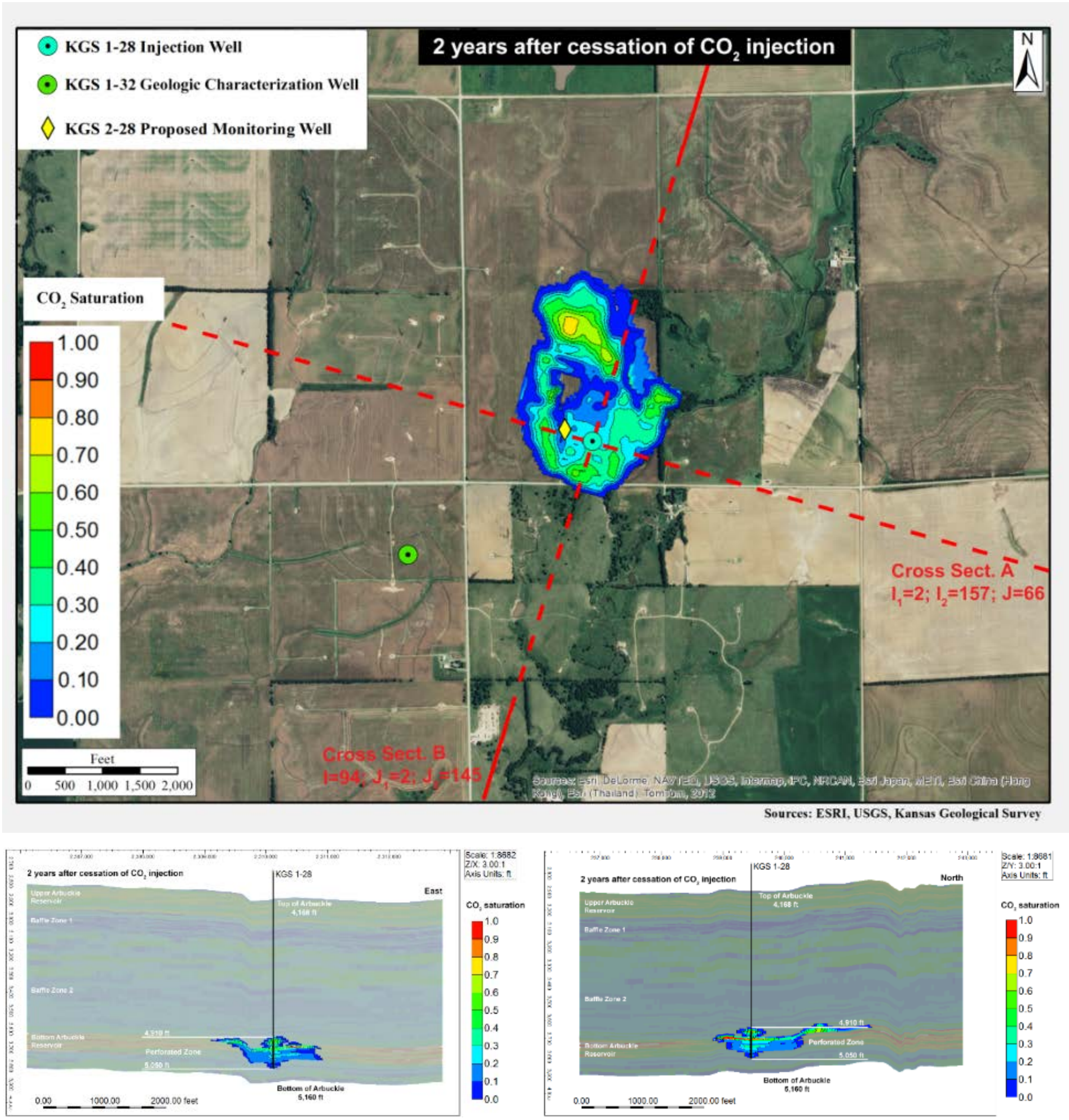


Figure 7. Location of monitoring wells and simulated plume boundary (free-phase CO_2) at the end of 2 years after the cessation of injection (assuming 26,000 metric tons of CO_2 injected).

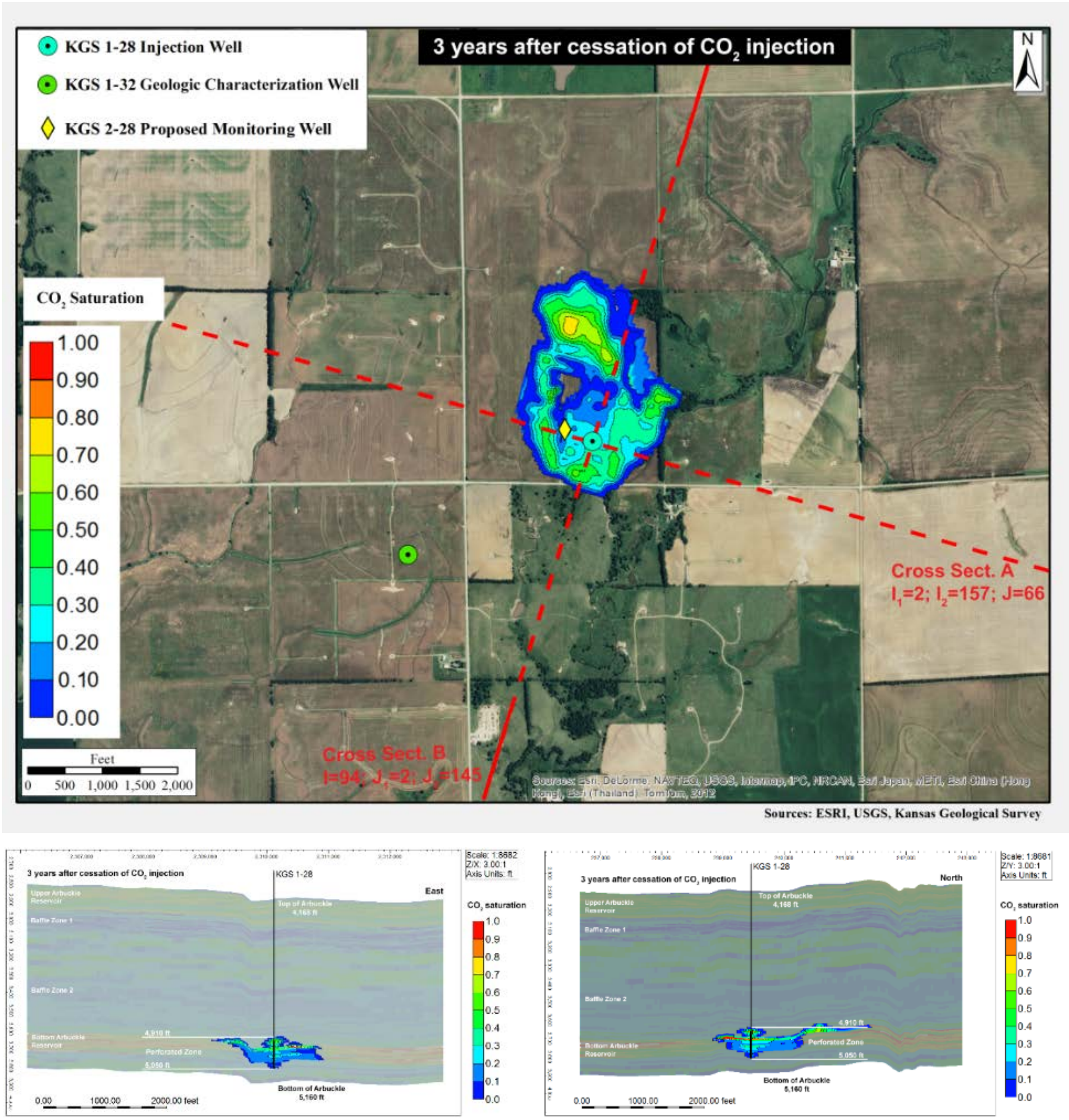


Figure 8. Location of monitoring wells and simulated plume boundary (free-phase CO_2) at the end of 3 years after the cessation of injection (assuming 26,000 metric tons of CO_2 injected).

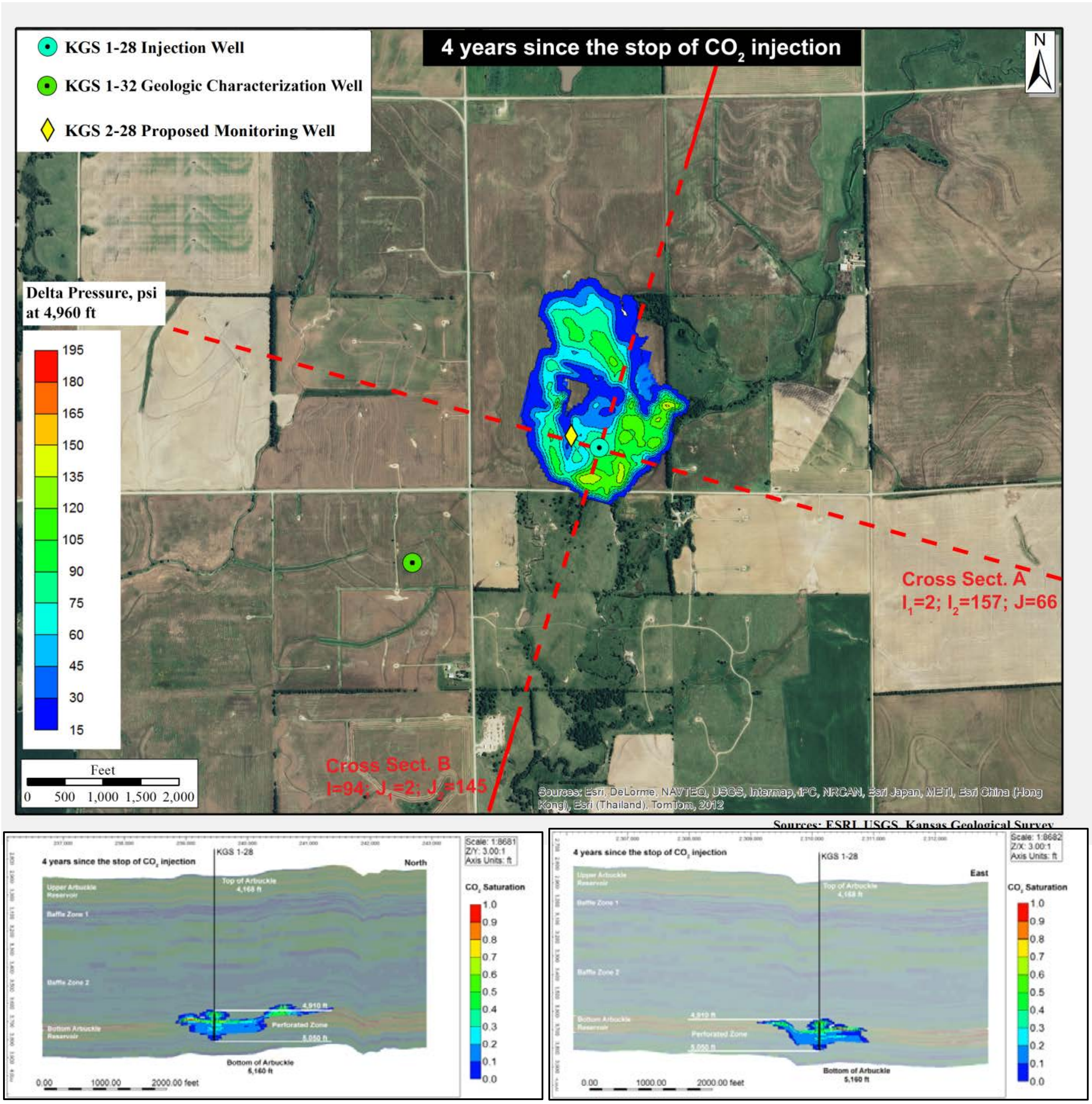


Figure 9. Location of monitoring wells and simulated plume boundary (free-phase CO_2) at the end of 4 years after the cessation of injection (assuming 26,000 metric tons of CO_2 injected).

