Plan revision number: 0
Plan revision date: 07/31/23

TESTING AND MONITORING PLAN
40 CFR 146.90

Bluebonnet Sequestration Project

1.0 Facility Information

Facility name: Bluebonnet Sequestration Project
Bluebonnet CCS 1 Well

Facility contact: [redacted], Project Manager
5 Greenway Plaza Houston, TX 77046
[redacted]

Well location: Winnie, Chambers County, Texas
[redacted] (North American Datum 1927)

This Testing and Monitoring Plan describes how the Bluebonnet Sequestration Hub, LLC will monitor the Bluebonnet Sequestration Project site pursuant to 40 CFR 146.90. In addition to demonstrating that the well is operating as planned, the carbon dioxide 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 geological models used to predict the distribution of the CO_2 within the storage zone to support AoR reevaluations and a non-endangerment demonstration.

Results of the testing and monitoring activities described below may trigger action according to the Emergency and Remedial Response Plan.

2.0 Overall Strategy and Approach for Testing and Monitoring

The monitoring well network is designed to detect unforeseen CO_2 and/or brine leakage out of the injection zone that could endanger the USDW, migrate to a different stratus, or create a risk for the people and environment. There are several components that integrate the master monitoring plan for the Bluebonnet Sequestration Project, which are classified in the following categories:

1. Operational Testing and Monitoring During Injection.
2. Mechanical Integrity Testing
3. Ground Water Quality and Geochemical Monitoring
4. Carbon Dioxide Plume and Pressure Front Tracking.
5. Near surface and Surface monitoring
6. Induced Seismicity

Table TM-1 shows a summary of the different methods proposed in the integrated monitoring plan for the Bluebonnet CCS 1. To simplify the implementation of the monitoring plan, the project was divided in the following periods:

a) Pre-Injection: a variable period of time prior to CO_2 injection into the site. This period identifies the time frame to do site characterization and collect baselines for monitoring activities.

b) Injection Period: this timeframe identifies the period from first injection on the site until injection ceases for the project and the Post Injection Site Care starts.

c) Post Injection Period until CO_2 Plume stabilizes: defines the timeframe from the end of injection to the moment the CO_2 plume stabilizes. At the beginning of this period the CO_2 injector wells will be plugged and abandoned based on the Plugging and Abandonment Plan proposed. The monitoring wells might continue tracking CO_2 plume migration and changes in the reservoir pressure if needed based on the model projection.

d) Post Injection Period from Plume Stabilization to Closure: this period defines the time frame from plume stabilization to the date the site is approved for permanent closure. During this period the project is proposing to plug and abandon most of the monitoring wells drilled by the project, if they are still on operation, and continue monitoring with near surface and surface techniques until the project obtains the approval to permanently close the facility.

Table TM-1—Summary Table for Bluebonnet CCS 1 Testing and Monitoring Plan

Description	Method	Location	Pre	Injection Period	Requirement
Operational testing and monitoring during injection.	[redacted]				40 CFR 146.90(a)
					40 CFR 146.88 (e)(1) 40 CFR 146.90(b) 40 CFR 146.89 (b)
					40 CFR 146.88 (e)(1) 40 CFR 146.90(b) 40 CFR 146.89 (b)
					40 CFR 146.88 (e)(1) 40 CFR 146.90(b) 40 CFR 146.89 (b)
					40 CFR 146.89(b)
					40 CFR 146.88(e)(1) 40 CFR 146.88 (a)
					40 CFR 146.88 (e)(2)
					40 CFR 146.90(c)(1)
					40 CFR 146.90(f)

Table TM-1—Summary Table for Bluebonnet CCS 1 Testing and Monitoring Plan (continued)

Description	Method	Location	Pre	Injection Period	Requirement
Mechanical Integrity testing.	[redacted]				40 CFR 146.87 (a)(2)(ii) 40 CFR 146.87 (a)(3)(ii)
					40 CFR 146.89(c)
					40 CFR 146.90 (e)
					40 CFR 146.89(c) 40 CFR 146.90(e)
					40 CFR 146.89(b)
Ground water quality and geochemical monitoring					40 CFR 146.90(d)
					40 CFR 146.90(d)
					40 CFR 146.90(d)
					40 CFR 146.90(g)(1)
					40 CFR 146.90 (h) 40 CFR 146.90(d)

Table TM-1—Summary Table for Bluebonnet CCS 1 Testing and Monitoring Plan (continued)

Description	Method	Location	Pre	Injection Period	Requirement
Carbon Dioxide Plume and Pressure Front Tracking	[redacted]				40 CFR 146.90(g)(1)
					40 CFR 146.90(g)(1)
					40 CFR 146.90(g)(2)
					40 CFR 146.90(g)(2)
					40 CFR 146.90(g)(2)
Near Surface & Surface					
					40 CFR 146.90 (h)
					40 CFR 146.90 (h) 40 CFR 146.90(d)
					40 CFR 146.90 (h)
					40 CFR 146.90 (h)
Induced Seismicity					

This monitoring plan was tailored based on a qualitative risk assessment of the site. Table TM-2 shows a summary table with the residual risk ranking assuming the proposed controls and mitigations of the project design and monitoring plan are in place.

Table TM-2—Risk Ranking for Bluebonnet CCS 1 Evaluation

No	Risk	Probabili	Impact	Ranking
[redacted]				

The proposed integrated monitoring plan, includes a layout of [redacted]

[redacted] to be able to track the CO_2 plume extension and rate of migration, the development of the pressure front, and changes in the composition of deep and shallow aquifers as part of the holistic approach to ensure stakeholders and regulators that the site is operating safely and efficiently and that the CO_2 is permanently stored in the subsurface. Figures TM-1 and TM-2 show the location and spatial distribution of the monitoring wells.

[redacted]

Figure TM-1—Location and layout of In Zone and Above Confining Zone monitoring wells relative to the injector wells and the CO_2 plume and pressure front development.

[redacted]

Figure TM-2—Location and layout of USDW monitoring wells and freshwater shallow wells relative to the AOR.

Well locations show the approximate position of the proposed monitoring wells. The exact locations might have a slight variation in latitude and longitude depending on the final design of the surface pads and the negotiations with the landowners when the locations are surveyed.

The proposed Testing and Monitoring Plan aims to ensure sufficient geospatial and monitoring data is collected to validate the numerical simulation model, history match, and adjust the injection operating parameters and ensure the site is operating as designed, efficiently and safely. The monitoring results would allow the Project to re-evaluate the AOR and prove no endangerment to the USDW.

Each of these methods and their application in the proposed monitoring plan is discussed in the following sections. Results of the testing and monitoring activities described below may trigger action according to the Emergency and Remedial Response Plan.

The proposed Testing and Monitoring Plan will be reviewed and updated as a minimum every 5 years during AOR reevaluation or sooner is needed.

2.1 Quality assurance procedures

A quality assurance and surveillance plan (QASP) for testing and monitoring activities, required pursuant to 146.90(k), is provided as a separate document in this permit.

2.2 Reporting procedures

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

3.0 Operational Testing and Monitoring During Injection

3.*1 Carbon Dioxide Stream Analysis [40 CFR 146.90(a)].*

The Bluebonnet Sequestration Hub, LLC will analyze the CO_2 stream during the operation period to yield data representative of its chemical and physical characteristics and to meet the requirements of 40 CFR 146.90(a).

3.1.1 Sampling location and frequency

The CO_2 stream sampling will occur quarterly during operation either upstream or downstream of the custody transfer flowmeter that measures the flow rate of the injectant at the site, Multiple samples will be acquired during the startup period of the project (first injection) to validate the CO_2 stream complies with the requested minimum specifications. After the start up period, a sample will be taken 3 months after start of injection, at 6 months, at 9 months, and at 12 months as minimum frequency, continuing every quarter. The sampling period could be increased and could slightly shift in timing depending on the operations.

The project has developed a minimum standard CO_2 specification, as shown in Table TM-3, to be enforced with the emitters and distribution channels that control the quality of the CO_2 injected at the site. The project will install a gas analyzer at the custody transfer meter located in the sequestration site to monitor CO_2 quality continuously before it is distributed to each well in the site to detect any major deviation from the contractual specifications. The project could require additional components to be limited and analyzed based on final contractual terms with the emitters.

Table TM-3—CO_2 Stream Specification

Component	Specification
CO_2 (% mol)	[redacted]
Water (lbs/MMCF)	
Nitrogen (% mol)	
Oxygen (ppm by wgt)	
Hydrogen (% mol)	
SOx (ppm by wgt)	
NOx (ppm by wgt)	
Hydrogen Sulfide (ppm by wgt)	
Hydrocarbons (%mol)	
Carbon Monoxide (ppm by wgt)	
Glycol (gal/MMSCF)	
Ammonia (ppm by wgt)	
Argon (%mol)	
Sulfur (ppm by wgt)	

The CO_2 composition will be monitored continuously at each receipt point into the pipeline network along with at the delivery point to the sequestration site. In addition, samples will be collected and analyzed periodically at each receipt point and delivery point.

If the inline analyzers or sample results indicate a deviation from the CO_2 specification, the sampling frequency for the relevant receipt point(s) will be increased until the sampling results return to normal for a specified period.

If the CO_2 delivered to a receipt point does not meet the CO_2 specification, the project will notify the CO_2 source facility and either shut-in the source facility or increase the sample frequency, depending on the risk associated with the out-of-spec component.

If a CO_2 source facility is shut-in, offtake will only resume from that facility once it has demonstrated the resumption of in-spec product for an agreed period between 12 and 48 hours.

3.1.2 Analytical parameters

The Bluebonnet Sequestration Hub, LLC, will analyze, as minimum, the CO_2 for the constituents identified in Table TM-4 as minimum requirement, but not limited to.

Table TM-4—CO_2 Stream Analysis

Component	Frequency	Analytical Method
[redacted]		

The project may deem it necessary to test additional elements to ensure the CO_2 delivered in the Pelican Sequestration Hub complies with contractual specifications.

Isotopes will be analyzed during the first year of operation and after any major change of CO_2 source composition to fingerprint the stream.

3.1.3 Sampling methods

- A sampling station will be installed with the ability to purge and collect samples into a container that will be sealed and sent to the third-party authorized laboratory. All sample containers will be labeled with durable labels and indelible markings. A unique identification number and sampling date will be recorded on the sample containers.

- Sampling procedures will follow contractor protocols to ensure the sample is representative of the injectant and samples will be processed, packaged, and shipped to the contracted laboratory, following standard sample handling and chain-of-custody guidance. Sampling methods are described in the QASP.

3.1.4 Laboratory to be used/chain of custody and analysis procedures

The samples will be analyzed by a third-party laboratory using standardized procedures for gas chromatography, mass spectrometry, detector tubes, and photo ionization. Analytic methods and chain of custody procedures are described in the QASP.

3.2 Monitoring and Recording of Operating Parameters in Injector Wells [40 CFR 146.88(e)(1), 146.89(b), and 146.90(b)]

The Bluebonnet Sequestration Hub, LLC will install and use continuous recording devices to monitor injection pressure, rate, and volume; the pressure on the annulus between the tubing and the long string casing; and the temperature of the CO_2 stream, as required at 40 CFR 146.88(e)(1), 146.89(b), and 146.90(b).

To comply with the requisite of monitoring the annular volumes between tubing and casing, the project proposes to install [redacted], additional to the surface gauges installed in the wellhead, to track any potential mechanical integrity and replace the continuous recording of added annular volume with weekly inspection and recording of the volumes during those inspections. This will allow a better control of fluids added and improve the analysis of annular variation due to temperature dilatation of the fluids and tubulars versus potential mechanical integrity issues.

Injection operations will be continuously monitored and controlled by the operations staff, utilizing the process control system. The system will continuously monitor, control, record, and alarm for critical system parameters of pressure, temperature, and flow rate.

The process control system will limit maximum flow to [redacted] MT/day, or approximately [redacted] MMscfd, and limit the wellhead pressure to [redacted] psig to protect the surface equipment.

The system will initiate a shutdown if specified control parameters deviate from the intended operating range and will allow for remote shutdown under emergency conditions. Trend analysis will help evaluate the performance (e.g., drift) of the instruments, suggesting the need for maintenance or calibration.

3.2.1 Monitoring location and frequency

Real time monitoring activities will begin during the start-up of the wells for first injection. The injection pressure and temperature will be continuously measured at the surface via real-time pressure and temperature (P/T) instruments installed in the CO_2 injection line near the interface with the wellhead. The pressure will be measured by electronic pressure transmitter with analog output mounted on the CO_2 line associated with the injection well. The temperature will be measured by an electronic temperature transmitter mounted in the CO_2 line at a location near the pressure transmitter, and both transmitters will be located near the wellhead.

The flow rate of CO_2 injected into the well will be measured by flow meter skids with [redacted] meters in the CO_2 injection line near the interface with the wellhead. Piping and valving will be configured to permit flow meter calibration. The flow transmitter will be connected to a remote terminal unit (RTU) on the flow meter skid.