The parameters to be analyzed as part of fluid sampling in the Arbuckle (and associated analytical methods) are presented in Table 6.

Table 6. Summary of 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
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 7 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 7. Post-injection phase pressure-front monitoring.

Target Formation	Monitoring Activity	Monitoring Location(s)	Frequency
Direct Pressure-Front Monitoring			
Arbuckle	Pressure/temperature monitoring	KGS 1-28 and KGS 2-28 (pressure transducers within the perforations)	Continuous (every 30 seconds, then every 30 minutes when bottomhole pressure has decreased to within 5% of pre-injection levels)
Indirect Pressure-Front Monitoring			
Multiple	Passive seismic monitoring (also used for seismicity monitoring)	As shown in Figure 3	Continuous (downloaded monthly)

Target Formation	Monitoring Activity	Monitoring Location(s)	Frequency
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)	cGPS: 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 post-injection phase is presented in Figure 10 through Figure 14. The simulated pressure profiles (over time) at the Arbuckle injection and monitoring wells (KGS 1-28 and KGS 2-28) are presented in Figure 15 and Figure 16, respectively.

These images are included in this Plan for comparison with monitoring results during the post-injection period. The images in Figure 10 through Figure 16 reflect the modeling scenario with conditions that resulted in the greatest plume migration (referred to as 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.

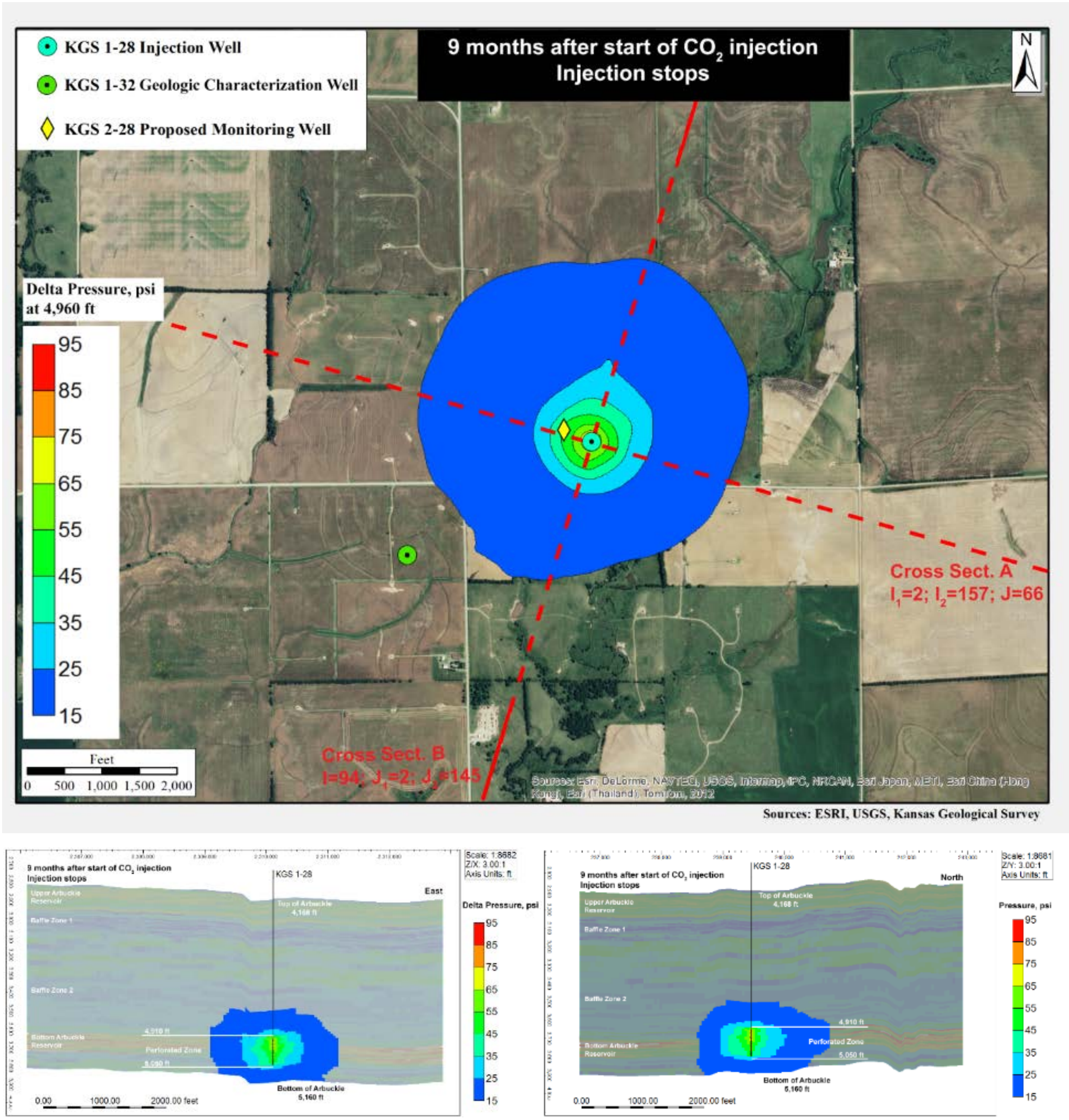
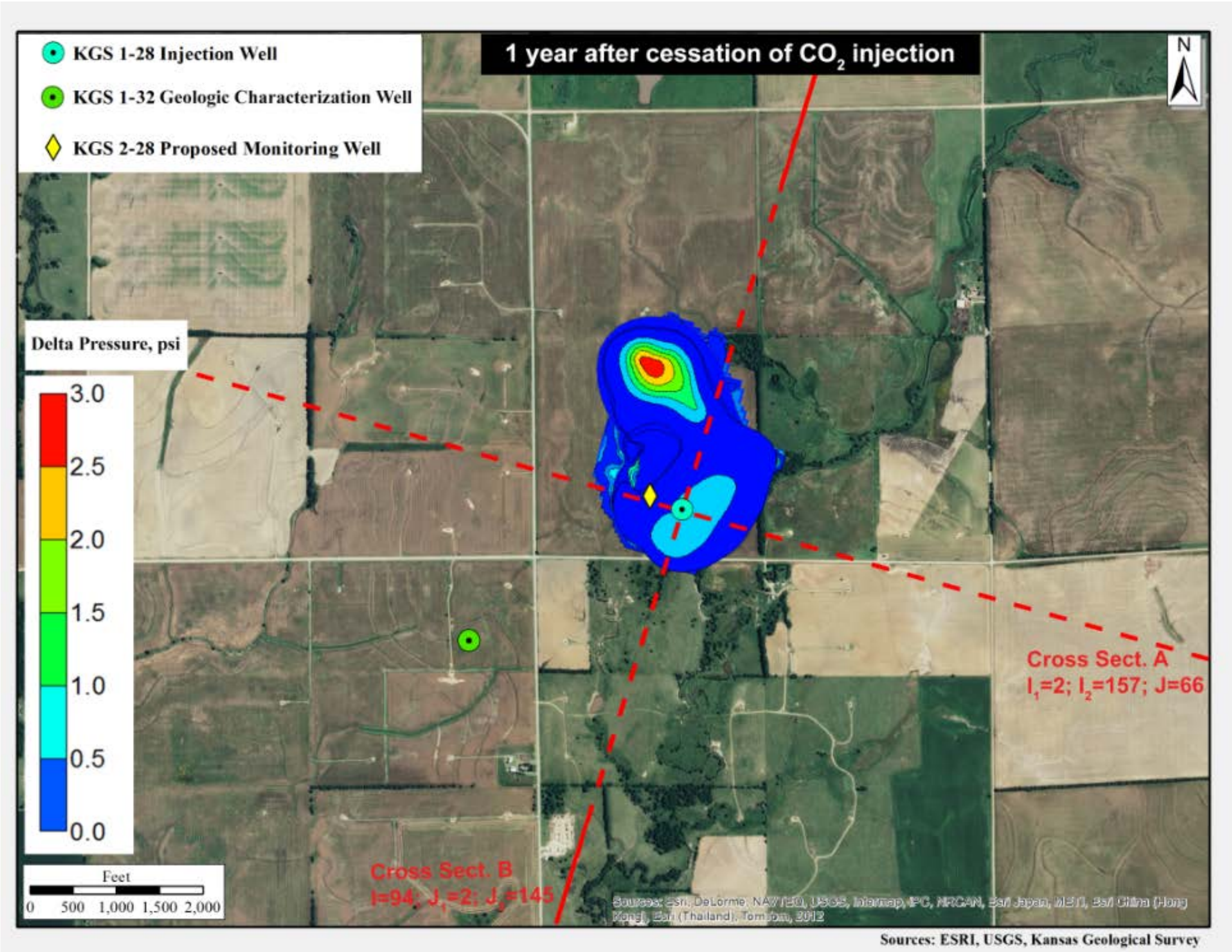
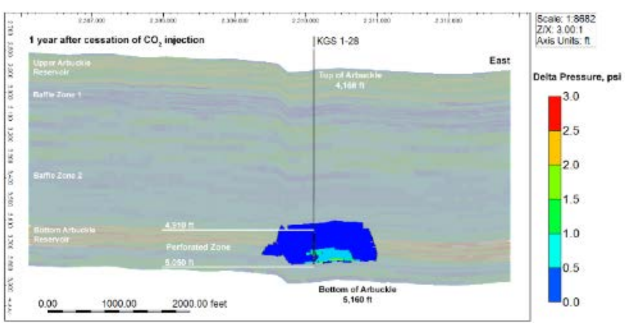


Figure 10. Location of monitoring wells and increase in pore pressure at the beginning of the post-injection phase (assuming 26,000 metric tons of CO_2 injected).





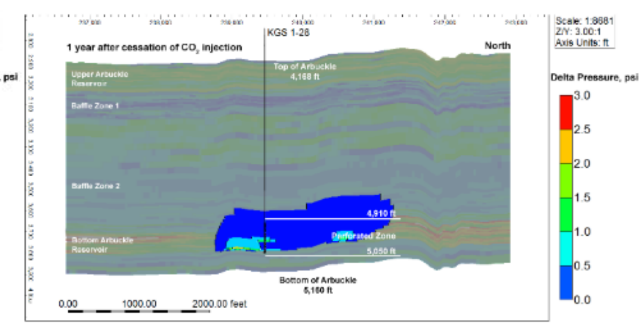


Figure 11. Location of monitoring wells and increase in pore pressure at the end of 1 year after the cessation of injection (assuming 26,000 metric tons of CO_2 injected).