A pressure and temperature (P/T) gauge will be installed downhole as part of the upper completion and will be ported into the tubing to continuously measure CO_2 injection pressure and temperature at reservoir. The downhole sensor will be the point of compliance for maintaining injection pressure below 90% of formation fracture pressure, as well as to evaluate the reservoir performance and history match the operation with the projection of the model.

If the downhole gauge stops working between scheduled maintenance events, then the surface pressure limitation approved for this permit will be used as a backup until the downhole gauge is repaired or replaced. For calibration purposes, in lieu of removing the injection tubing, the accuracy of the downhole gauges will be demonstrated by using a second pressure gauge with current certified calibration lowered into the well at the same depth as the permanent downhole gauge.

Electronic pressure gauges and temperature sensors will be used to continuously monitor the pressure and temperature of the annulus between the tubing and long string casing at the surface. Gauges and sensors will be connected to the automation system to provide continuous data analysis as well as alarms for malfunctioning events when the values deviate from the intended operating range.

Annular pressure will be kept between [redacted] psi on surface and the addition of volume or changes in pressure will be noted by the operator in the field and recorded in the project well databases weekly. [redacted]

[redacted]

Automated shut off devices will be installed at each exit of the flow lines in the wellhead and will be connected to the control system. If the operation parameters deviate from the program operational limits, the system will send an alarm to the operators to evaluate and correct the situation and might start shut down protocol, if the parameter exceeds the maximum operating limits.

The Bluebonnet Sequestration Hub, LLC will perform the activities identified in Table TM-5 to monitor operational parameters. All monitoring will take place at the locations and frequencies shown in the table.

Table TM-5—Monitoring Devices, Locations, and Frequencies for Continuous Monitoring During Injection Operations in the CO_2 Injector Wells

Parameter	Device(s)	Location	Min. Sampling Frequency	Min. Recording Frequency
[redacted]				

The Bluebonnet Sequestration Hub, LLC will properly plug and abandon the injector wells upon cessation of injection after approval from the Director.

3.2.2 Monitoring devices description and technical specifications

Technical specifications for the tools to use for real time data acquisition are described in the QASP.

3.3 Corrosion Monitoring [40 CFR 146.90(c)]

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

The Bluebonnet Sequestration Hub, LLC will monitor corrosion using Corrosion Coupons and collect samples according to the description below. The project will complement the corrosion coupons with visual inspection of the facilities, a robust leak detection and repair program, the use of optical gas imaging cameras (OGI), and the data collected in real-time from the fiber optic installed in the injector wells.

During well material selection, the Bluebonnet Sequestration Hub, LLC simulated the chemical reactions of the selected material, the formation waters, and the proposed CO_2 stream at downhole conditions. The Project proceeded to test the selected metallurgic to the maximum limits of the specification and operating parameters to validate the correct selection for downhole materials that will be exposed to the injection stream and formation waters. The results of material testing are in progress and will be available for the Director to review.

During planned well maintenance operation in the CO_2 injector wells, the Bluebonnet Sequestration LLC will run a casing inspection log to evaluate the casing conditions downhole (Casing Inspection Logs are discussed in the section associated with mechanical integrity).

3.3.1 Monitoring location and frequency

Table TM-6—Monitoring Location and Frequency of Leak and Corrosion Detection Devices

Tool	Location	Pre-Injection	Injection
[redacted]			

Notes:

[redacted]

Multiple inspections using OGI cameras will be performed during the startup of the well (first injection) after authorization to inject is received and will continue quarterly as minimum frequency during the injection period.

Visual inspection will continue weekly, during the injection period, after the start-up of the well to identify potential leaks, as well as to validate that the system is operating between design limits and efficiently. The field operator will be provided with handheld devices to measure explosive gases, H_2S, and CO_2 as part of the safety requirements of the site. The field inspection will continue quarterly in the post injection period.

[redacted]

3.3.2 Corrosion Coupons analysis description

Samples of selected materials in the wells and facilities (coupons) will be exposed to the injected CO_2 stream and monitored for signs of corrosion to verify that the selected materials meet the minimum standards for material strength and performance and to identify well maintenance needs. Coupons shall be collected and sent quarterly to a third-party company for analysis conducted in accordance with NACE Standard SP-0775-2018-SG to determine and document corrosion wear rates based on mass loss. The project will start corrosion coupon monitoring after the start of injection and will continue quarterly.

Table TM-7—Summary of methods to evaluate Corrosion Coupons

Parameters	Analytical Method	Resolution Instruments	Precisions/Std Dev
[redacted]			

NACE SP0775-2018-SC: Preparation, Installation, Analysis, and Interpretation of Corrosion Coupons in Oilfield Operations

Table TM-8—List of Equipment with Materials of Construction

Equipment Coupon	Material of Construction
[redacted]	

3.4 Pressure Fall-Off Testing [40 CFR 146.90(f)]

The Bluebonnet Sequestration Hub, LLC will perform pressure fall-off tests in the CO_2 injector well during the injection phase as described below to meet the requirements of 40 CFR 146.90(f).

3.4.1 Testing location and frequency

Pressure fall-off testing will be conducted upon completion of the injection well to characterize reservoir hydrogeologic properties, aquifer response model characteristics, and changes in near-well/reservoir conditions that may affect operational CO_2 injection behavior.

Pressure fall-off testing will be conducted in the CO_2 injector wells at least once every five (5) years during injection for AoR review until the wells are plugged . The objective of the periodic pressure fall-off testing is to determine whether any significant changes in the near-wellbore conditions have occurred that may adversely affect the well or reservoir performance.

3.4.2 Testing details

Detailed procedure and analytics proposed for the fall-off test are described in the QASP.

3.5 Tracking and Recording Surface Pressure and Temperature in Monitoring Wells

The Bluebonnet Sequestration Hub, LLC will continuously measure pressure and temperature in monitoring wells (In Zone and Above Confining Zone) at the surface via real-time pressure and temperature (P/T) instruments installed in the wellhead.

A pressure and temperature (P/T) gauge will be installed downhole as part of the upper completion and will be ported into the tubing to continuously measure pressure and temperature in the reservoir. These measurements will allow the project to calibrate and verify the model, improve predictive capability for confirming CO_2 containment, and evaluate the development of the pressure front.

Since the changes in reservoir pressure precede the movement of the CO_2 plume, In Zone Monitoring wells will provide data to history match the model and calibrate the response expected from the reservoir regarding the development of pressure front and CO_2 plume migration.

Abnormal changes of pressure in Above Confining Zone monitoring wells could indicate a potential leak path from the reservoir to the upper zones.