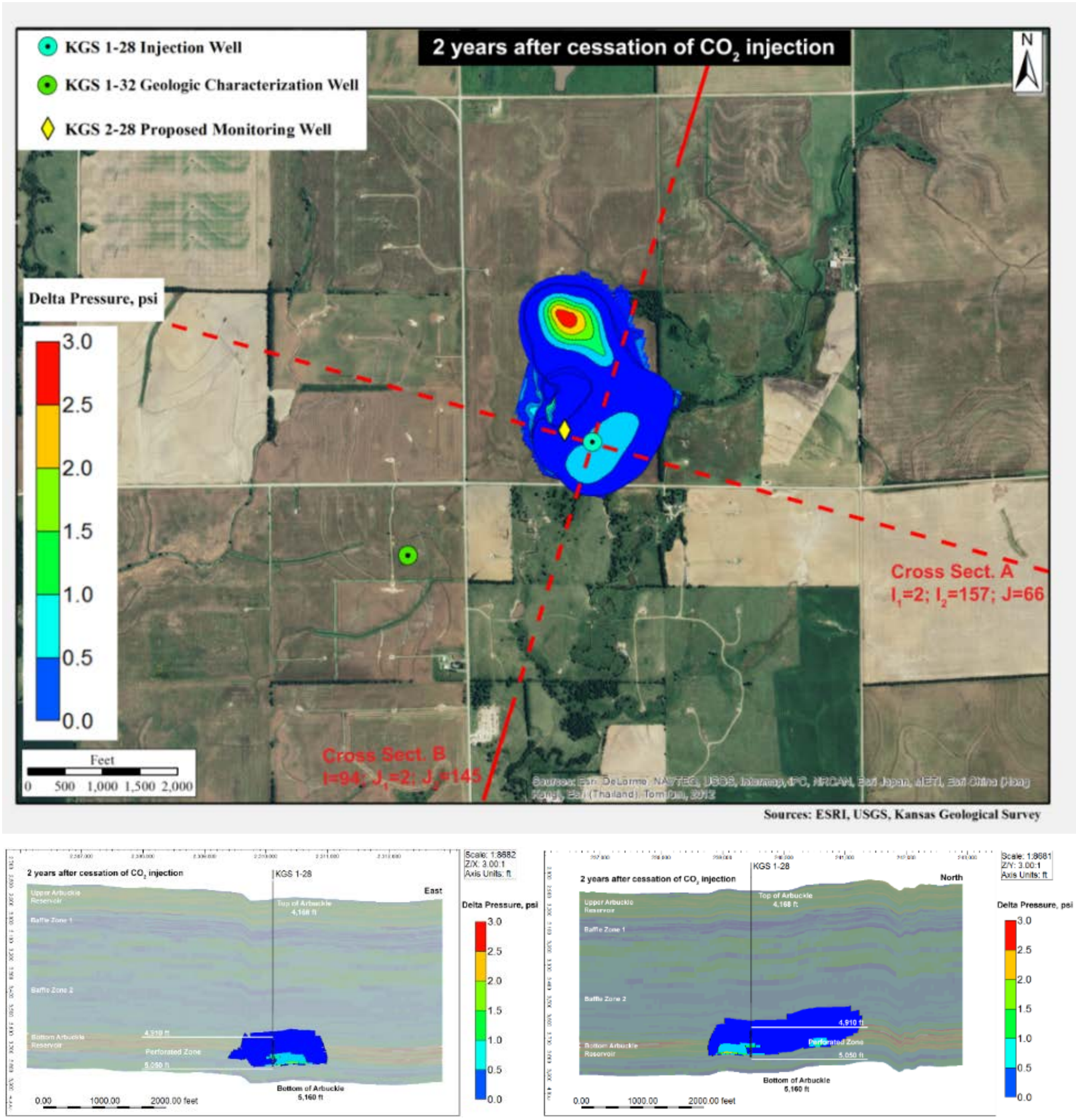


Figure 12. Location of monitoring wells and increase in pore pressure at the end of 2 years after the cessation of injection (assuming 26,000 metric tons of CO_2 injected).

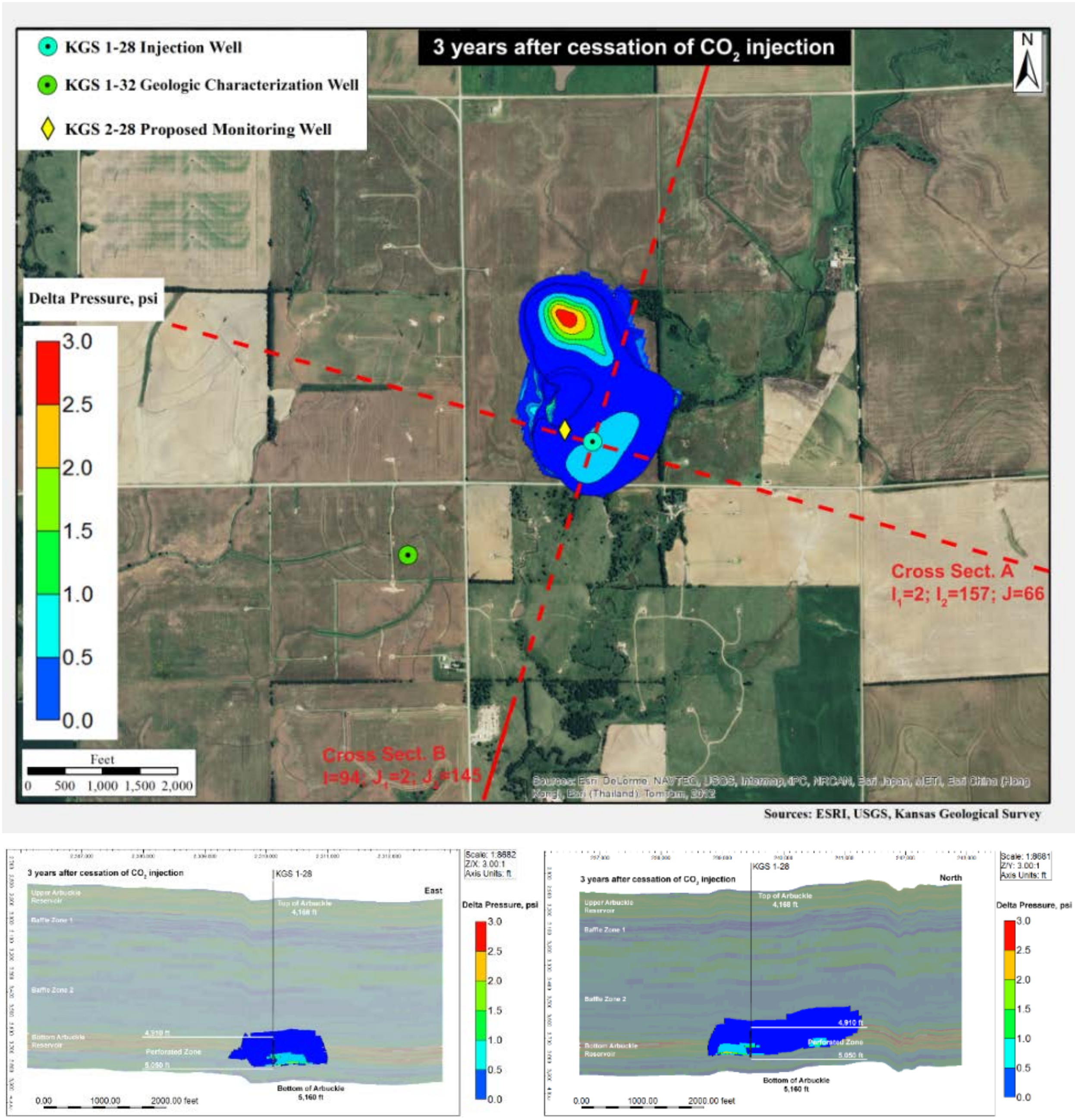


Figure 13. Location of monitoring wells and increase in pore pressure at the end of 3 years after the cessation of injection (assuming 26,000 metric tons of CO_2 injected).

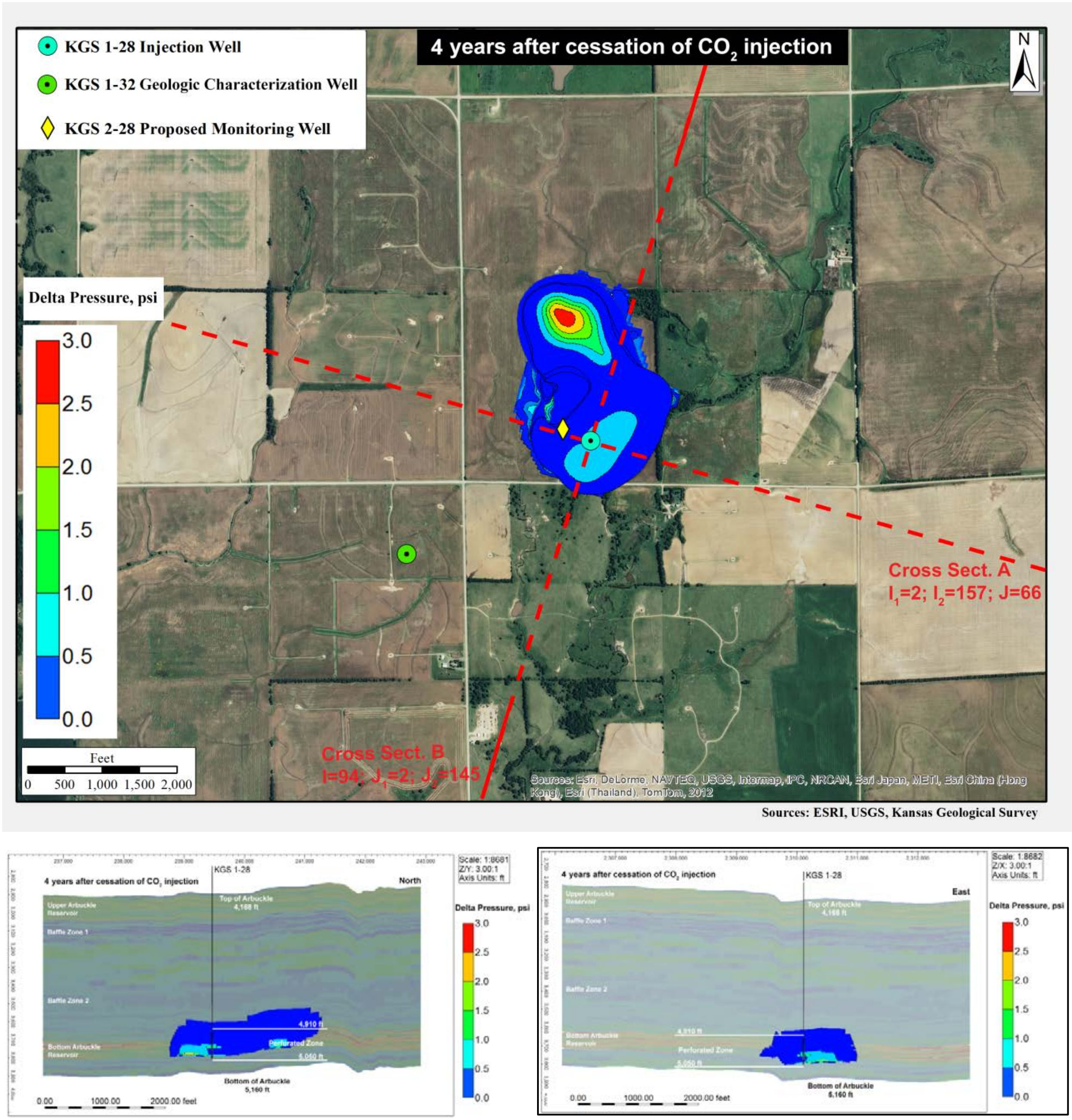


Figure 14. Location of monitoring wells and increase in pore pressure at the end of 4 years after the cessation of injection (assuming 26,000 metric tons of CO_2 injected).