Details of the In Zone Monitoring wells as well as the Above Confining Zone monitoring wells are provided in the following sections.

3.5.1 Monitoring location and frequency

Table TM-9—Monitoring Location and Frequency of Pressure and Temperature Gauges

Tool	Location	Pre-Injection	Injection	Post-Injection	Min. Sampling Frequency	Min. Recording Frequency
[redacted]						

If the downhole gauge stops working between scheduled maintenance events during the injection period, the project might install a temporary downhole gauge with wireline and reduce the frequency of data collection to 1 sample per day or less, depending on the pressure behaviors observed before the failure.

3.6 Visual Inspection and Leak Detection and Repair (LDAR) **Program U***sing Optical Gas Imaging Camera (OGI)*

The project will perform visual inspection of the facilities and wells as part of the maintenance and mechanical integrity program. Inspection will start from the commissioning date, during startup of the facilities and well, and will continue weekly after the site is injecting steadily. Quarterly, field inspections will be performed after the start of injection and continue to injection ceasses and will be aimed at identifying potential leaks, with the use of OGI cameras.

OGI cameras are highly specialized versions of infrared or thermal imaging cameras. They are composed of a lens, detector, and some electronics to process the signal and a viewfinder to give the user the final product. The material used as the detector will depend on the type of gas to be measured. Detectors are cooled to specific operating temperatures where they become nonconductive. Once exposed to the incident photon, the electron will move to the conduction band and detector can carry a photocurrent proportional to the intensity of the incident radiation.

During this process, the camera software will process and adjust the signal of the detector array, giving a thermographic image that shows relative temperatures across the target object or scene. The image is a true representation of the radiation intensity regardless of the source of thermal radiation. The OGI cameras use unique spectral filters that enable them to detect a gas compound. The filter restricts the wavelengths of radiation allowed to pass through the detector to a very narrow band called band pass. This technique is called spectral adaptation.

Optical Gas Imaging cameras provide the power to spot invisible gases as they escape, so that the operation team can find the leak in a reliable way. Cameras rely on infrared images to detect the leaks and they are used during the inspection of facilities, pipelines, and well locations.

4.0 Mechanical Integrity Testing

4.1 External Mechanical Integrity Testing [40 CFR 146.89(c) ,40 CFR 146.90(e), 40 CFR 146.87 (a)(2)(ii), 40 CFR 146.87 (a)(3)(ii)]

After installation of the long string casing during construction the CO_2 injector and monitoring wells, the Bluebonnet Sequestration Hub, LLC will perform a cement logging evaluation, with one or more of the following tools, to validate zonal isolation between the injection zone, confining zones, and overburden formations [40 CFR 146.87 (a)(2)(ii) 40 CFR 146.87 (a)(3)(ii)]:

a) Cement Bond Logging
a) Ultrasonic cement evaluation tool.
a) Variable density log (VDL)

The Bluebonnet Sequestration Hub, LLC will [redacted]

[redacted]

a) Pulse neutron through tubing.
b) Electromagnetic casing inspection log.
c) Temperature Log

Additionally, during well maintenance operations or workovers for the CO_2 injector well and the monitoring wells, an ultrasonic casing inspection tool might be run to evaluate casing thickness and conditions. At the end of the injection period, the Bluebonnet Sequestration Hub, LLC plans to properly abandon the CO_2 injector well.

[redacted]

a) Pulse neutron through tubing.
b) Electromagnetic casing inspection log.
c) Temperature Log

For [redacted] the Project will run one of the following tools at least every 5 years or during planned well maintenance or workover activities to demonstrate external mechanical integrity:

a) Pulse neutron through tubing.
b) Electromagnetic casing inspection log.
c) Temperature Log

4.1.1 Testing location and frequency

Table TM-10 below provides a summary of the external mechanical integrity tools.

Table TM-10—Corrosion Monitoring and Surface Leak Detection Tools

Tool	Location	Pre-Injection	Injection
[redacted]			

4.1.2 Testing details

The logging industry has made an impressive advance in tools that provide images of and data identifying the quality of the cement bond behind the casing after cementing jobs are complete. The casing inspection tool and multi-finger calipers can provide information about ovality, collapse, or damage in the casing, as well as estimations of wall thickness to evaluate wearing and corrosion effects.

The most advanced tools can evaluate up to five concentric tubulars to measure changes in thickness that could be related to corrosion or wearing effects.

The tools described below are readily available technologies on the market and the basis of the project's master monitoring program for mechanical integrity. No specific provider has been selected. In the future, new technologies or tools may be proposed for further discussion with regulators.

4.1.2.1 Cement bond logging, variable density log and ultrasonic cement evaluation

Cement Bond Log (CBL): is a basic method to evaluate cement quality in the annulus. It is an acoustic wave measurement. The tool usually includes a transmitter and receiver, separated by three (3) ft. The acoustic wave is emitted by the transmitter, propagated down and across the annulus, and recorded by the receiver. The attenuation of the wave is analyzed to interpret the bonding behind the pipe. Signal coming from a properly cemented casing will be more attenuated than the signal coming from a poorly cemented one.

The arriving signal recorded by the receiver is a mixed signal coming from casing, cement, mud, and formations. Each signal has its own pathway because they travel at different velocities through each medium. The signal through the casing is the fastest, as sound travels the quickest through steel. As a result, it is the first signal detected on the receiver. The second signal most likely to arrive is the signal through the formation and the last one is the drilling fluid signal, because sound travels slower in a liquid.

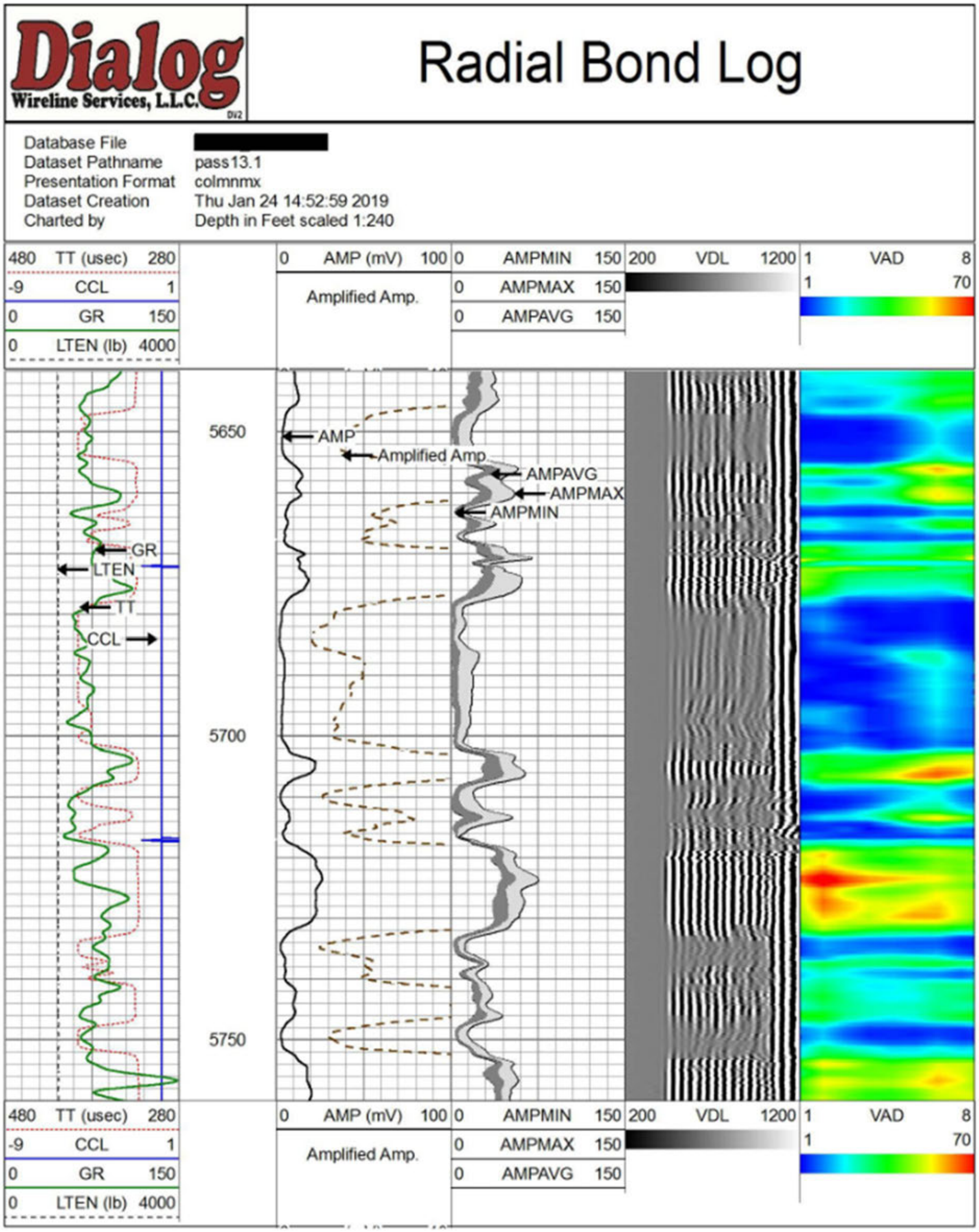

Figure TM-3—CBL and VDL Example from Dialog Wireline Services Web Page

Variable Density Log (VDL): is commonly used as an adjunct to the cement bond log and offers better insights with its interpretation. In most cases, micro-annulus and fast-formation-arrival effects can be identified using this additional display.

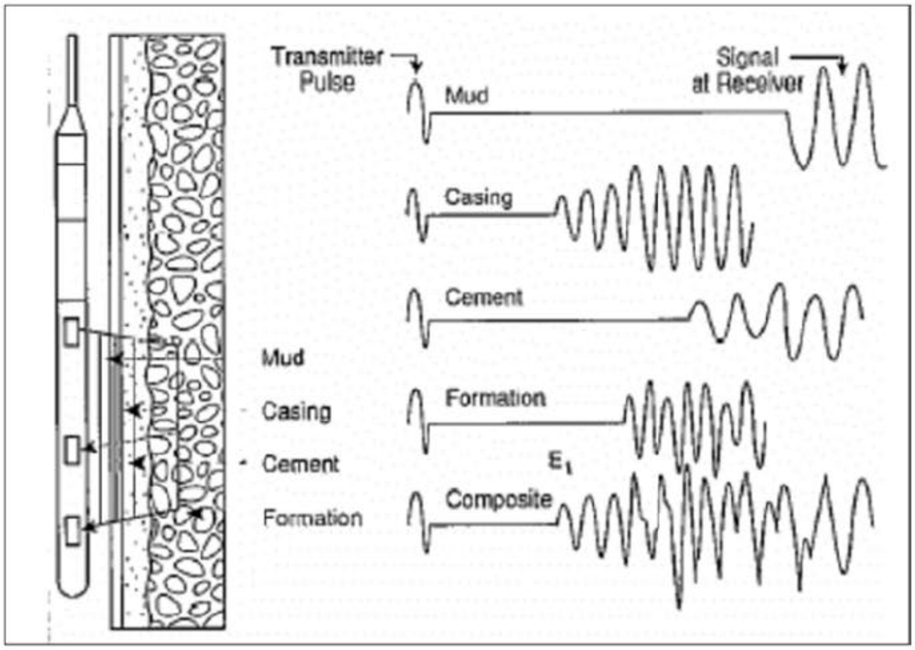

Figure TM-4—Signal Received by CBL-VDL

4.1.2.2 Ultrasonic cement and casing evaluation tools

[redacted]

The rate of decay of the waveforms received indicates the quality of the cement bond at the cement-casing interface and the resonant frequency of the casing provides the casing wall thickness required for pipe inspection. The resulting 360° data coverage enables evaluation of the quality of the cement bond and determination of both the internal and external condition of the casing.

[redacted]

[redacted]

4.1.2.3 Distributed temperature sensing

Distributed Temperature Sensing (DTS) technology uses fiber optic sensor cables, typically several kilometers in length, that function as linear temperature sensors. The result is a continuous temperature profile along the entire length of the sensor cable. DTS utilizes the Raman effect to measure temperature. An optical laser pulse sent through the fiber results in some scattered light reflecting to the transmitting end, where the information is analyzed. The intensity of the Raman scattering is a measure of the temperature along the fiber. The Raman anti-Stokes signal changes its amplitude significantly with changing temperature, while the Raman Stokes signal is relatively stable. The position of the temperature reading is determined by measuring the arrival timing of the returning light pulse like a radar echo.

The fiber optic cable is run alongside the casing as an umbilical and it is protected with clamps and centralizers to avoid any damage while deploying it into the well. The fiber is connected on the surface to an interrogator to convert the signal to temperature values and data is transmitted to the monitoring platform in real time for surveillance purposes.

The maintenance and calibration of the equipment will be performed according to the manufacturer's manuals and will be the responsibility of the technology provider. Tables TM-11 and TM-12 show technical specifications for [redacted].