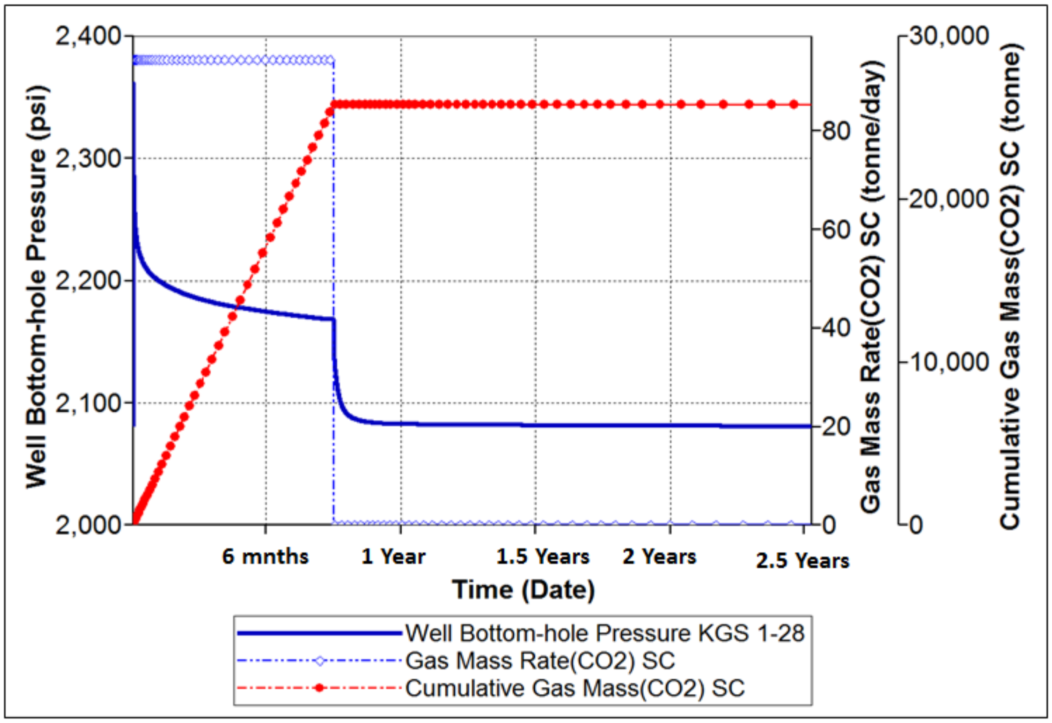


Figure 15. Pressure profile in the Arbuckle injection well (KGS 1-28) for the 24-month simulation period.

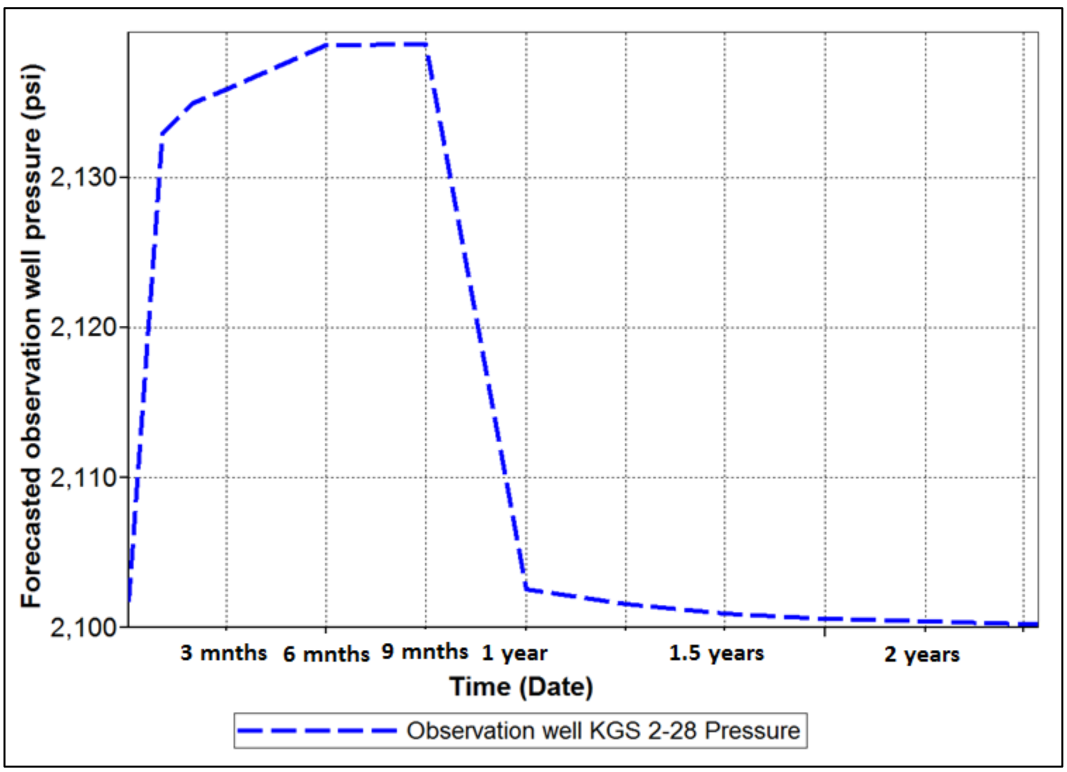


Figure 16. Pressure profile at the Arbuckle monitoring well (KGS 2-28) at the depth of 5,050 ft for the 24-month simulation period.

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 8. 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 8. Seismicity and fault monitoring.

Target Formation	Monitoring Activity	Monitoring Location(s)	Injection Phase Frequency
Multiple	Seismicity monitoring-passive seismic (also used for indirect pressure-front monitoring)	As shown in Figure 3	Continuous (downloaded 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 to the Testing and Monitoring Plan (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 of this permit).

Alternative Post-Injection Site Care Timeframe

Berexco will conduct post-injection monitoring for 4 years following the cessation of injection operations, and during this period, all analyses and tests described in this PISC and Site Closure Plan will be conducted. EPA approved an alternative PISC timeframe based on information Berexco provided pursuant to 40 CFR 146.93(c). This demonstration is based on the computational modeling to delineate the AoR; predictions of plume migration, pressure decline, and carbon dioxide trapping; site-specific geology; well construction; and the distance between the injection zone and the nearest USDWs.

Berexco will conduct all of the monitoring and report the results as described in the "Post-Injection Monitoring Plan" above. This will continue until Berexco demonstrates, based on monitoring and other site-specific data, that no additional monitoring is needed to ensure that the project does not pose an endangerment to any USDWs, per the requirements at 40 CFR 146.93(b)(2) or (3).

If any of the information on which the demonstration was based changes or the actual behavior of the project varies significantly from modeled predictions, e.g., as demonstrated during an AoR reevaluation, the operator may update this PISC and Site Closure Plan pursuant to 40 CFR 146.93(a)(4). Berexco will update the PISC and Site Closure Plan within 6 months of ceasing injection or demonstrate that no update is needed and as necessary during the duration of the PISC timeframe.

Non-Endangerment Demonstration Criteria

Prior to authorization of site closure, Berexco will submit a demonstration of non-endangerment of USDWs to the UIC Program Director, per 40 CFR 146.93(b)(2) or (3).

To make the non-endangerment demonstration, Berexco will issue a report to the UIC Program Director. This report will make a demonstration of USDW non-endangerment based on an evaluation of the site monitoring data in conjunction with the project's computational model. The report will detail how the non-endangerment demonstration uses site-specific conditions to confirm and demonstrate non-endangerment of USDWs. The report will include (or appropriately reference): all relevant monitoring data and interpretations upon which the non-endangerment demonstration is based, model documentation and all supporting data, and any other information necessary for the UIC Program Director to review the analysis.

Site closure will not be authorized until the UIC Program Director approves the non-endangerment demonstration per 40 CFR 146.93(e). The non-endangerment demonstration report will include the following components:

Introduction and Overview

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

Summary of Existing Monitoring Data

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

Summary of Computational Modeling History

A summary of the computational modeling conducted for the project, pursuant to the AoR and Corrective Action Plan (Attachment B of this permit), will be submitted to support a demonstration of non-endangerment. The summary will include a narrative explanation of the computational modeling history, such as verification and validation activities, modifications to the modeling approach, and changes in the AoR delineation over the life of the project.

Monitoring data collected during the injection and post-injection phases will be compared to the results of computational modeling (see below) to show that the model accurately represents the site and can be used as a proxy to characterize the carbon dioxide plume and pressure front. Such data will include the results of direct and indirect monitoring above the confining zone; direct geochemical monitoring of the injection zone; 3D seismic surveys; CASSM; crosswell seismic monitoring; direct pressure monitoring in the injection zone; passive seismic monitoring; InSAR with cGPS; and any other relevant activities conducted during the life of the project. If carbonate precipitation and other forms of geochemical trapping are suspected to occur/to have occurred to any significant degree, Berexco will model the relevant processes at the end of the injection period to support the non-endangerment demonstration.

Statistical methods will be employed to correlate the data and confirm the model's ability to accurately represent the storage site. The validation of the computational model with the large volume of available data will be a significant element to support the non-endangerment demonstration. Further, the validation of the complete model over the areas, and at the points, where direct data collection has taken place will help to ensure confidence in the model for those areas where surface infrastructure preclude geophysical data collection and where direct observation wells cannot be placed. The report will describe the methods used to compare monitoring data to modeling results, as well as an explanation of any remaining disagreement or areas of uncertainty and how these issues have been resolved.

Evaluation of Carbon Dioxide Plume

As part of the report, Berexco will support a demonstration of non-endangerment to USDWs by showing that, during the post-injection phase, the carbon dioxide plume is behaving as predicted and not migrating to unintended areas. During the life of the project, Berexco will use a combination of direct and indirect monitoring methods to track the plume, including direct fluid sampling in the injection zone, 3D seismic surveying (one survey will be conducted prior to site closure, for comparison with the previously acquired baseline survey to support the non-endangerment demonstration), CASSM monitoring, and cross-well seismic surveys. A good correlation between the results of these methods and the values predicted by the model will provide evidence of the model's ability to represent the system. Using statistical methods to compare the results of the geochemical monitoring, geophysical techniques, and model predictions will allow validation of the model's ability to predict plume movement and further demonstrate non-endangerment.

The Arbuckle injection zone consists of three zones extending from 4,170 feet below kelly bushing (KB) to 5,160 feet below KB. The lower zone, consisting of approximately the bottom 100 feet, is vuggy and highly permeable. The upper 130 feet of the zone is also highly permeable. The area between these two zones is known as the mid-Arbuckle baffle zone and has a lower permeability. This baffle zone is expected to restrict vertical movement of the plume. Figure 5 through Figure 9 above (in the "Plume Monitoring" section) show the plume behavior as predicted by the model at the cessation of injection through the end of 4 years after cessation of injection.

The model also predicts that the horizontal spread of the plume will be confined to a relatively small area that is free from artificial penetrations of the confining zone except for the injection and monitoring wells. Figure 17 and Figure 18 show that the extent of the plume is expected to reach its maximum in the southern, western, and eastern directions within 4 years of cessation of injection. Thereafter, the plume only continues to grow gradually in the northwestern direction, which is the farthest edge of the plume from the lateral boundary of the nearest USDW. The non-endangerment demonstration report will provide a synthesis of modeling results, monitoring data, and other site-specific information to support these predictions.

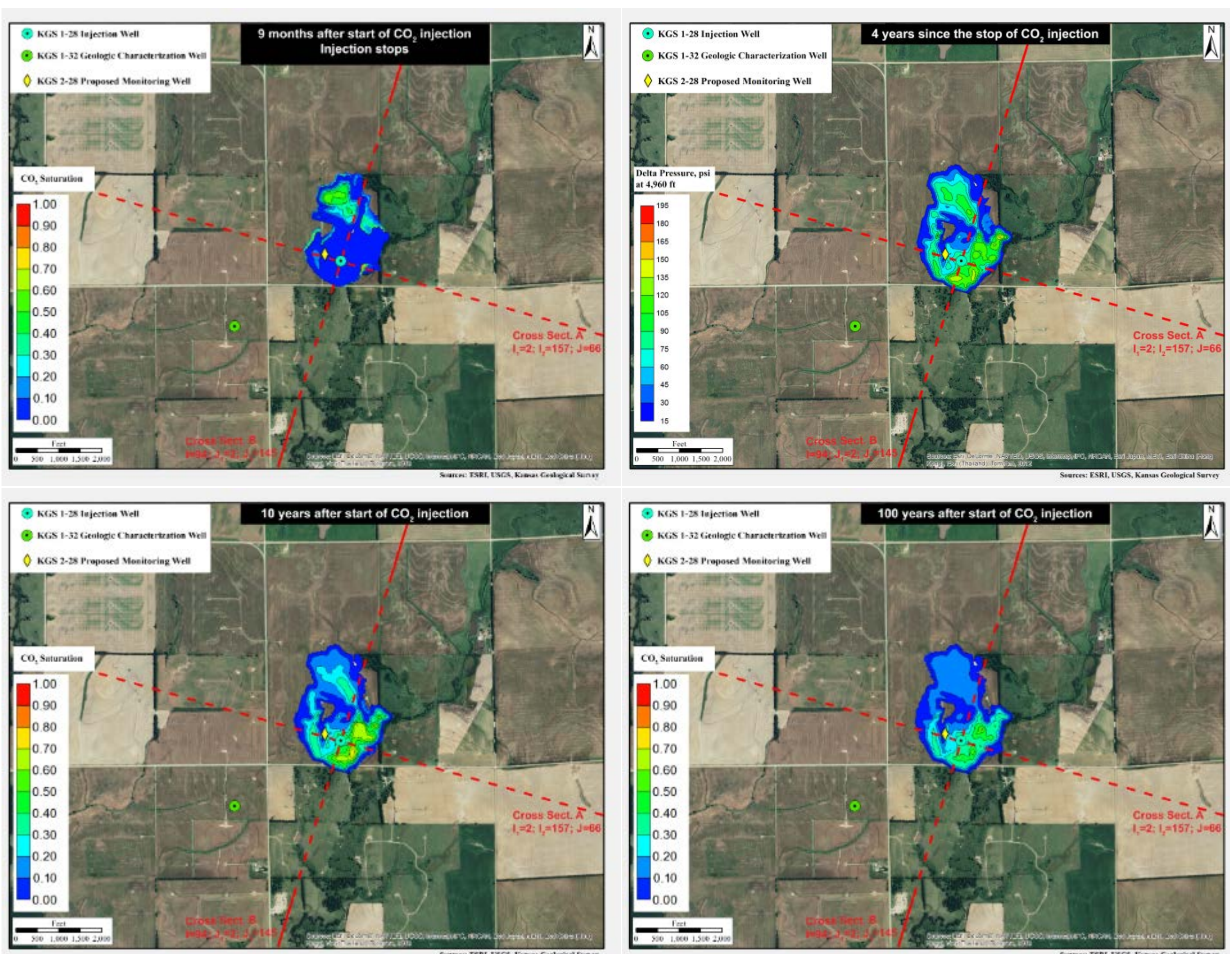


Figure 17. Location of monitoring wells and simulated plume boundary (free-phase CO_2) at the beginning of the post-injection phase (top left), 4 years after the cessation of injection/the end of the proposed post-injection phase (top right), 9 years after the cessation of injection (bottom left) and the end of the 100-year model period (bottom right), assuming 26,000 metric tons of CO_2 injected.

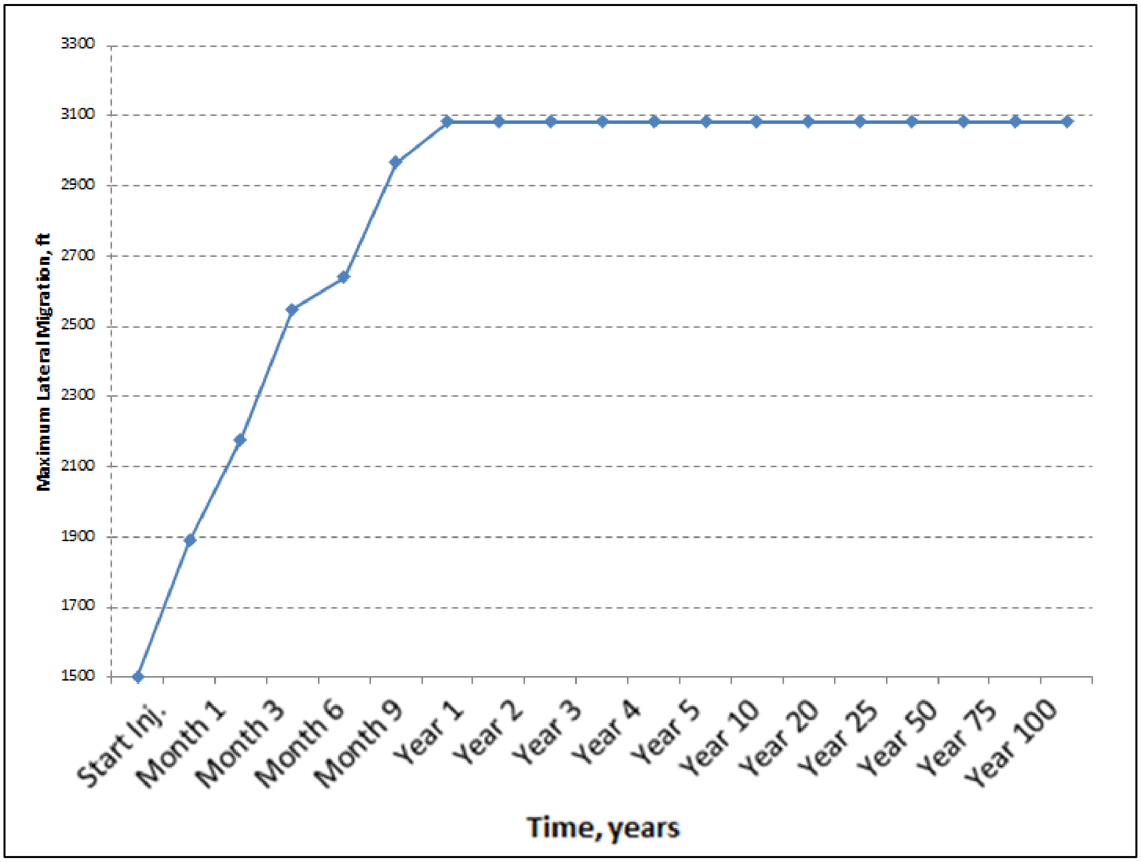


Figure 18. Modeled horizontal migration of the CO_2 plume (maximum lateral extent of CO_2 plume migration, defined by the 0.5% CO_2 saturation isoline, assuming 26,000 metric tons of CO_2 injected).

Evaluation of Reservoir Pressure

As part of the report, Berexco will submit data to provide evidence that, during the post-injection phase, the pressure within the Arbuckle has rapidly decreased toward its pre-injection static reservoir pressure. Because the increased pressure during injection is a primary driving force for fluid movement that may endanger a USDW, pressure decay will provide evidence of non-endangerment.

During the post-injection phase, Berexco will monitor the downhole reservoir pressure at the injection well and at monitoring well KGS 2-28, using downhole pressure gauges. The measured pressure at a specific depth interval will be compared against the pressure predicted by the computational model. Berexco will also use the results of passive seismic monitoring to supplement the direct pressure monitoring. Agreement between the actual and the predicted values will help validate the accuracy of the model and support a demonstration of non-endangerment. Using statistical methods to compare the monitoring results will allow validation of the model's ability to predict pressure behavior and further demonstrate non-endangerment.

Figure 10 through Figure 14 above (in the "Pressure-Front Monitoring and Other Related Monitoring" section) show the predicted pressure distributions through the life of the project. The pressure profiles (over time) at the Arbuckle injection and monitoring wells (KGS 1-28 and

KGS 2-28) are presented in Figure 19 and Figure 20 (also shown in Figure 15 and Figure 16 above). The figures show the predicted pressure increase will decay quickly within the first 3 months after injection ceases. The maximum pressure increase predicted to occur at the monitoring well is less than 60 psi. The non-endangerment demonstration report will provide a synthesis of modeling results, monitoring data, and other site-specific information to support these predictions.

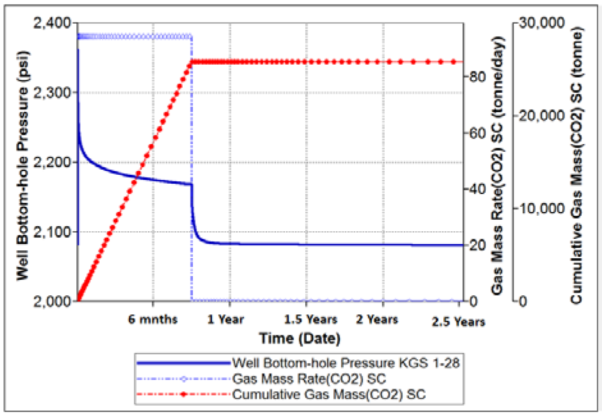


Figure 19. Pressure profile in the Arbuckle injection well (KGS 1-28) for a 24-month simulation period.

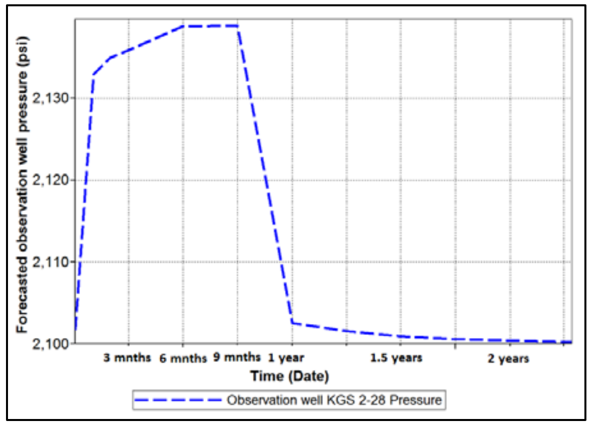


Figure 20. Pressure profile in the Arbuckle monitoring well (KGS 2-28) for a 100-year simulation period.