Table TM-11—Technical Specification for [redacted]

Parameter	Value
[redacted]	

Table TM-12—Technical Specification for [redacted]

Parameter	Value
[redacted]	

4.1.2.4 Electromagnetic casing inspection tool

[redacted]

4.1.2.5 Temperature log

Temperature logs are used to locate gas entries, detect casing leaks, and evaluate fluid movement behind casing. They are also used to detect lost-circulation zones and cement placement. Temperature logs are used as a basic diagnostic tool and are usually paired with other tools like acoustics or multi arms calipers if more in depth analysis is required.

Temperature instruments used today are based on elements with resistances that vary with temperature. The variable resistance element is connected with bridge circuitry or constant current circuit, so that a voltage response proportional to temperature is obtained. The voltage signal from temperature device is then usually converted to a frequency signal transmitted to the surface, where it is converted back to a voltage signal and recorded. The absolute accuracy of temperature logging instruments is not high (in the order of +- 5°F), but the resolution is good (0.05°F) or better, although this accuracy can be compromised by present day digitalization of the signal on the surface. The temperature instrument usually can be included in the string with other tools, such as radioactive tracer tools or spinners flowmeters. Temperature logs are run continuously, typically at cable speeds of 20 to 30 ft/min. (A.Daniel Hill).

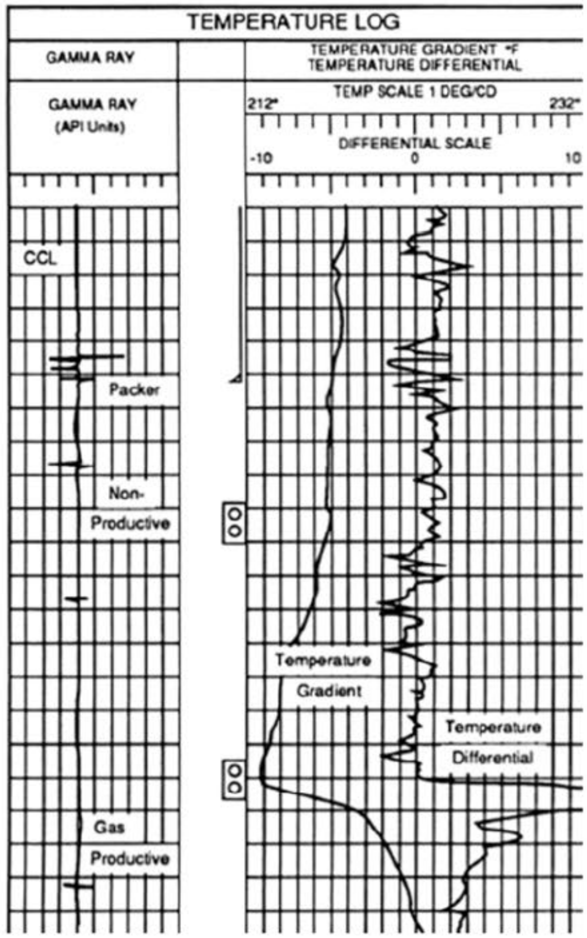

Figure TM-5—Example of temperature log output

4.1.2.6 Pulse neutron log

Pulse neutron log (PNL) provides formation evaluation and reservoir monitoring in cased holes. PNL is deployed as a wireline logging tool with an electronic pulsed neutron source and one or more detectors that typically measure neutrons or gamma rays. High-speed digital signal electronics process the gamma ray response and its time of arrival relative to the start of the neutron pulse. Spectral analysis algorithms translate the gamma ray energy and time relationship into concentrations of elements. Each logging company has its own proprietary designs and improvements on the tool.

[redacted]

[redacted]

[redacted]

4.1.3 Description and technical specifications of the tools for external mechanical integrity evaluation

Detailed information and technical references of these tools are provided in the QASP.

4.2 Internal Mechanical Integrity Testing [40 CFR 146.89(b)]

The Bluebonnet Sequestration Hub, LLC, will perform an annular pressure test in the CO_2 injector well as well as in monitoring wells to proof internal mechanical integrity of the system according to 40 CFR 146.89(b).

Annular pressure testing is used to validate mechanical integrity in the system. Tests will be performed according to the frequency presented in table TM–13.

Table TM-13—Annular Pressure Testing Frequency

Tool	Location	Pre-Injection	Injection
[redacted]			

If the additional monitoring systems indicate a potential mechanical integrity issue, the Bluebonnet Sequestration Hub, LLC will perform trouble shouting and perform an annular pressure test as part of the protocol, if needed.

An overview of the procedure is as follows: First, shut-in the well to stabilize the pressures in the injectors and validate static conditions in the monitoring wells. Connect the testing equipment to the annular valves and test surface lines to 1,500 psi above the testing pressure. Ensure that there are no surface leaks from the pumping unit to the wellhead valve. Bleed any air in the system. If needed, fill the annular space with packer fluid and corrosion inhibitor (if so, it should require only a minimal amount). Record the initial tubing and casing pressure. The well will be tested to [redacted] psi in the annular space and the pressure should not decrease more than [redacted]% in [redacted] minutes. Monitor continuously the tubing and casing pressures. Record the final tubing and casing pressure, then bleed the pressure and volume. If the pressure decreases more than [redacted]%, bleed the pressure, test the surface connection, and repeat the test. If there is an indication of mechanical failure, the operator will prepare a plan to repair the well and discuss it with the Director.

Surface gauges should be calibrated according to manufacturer recommendations. There should be a pressure range that will allow the test pressure to be near the mid-range of the gauge. Additionally, the gauge must be of sufficient accuracy and scale to allow an accurate reading of [redacted]% change to be read. The test results will be documented and stored in the centralized database of the project for reporting and documentation.

5.0 Ground Water Quality and Geochemical Monitoring [40 CFR 146.90(d)]

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

The selection of the ground water monitoring locations was based on the original assessment of the AOR for existing legacy wells, the results of the numerical simulation for CO_2 plume and pressure front, and the risk assessment performed by the project. The location, techniques, and frequency were optimized taking in consideration the complementary techniques proposed in this monitoring plan for direct and indirect measurements, such as 2D seismic surveys, 3D time lapse VSP, pulse activate neutron logs, soil gas analysis, and others that are explained in additional sections of this document.

The Bluebonnet Sequestration Hub, LLC selected [redacted] shallow water wells distributed around the AoR to sample and test the freshwater aquifer in the area. These wells targeted the Upper Chicot Aquifer to provide water for domestic and irrigation uses. Additionally, the project will drill [redacted] USDW wells targeting the lower section of the Evangeline Aquifer.