Evaluation of Unanticipated Events

As part of the report, Berexco will summarize any emergencies or other unanticipated events that occurred during the injection and post-injection phases and explain how they have been resolved such that there is no further endangerment of USDWs. Such events may include (but are not limited to) the examples presented in Table 9.

Table 9. Examples of unanticipated events that could potentially occur during the life of the project and the types of data that might be used to demonstrate that any associated issues have been resolved such that they will not/will no longer endanger USDWs.

Example Events	Example Data Used to Demonstrate Resolution
Identification of previously unidentified well(s) within the AoR that penetrate the confining zone	Documentation of the determination whether the well(s) require corrective action and, if applicable, records of any corrective action that was completed
Detection of CO_2 or other unanticipated parameters/levels of parameters above the confining zone	Documentation of associated monitoring activities (e.g., ground water samples, 2D seismic surveys) and data analysis, an explanation of the cause of the anomalous results and any impacts, and any follow-up actions taken
Any divergence from planned operational parameters	Documentation of the divergence/change (e.g., pressure, total volume) and data analysis, an explanation of any impacts, and any follow-up actions taken

Example Events	Example Data Used to Demonstrate Resolution
Indication that the that the fault interpreted to be located on the western end of the AoR is affecting CO_2 containment	Documentation of associated monitoring activities (e.g., pressure monitoring, passive seismic monitoring) and data analysis, an explanation of any impacts, and any follow-up actions taken
Evidence of induced seismic event(s)	Documentation of associated monitoring activities (e.g., passive seismic monitoring) and data analysis, an explanation of any impacts, and any follow-up actions taken
Non-compliance with any other Class VI permit condition, any event that triggers an unscheduled AoR reevaluation according to the AoR and Corrective Action Plan (Attachment B to this permit), and/or any event that triggers action according to the approved Emergency and Remedial Response Plan (Attachment F to this permit)	A description of how the approved Emergency and Remedial Response Plan was implemented (including references to relevant reporting) and the actions taken to return to compliance

Site Closure Plan

Following the UIC Program Director's approval of the non-endangerment demonstration and authorization of site closure, Berexco will conduct site closure activities to meet the requirements of 40 CFR 146.93(e) as described below. Berexco will submit a final Site Closure Plan and notify the permitting agency at least 120 days prior of its intent to close the site. Once EPA has approved closure of the site, Berexco will plug the monitoring wells; restore the site and move out all equipment; and submit a site closure report to EPA. The activities, as described below, represent the planned activities based on information provided to EPA with the permit application. A final Site Closure Plan will be submitted to the UIC Program Director for approval with the notification of the intent to close the site. The final site closure plan may employ different methods and procedures. These updated methods and procedures will need to be approved by the Director as being appropriate and protective of the environment. If the proposed modifications are significant then the updated plan will be subject to a public comment period.

Monitoring Well Plugging

The monitoring well plugging plan identifies steps for testing bottom hole reservoir pressure and external mechanical integrity, the type/number/method and placement of plugs, and type/grade/quantity of CO_2-resistant material to be used.

As discussed, the design and construction of KGS 2-28 is expected to be similar to KGS 1-28 (i.e., the injection well) as the geologic formations are expected to be similar at the two sites. Therefore, Berexco will plug KGS 2-28 in a manner consistent with Class VI requirements for injection well plugging in 40 CFR 146.92. This will be confirmed after construction of KGS 2-28; if the as-built construction of KGS 2-28 differs substantially from the planned design such that the following plugging procedures are not appropriate, Berexco will revise this Post-Injection Site Care and Site Closure Plan and resubmit it to EPA. Shallow monitoring wells (SW-1, SW-2, and SW-3) located in the Wellington formation will be plugged in accordance with state requirements.

Plugging the Arbuckle Monitoring Well

The Arbuckle monitoring well (KGS 2-28) will be plugged by following one of two options:

- Option 1: Plugging to the Mississippian Formation and utilizing as a KCC regulated well.
- Option 2: Plugging the well to the surface and abandoning it.

<u>Planned Tests or Measures to Determine Bottom-hole Reservoir Pressure</u>

Berexco will record the bottomhole pressure from a downhole pressure gauge and calculate the kill fluid density.

<u>Planned External Mechanical Integrity Test(s)</u>

Berexco will conduct a temperature log to verify external MI prior to plugging the injection well as required in 40 CFR 146.92(a).

<u>Information on Plugs</u>

The tables below incorporate the following potential plugging scenarios: Option 1 in Table 10 and Option 2 in Table 11.

Table 10. Plug information for Option 1 (plugging to Mississippian).

Option 1	**Plug #1**	**Plug #2**
Diameter of Boring in Which Plug Will be Placed (inches)	7.875	7.875
Sacks of Cement to be Used (each plug)	27	95
Slurry Volume to be Pumped (cu. ft)	35	125
Slurry Weight (lb/gal)	15	15
Calculated Top of Plug (ft)	4,885	3,930
Bottom of Plug (ft)	5,155	4,885
Type of Cement or Other Material	AA-2 Cement	AA-2 Cement
Method of Emplacement	Balanced plug	Balanced plug

Table 11. Plug information for Option 2 (plugging to the surface).

Option 2	**Plug #1**	**Plug #2**	**Plug #3**
Diameter of Boring in Which Plug Will be Placed (inches)	7.875	7.875	7.875
Sacks of Cement to be Used (each plug)	123	20	100
Slurry Volume to be Pumped (cu. ft)	160	26	130
Slurry Weight (lb/gal)	15	15	15
Calculated Top of Plug (ft)	3,930	3,400	0

Option 2	Plug #1	Plug #2	Plug #3
Bottom of Plug (ft)	5,155	3,600	750
Type of Cement or Other Material	AA-2 Cement	Bridge plug @ 3,600 ft	AA-2 Cement
Method of Emplacement	Retainer @ 4,885 ft & cement plug	Balanced plug	Balanced plug

Berexco will inform EPA which plugging option will be conducted prior to plugging operations via a notice of intent to plug per 40 CFR 146.92(c), and will not proceed with plugging operations until EPA approves the specific plugging operations described.

The volume and depth of the plug or plugs is based on the expected geology and downhole conditions of the well. The cement(s) formulated for plugging will be compatible with the carbon dioxide stream. The cement formulation and required documents will be submitted to the agency with the well plugging plan. Berexco will report the wet density and will retain duplicate samples of the cement used for each plug. Figures 21 and 22 present plugging schematics for both plugging options.

Narrative Description of Plugging Procedures

Berexco will perform one of the following activities to plug the monitoring well, after notification of and consultation with EPA:

Monitoring Well Plugging – Option 1 (Plug to the Mississippian Formation)

1. The Arbuckle monitoring well (KGS 2-28) will be plugged to the top of the Pierson formation (the top of the confining zone). (See Figure 21.)
2. In compliance with 40 CFR 146.92(c), notify the EPA UIC Program Director at least 60 days before plugging the well and provide an updated plugging plan, if applicable.
3. Bottomhole reservoir pressure will be obtained prior to well plugging.
4. Before abandonment, a temperature log will be run and compared with the baseline temperature log in addition to temperature logs during injection and post-injection to determine external mechanical integrity.
5. The well will be flushed with brine to force any present CO_2 into the formation, and a minimum of two wellbore volumes will be injected without exceeding 3,408 psi. The bottomhole pressure and temperature will be logged to ensure external mechanical integrity.
6. Plugging will commence at the bottom of the well by squeezing cement into the perforations and spotting balanced cement plugs. Twenty-seven sacks of CO_2-compatible cement will be placed to plug to a depth of approximately 4,885 ft.
7. A retainer will be set at the top of the injection zone at 4,885 ft or just above the injection zone. Ninety five sacks of CO_2-compatible cement will be placed to a plug depth of 3,930 ft.

Monitoring Well Plugging – Option 2 (Plugging the Well to the surface and Abandonment)

1. The Arbuckle monitoring well (KGS 2-28) will be plugged to the surface and abandoned (Figure 22).
2. In compliance with 40 CFR 146.92(c), notify the EPA UIC Program Director at least 60 days before plugging the well and provide updated plugging plan, if applicable.
3. Bottomhole reservoir pressure will be obtained prior to well plugging.
4. Before abandonment, a temperature log will be run and compared with the baseline temperature log in addition to temperature logs during injection and post-injection to determine external mechanical integrity.
5. The wells will be flushed with brine to force any present CO_2 into the formation, and a minimum of two wellbore volumes will be injected without exceeding 3,408 psi. The bottomhole pressure and temperature will be logged to ensure external mechanical integrity.
6. Plugging will commence at the bottom of the well by squeezing cement into the perforations and spotting balanced cement plugs. Approximately twenty seven sacks of CO_2-compatible cement will be used to plug to 4,885 ft.
7. A retainer will be set at 4,885 ft and approximately ninety five sacks of cement will be placed to a plug depth of 3,900 ft.
8. The wellbore will then be filled with mud to a depth of approximately 3,600 ft, or just below the bottom of the Cherokee formation. The first cast iron bridge plug will be set at the bottom of the Cherokee formation at approximately 3,600 ft. This will be followed by 20 sacks of CO_2-compatible cement to plug from the top of the bridge plug to approximately 3,400 ft, and then mud will be filled to the approximately 750 ft. A second iron bridge plug will be placed at approximately 750 ft. The plug will be topped with 100 sacks of CO_2-compatible cement to plug from approximately 750 ft to surface.