The Bluebonnet Sequestration Hub, LLC will drill [redacted] confining zone. This well will provide water characterization and fingerprinting of the water above the lower confining zone and below the USDW. During injection and post injection period, the well will provide information about any potential change in water composition due to an unexpected leak path from the reservoir.

As part of the monitoring system, the Bluebonnet Sequestration LLC plans to install [redacted] that will allow to detect any mechanical integrity issue that could cause contamination of CO_2 or brines in the above confining zone and / or in the USDW. This technique is described in the mechanical integrity section.

The Bluebonnet Sequestration Hub, LLC plans also to install In Zone Monitoring wells, Bluebonnet IZM 01 and Bluebonnet IZM 02, and recomplete the stratigraphic well Encanto 01 as In Zone Monitoring number 3. These wells will be described in the section related to CO_2 plume extension and pressure front tracking, but as they penetrate the above confining zone and the USDW, they will be to track any potential leakage from the reservoir through logging in the wells and the used of indirect methods as [redacted].

A 2D time lapse seismic survey will be used at the site as part of the indirect methods to track the CO_2 plume extension and will complement the well monitoring network.

Figure TM-6 shows the proposed well network for groundwater and above confining zone monitoring.

[redacted]

Figure TM-6—Proposed well network for groundwater and above confining zone monitoring

5.1 Freshwater shallow aquifer water sampling and testing

The shallowest freshwater aquifer of importance, the Chicot aquifer, is predominantly composed of Pleistocene sand and gravel and is directly underlain by the Evangeline aquifer, predominantly composed of Pliocene sand and clay. These two aquifers are hydraulically connected and separated only by a gradation in grain size with depth. The Chicot and Evangeline aquifers are the primary sources of groundwater used for drinking in the region, and thus, will be the most likely the regional target for USDW monitoring.

The proposed locations for sampling and testing the shallow freshwater aquifer (show in the figure TM-6 in purple) were selected to cover an extensive area inside and around the defined AOR. The identified locations for sampling were evaluated for age of installation, use, depth, and relative location to the AoR and the other monitoring wells. The Bluebonnet Sequestration Hub, LLC plans to start sampling and characterization of the shallow freshwater aquifer [redacted] before the start of the injection period. The characterization includes not only the complete water analytics shown in Table TM-20, but the isotopic fingerprinting of wells to be reviewed in the future to be used as appropriation tools.

Some of these locations might present mechanical integrity or accessibility issues at the moment of acquiring the sample and those will be reported once the complete assessment is done and sampling protocols are started.

5.1.1 Monitoring location and frequency

Table TM-14 shows the planned location for sampling of the fresh water shallow aquifer and Table TM-15 shows the frequencies proposed.

Table TM-14—Location of the Freshwater Shallow Water Wells Selected for Sampling in the AOR

Well No	Use	County	Latitude	Longitude	Date Completion	Measured Depth (ft)	Aquifer
[redacted]							

Table TM-15—Location and Frequency of Water Sampling and Testing in the Freshwater Shallow Water Wells

Monitoring Location(s)	Monitoring Activity	Target Formation	Pre-Injection	Injection Period
[redacted]				

5.2 USDW wells water sampling and testing

These wells will allow the characterization and fingerprinting of waters in the deepest section of the USDW . The well will monitor water composition changes during injection and post injection periods.

5.2.1 Monitoring location and frequency for water sampling in USDW wells

Table TM-16—Location of USDW Wells to be Drilled for Water Sampling and Testing

Well Name	Latitude	Longitude	Elevation (ft)	Status	Target monitoring Depth TVDSS (ft)	Target Formation
[redacted]						

Table TM-17—Location and Frequency of the Water Sampling and Testing in the USDW Wells

Monitoring Location(s)	Monitoring Activity	Target Formation	Pre-Injection	Injection Period
[redacted]				

Figures TM- 7, TM-8, and TM-9 show the well designs and schematics of the [redacted]

[redacted]

Figure TM-7— [redacted] **Design**

[redacted]

Figure TM-8—[redacted] **Design**

[redacted]

Figure TM-9—[redacted] **Design**

5.3 Above Confining Zone Well water sampling and testing

[redacted] well will be drilled as part of the master monitoring plan. The well will be drilled and perforated in the first permeable zone above the [redacted] confining zone. Pressure and temperature gauges will be tubing deployed to track any changes above the seal that could indicate a potential leak into the USDW. The well will test water quality at the first permeable sand above the [redacted] confining zone and will track potential changes of pressure above that could indicate a leak path. Figure TM-10 shows a diagram and detailed construction of [redacted] well.

The well will be equipped with a U-Tube line that allows to collect samples from the reservoir at the frequency proposed by the project. Those samples will be sent to third party laboratory for the analysis. The description of the system is presented in the QASP document.

[redacted] is located closer to the Bluebonnet CCS 1 injector well to evaluate the effect of the reservoir pressurization at the highest point of pressure and validate the sealing capacity of the upper confining zone. The location was also selected to monitor closely the area in proximity with the town of Winnie and the [redacted]

5.3.1 Monitoring location and frequency for water sampling in Above Confining Zone Well

Table TM-18—Location of the [redacted] Well

Well Name	Latitude	Longitude	Elevation (ft)	Status	Target monitoring interval TVDSS (ft)	Target Formation
[redacted]						

Table TM-19—Location and Frequency of Water Sampling and Testing in [redacted] Well

Monitoring Locations	Monitoring Activity	Target Formation	Pre-injection	Injection Period
[redacted]				

If the downhole gauge stops working between scheduled maintenance events during the injection period, the project might install a temporary downhole gauge with wireline and reduce the frequency of data collection to 1 sample per day or less, depending on the pressure behaviors observed before the failure.

Figure TM-10 shows the well design and schematic of [redacted].

[redacted]

Figure TM-10—Well Design and Schematic for [redacted] Well

5.4 Analytical parameters for water testing in groundwater and above confining zone samples

Table TM-20 identifies the parameters to be tested and monitored and the analytical methods the Bluebonnet Sequestration Hub, LLC proposed as minimum required in the water testing protocol, but not limited to, for groundwater and above confining zone water samples.

[redacted]

Water testing will be performed by personnel of a certified laboratory, following the specific methods approved by EPA or others standard. Operators might audit the procedures and results of the selected laboratory with a third party to improve quality control.

The samples will be analyzed by a third-party laboratory using standardized procedures for gas chromatography, mass spectrometry, detector tubes, and photo ionization. Sampling methods and chain of custody procedures are described in the QASP.