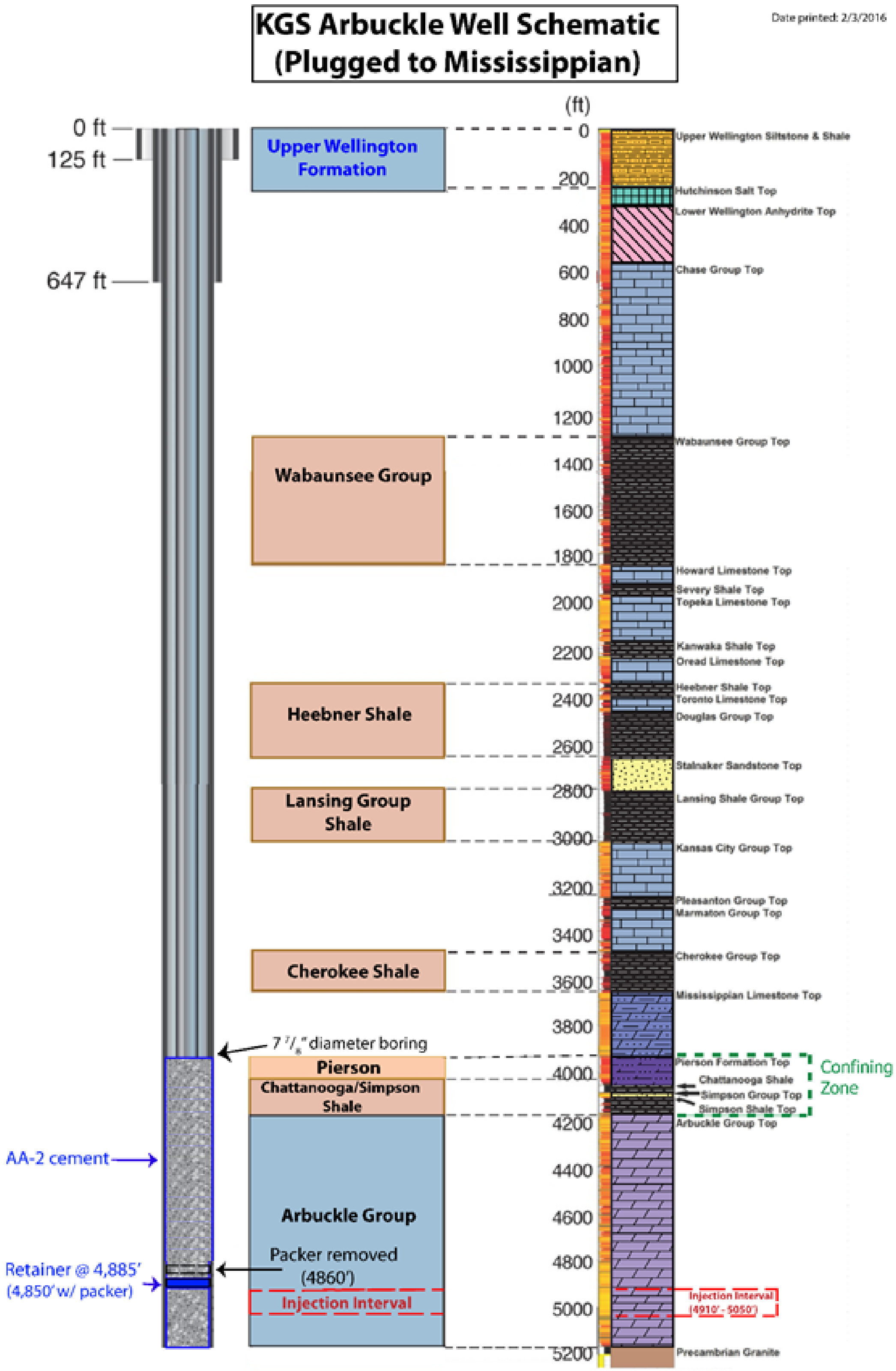


Figure 21. Representative plugging schematic for the Arbuckle monitoring well, KGS 2-28 (Option 1: plugged to Mississippian).

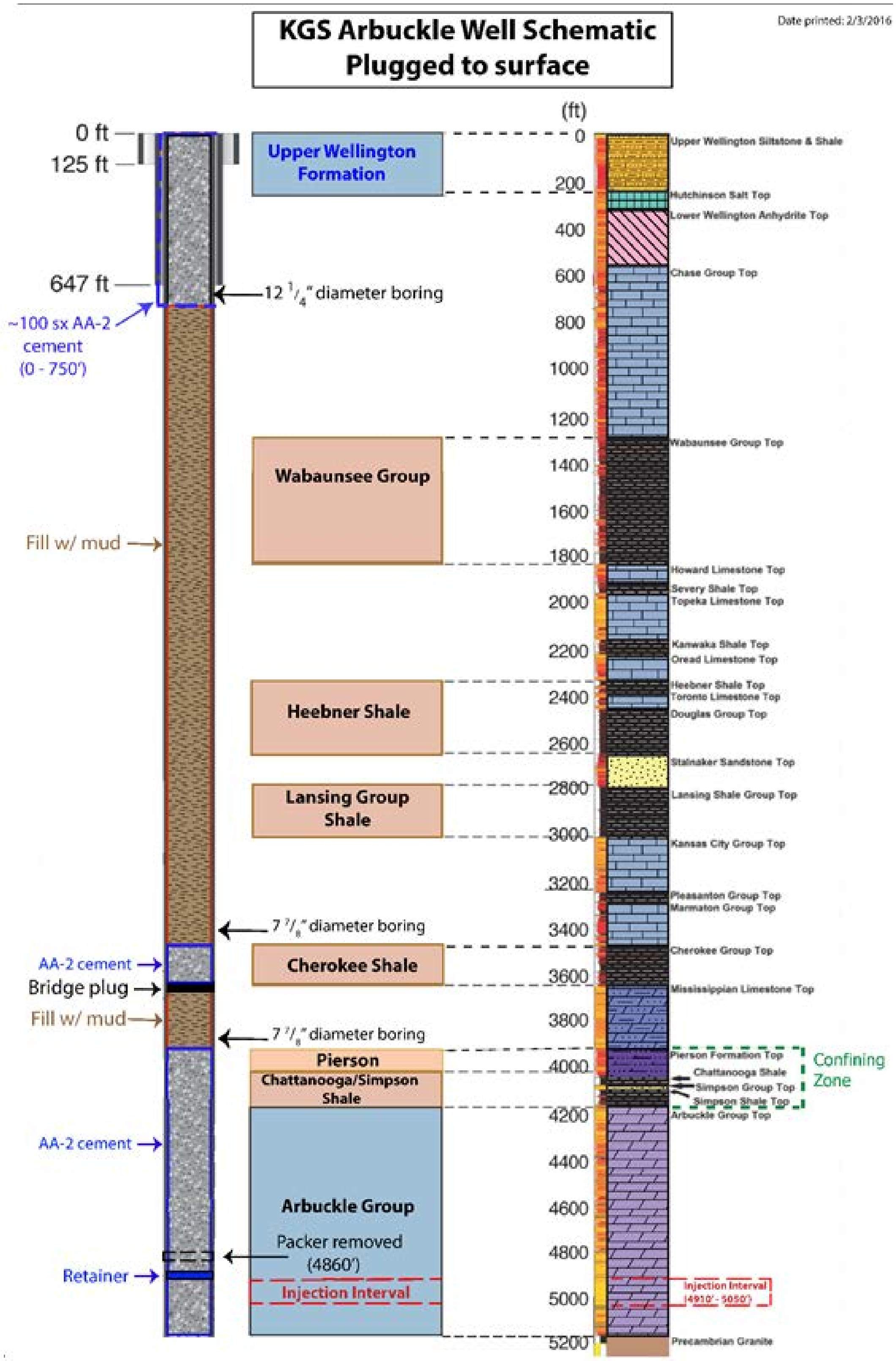


Figure 22. Representative plugging schematic for the Arbuckle monitoring well, KGS 2-28 (Option 2: plugged to Surface).

Planned Remedial/Site Restoration Activities

Plugging the Mississippian Monitoring Wells

The Mississippian wells are active oilfield wells and are not required to be plugged as part of the Class VI site closure activities, as long as Berexco demonstrates to the UIC Program Director that they do not pose a danger to any USDWs. If it becomes necessary to plug the Mississippian wells, they will be plugged according to applicable state requirements.

Plugging the Upper Wellington Monitoring Wells

As part of site closure activities, Berexco will plug the Upper Wellington monitoring wells in accordance with state requirements. Specifically, Kansas Department of Health and Environment Procedure # WWP-10 (of December 2016) will be followed. The well plugging schematics for each of the three Upper Wellington wells are presented in Figure 23 through Figure 25. Key steps that will be followed during well plugging include:

- Measure static water level.
- Measure the depth of the well to ensure that there are no obstructions that could interfere with proper plugging of the well.
- Fill the well from drilled total depth to three feet below ground level with neat cement.
- Verify that the volume of the grout placed during plugging operations is equal to or exceeds the volume calculated as necessary to properly plug the well and that no bridging of the grout material has occurred.
- Cut off and remove the casing at three feet below ground level. Backfill from the top of the remaining casing to the surface with clean compacted surface silts or clays.

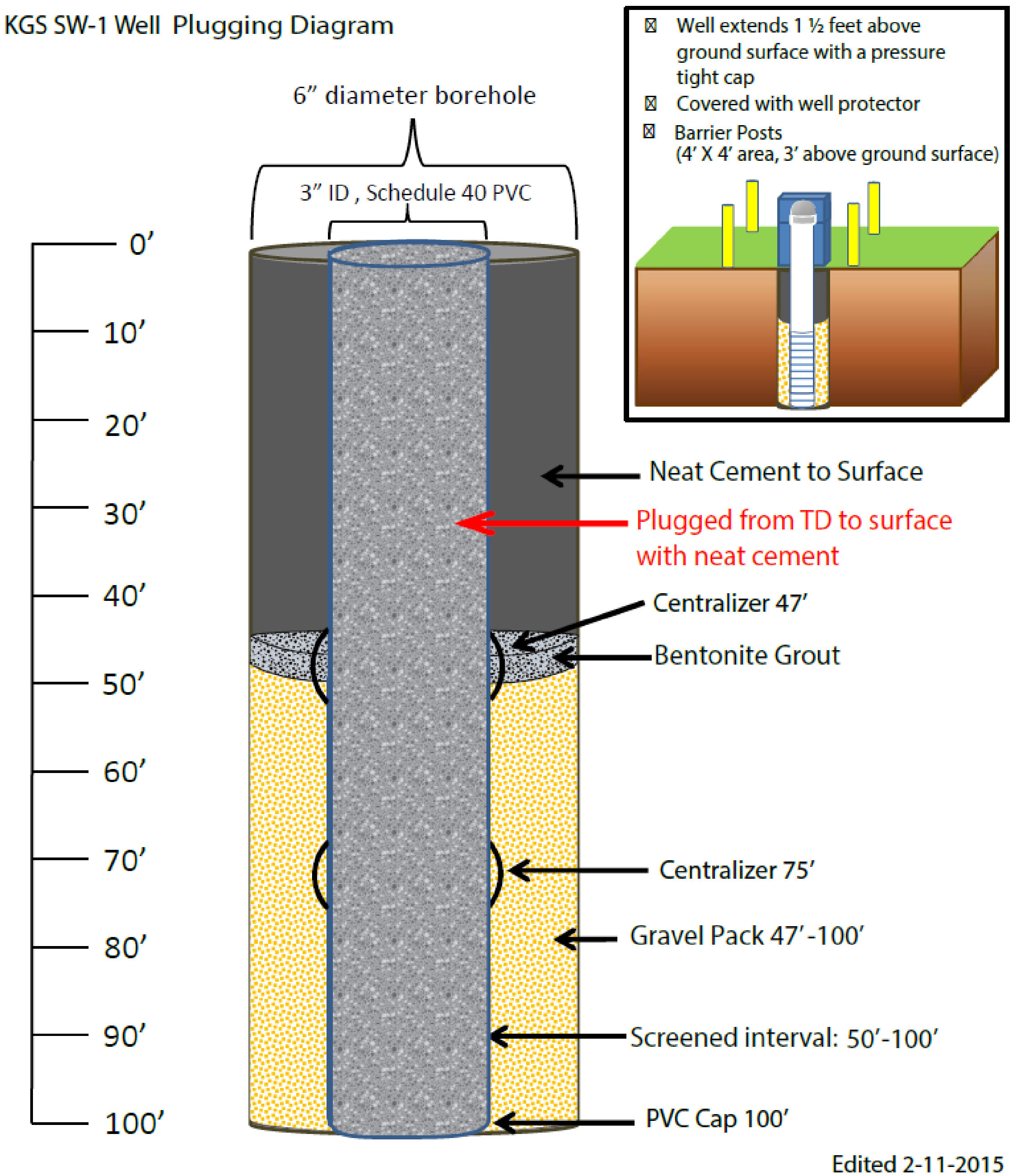


Figure 23. Well plugging schematic for Upper Wellington well KGS SW-1.

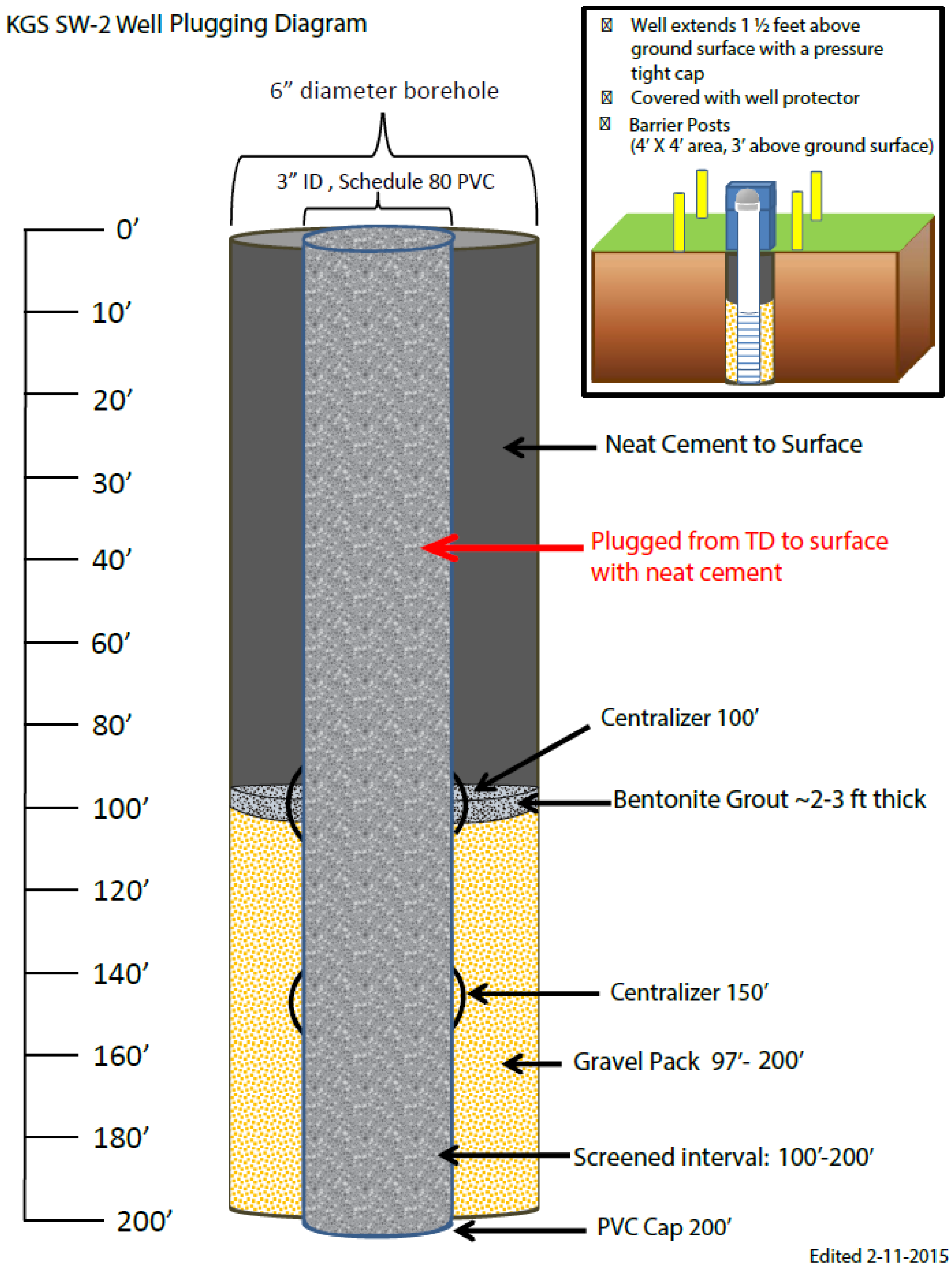


Figure 24. Well plugging schematic for Upper Wellington well KGS SW-2.

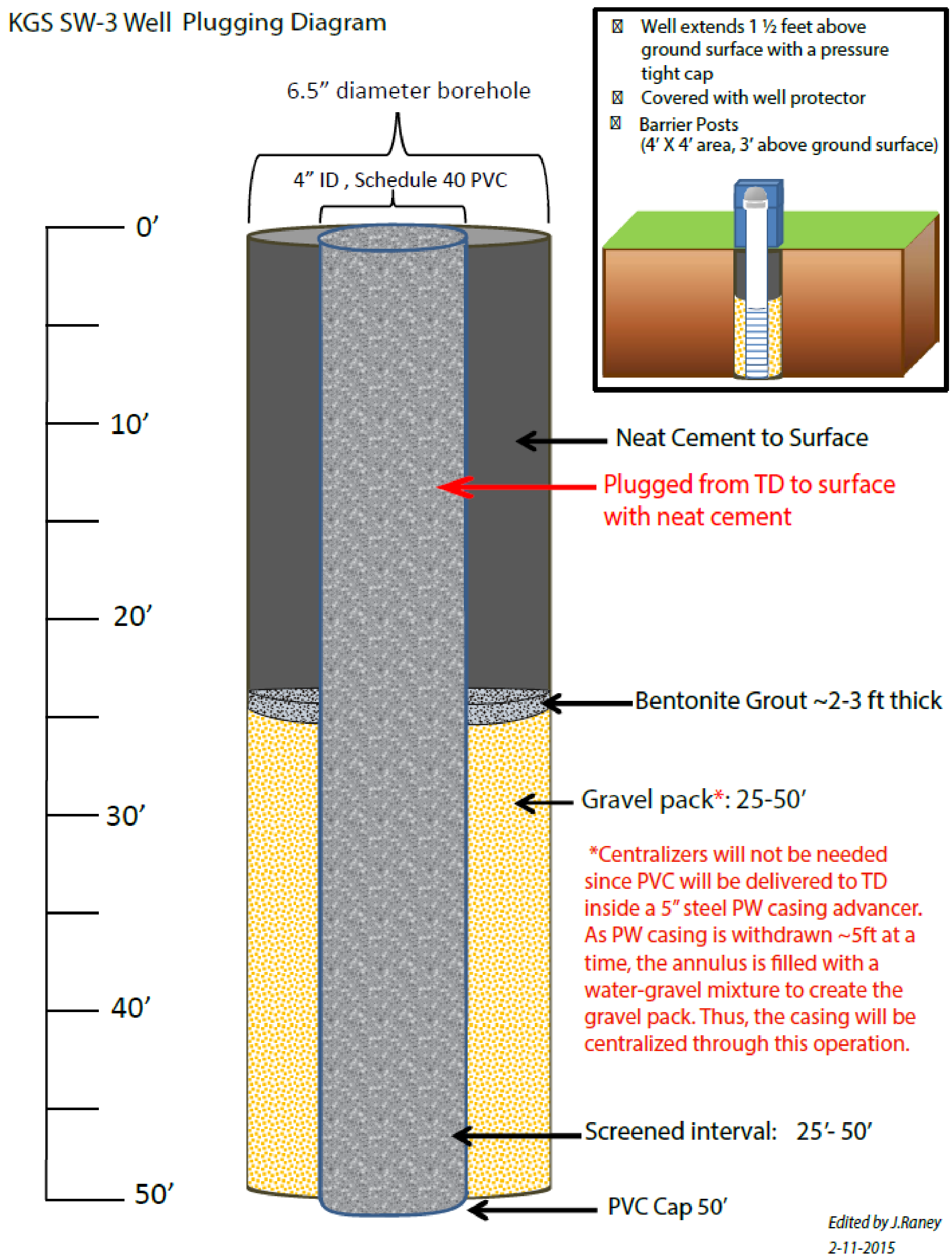


Figure 25. Well plugging schematic for Upper Wellington well KGS SW-3.

Other Site Closure Activities

All surface infrastructure assembled at the site for injecting CO_2 will be dismantled and removed from the site unless Berexco decides to utilize the same for future CO_2 enhanced oil recovery (EOR) operations. Berexco operates several oil wellfields in the area, and the company presently plans to utilize the Wellington Arbuckle wells to support wellfield activities. The pad at the site, built in 2010, will be maintained in its present condition.

Site Closure Report

A site closure report will be prepared and submitted within 90 days following site closure, documenting the following:

- Plugging of the monitoring wells (and the injection well if it has not previously been plugged),
- Location of sealed injection well on a plat of survey that has been submitted to the local zoning authority,
- Notifications to state and local authorities as required at 40 CFR 146.93(f)(2),
- Records regarding the nature, composition, and volume of the injected CO_2,
- Pre-injection, injection, and post-injection monitoring records, and
- Certifications that all injection and storage activities have been completed.

Berexco will record a notation to the property's deed on which the injection well was located that indicates the following:

- That the property was used for carbon dioxide sequestration,
- The name of the local agency to which a plat of survey with injection well location was submitted,
- The volume of fluid injected,
- The formation into which the fluid was injected, and
- The period over which the injection occurred.

The site closure report will be submitted to the permitting agency and maintained by the operator for a period of 10 years following site closure. Additionally, the operator will maintain the records collected during the PISC period for a period of 10 years after which these records will be delivered to the UIC Program Director.

Quality Assurance and Surveillance Plan (QASP)

The Quality Assurance and Surveillance Plan is presented in the Appendix of the Testing and Monitoring Plan.

Appendix: 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 injection phase activities are included for reference purposes only. Post-injection phase activities described in this plan are enforceable pursuant to 40 CFR 146.93(a).

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	Injection site or 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 (following initial annulus pressure test)	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	Wellington Unit 24 and 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 - Mississippian pressure monitoring	Wellington Unit 24	None	Monthly (becoming weekly if induced pressures in the Mississippian exceed 800 psi over background levels)	None
	Indirect monitoring - 2D seismic survey	As shown in Figure 4	Already acquired as of early 2017	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)

Class VI Rule Requirement	Activity	Location	Frequency - Pre-Injection Phase	Frequency - Injection Phase	Frequency - Post-Injection Phase
External mechanical integrity testing *[40 CFR 146.87(a)(4);146.90(e)]*	Temperature log	KGS 1-28 and KGS 2-28	One test at each well	One test at each well	One test at each well (before each well is plugged or converted)
	Noise log and/or oxygen activation log	KGS 1-28	One test	One test	One test (before the well is plugged or converted)
Internal mechanical integrity testing, in addition to continuous monitoring *[40 CFR 146.87(a)(4)]*	Annulus pressure test (via pressure gauge)	KGS 1-28 and KGS 2-28	One test	N/A	N/A
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 5 and the "Plume Monitoring" section for further details.	Quarterly
	Indirect monitoring - 3D seismic survey	As shown in Figure 4	Already acquired (April 2010)	None	One survey

[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 4.

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 - 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
	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 3	Continuous	Continuous (downloaded monthly)	Continuous (downloaded monthly)
Other monitoring *[40 CFR 146.90(i)]*	InSAR with cGPS	As described in Table 7	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 3	Continuous	Continuous (downloaded monthly)	Continuous (downloaded monthly)