Table TM-20—Summary of Analyses and Methods for Groundwater and ACZ Water Samples Testing

Parameter	Analytical Method
[redacted]	

5.5 Sampling methods for groundwater and above confining zone water samples

Water sampling will be performed by personnel of a certified laboratory, following the specific methods approved by the EPA or other standards. Operators might audit the procedures and results of the selected laboratory with a third party to improve quality control.

5.6 Laboratory to be used/chain of custody procedures

The samples will be analyzed by a third-party laboratory using standardized procedures for gas chromatography, mass spectrometry, detector tubes, and photo ionization. Sampling methods and chain of custody procedures are described in the QASP.

6.0 *Carbon Dioxide Plume and Pressure Front Tracking 40 CFR 146.90(g)*

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

6.1 Indirect methods for CO_2 plume extension and pressure front monitoring

Table TM-21 presents the indirect methods that the Bluebonnet Sequestration Hub, LLC will use to monitor the position of the CO_2 plume and pressure front, including the activities, locations, and frequencies the Bluebonnet Sequestration Hub, LLC will employ.

Table TM-21—Summary of Analyses and Methods for Indirect monitoring of CO_2 Plume Extension and Pressure Front Monitoring

Monitoring Locations	Monitoring Activity	Target Formation	Pre-injection	Injection Period
[redacted]				

6.1.1 Indirect Methods for CO_2 plume extension monitoring details

A multi-scale approach will be employed for plume migration and CO_2 saturation monitoring and potential leak detection with multiple seismic methods.

[redacted]

[redacted]

Figure TM-11—Proposed Geophysical Monitoring Program

6.1.1.1 3D surface seismic baseline survey

A 3D surface seismic baseline survey will be acquired covering the AOR prior to injection. [redacted]

[redacted]

[redacted]

[redacted]

Figure TM-12—Example modeled seismic response from CO_2 saturation at Encanto-1. Outcome from a single test case ([redacted]) shows a significant negative shift in the impedance profile when compared to the brine saturated base case.

6.1.1.2 2D surface seismic base line and time-lapse surveys

[redacted]

[redacted]

6.1.1.3 3D VSP baseline and time-lapse surveys

[redacted]

[redacted]

[redacted]

6.2 Direct Methods for CO_2 Plume Extension and pressure front monitoring.

Table TM-22 presents the direct methods that the Bluebonnet Sequestration Hub, LLC will use to monitor the CO_2 plume extension and pressure front, including the activities, locations, and frequencies.

Table TM-22—Summary of Analyses and Methods for Pressure Front Monitoring

Monitoring Locations	Monitoring Activity	Target Formation	Pre-injection	Injection Period
Direct Monitoring techniques				
[redacted]				

Table TM-23—Summary of Location and Sampling Frequency for Pressure Front Monitoring

Location	Device(s)	Location	Min. Sampling Frequency	Min. Recording Frequency
[redacted]				

6.3 Location selection for the In Zone Monitoring wells

Table TM-24—Location and Depth of In Zone Monitoring Wells

Well Name	Latitude	Longitude	Status	Depth (ft)	Target Formation	Target monitoring interval TVDSS (ft)
[redacted]						

6.3.1 [redacted]

[redacted]

[redacted]

Figure TM-13—Well Design and Schematic for [redacted] Well

6.3.2 [redacted]

[redacted]

[redacted]

[redacted]

The proposed schematic for the wells is presented in Figure TM-14.

[redacted]

Figure TM-14—Well Design and Schematic for [redacted] Well

6.3.3 [redacted]

[redacted]

The proposed schematic for the wells is presented in Figure TM-15 .

[redacted]

Figure TM-15—Well Design and Schematic for [redacted] Well

6.4 Design Bases for Plume and Pressure Front Tracking

In this section, we present forecasted injector bottom-hole pressure, reservoir pressure near the top perforation for the injection well, and the In Zone monitoring wells from year 1 to year 15 of injection. during CO_2 injection period. These predictions were based on our current understanding of the subsurface conditions and are the most likely outcomes of our monitoring program.

Bluebonnet Sequestration Hub LLC will continue to monitor and history match the field values with the numerical simulation model, if the data gathered in the future tracks the forecasted results. Significant deviations from these forecasts will trigger the needs for revisiting subsurface characterization and updating AoR delineation.

Table TM-25—Predicted monitoring well bottom-hole pressure for the injection period

[redacted]

7.0 Surface and Near Surface monitoring [40 CFR 146.90 (h)]

7.1 Soil gas monitoring and isotopic fingerprinting

The Bluebonnet Sequestration Hub, LLC will install soil gas sample stations and collect soil gas samples utilizing methodology developed by researchers at the GCCC. The samples will be analyzed by a certified commercial laboratory to determine gas composition as well as isotopic signatures of carbon and hydrogen elements. This data will be used to inform Process Based Soil Gas Monitoring to monitor for ecological stress and distinguish a leakage signal from natural vadose zone CO_2 providing for attribution at the site. Modeling and additional geochemical data from the subsurface overburden will be used to define diagnostic parameters for attribution in soil gas.

Soil gas assessment will consist of characterization of soil gas CO_2, CH4, O2, and N2 ratios within a process-based framework and collection of additional isotopic parameters for further assessment, if thresholds are ever exceeded (Table TM-27). [redacted], soil gas will be analyzed for CO_2, O2, N2, CH4, C1-C5 hydrocarbons, δ13C and 14C of CO_2, and CH4 and δD of CH4. At the end of characterization period, protocols for detection of leakage signal will be tailored to site base data.

As part of the process for designing and selection of the soil gas station locations, an airborne electromagnetic survey will be conducted over the area of interest. The aerial electromagnetic (EM) data will be used to identify and map the extent of near-surface and surface salinization. This environmental determination will inform additional parameters for groundwater monitoring to complement soil gas as part of the near surface monitoring strategy. This survey will be performed with aircraft mounted sensors that allow it to cover extensive areas of investigation

7.1.1 Sampling location and frequency for soil gas

[redacted]

[redacted]

Figure 1. Schematic of gas sampling station construction showing individual gas wells set at different levels. Not to scale.

Figure TM-16—Schematic of Gas Sampling Station

Table TM-26—Gas Sampling Locations, Frequencies, and Methods

Monitoring Locations	Monitoring Activity	Target Formation	Pre-injection	Injection Period
[redacted]				

7.1.2 Parameters for soil gas analysis

Table TM-27—Soil Gas Analysis Parameters

Soil Gas Parameter	Analysis method
[redacted]	

7.1.3 Sampling soil gas analysis

Sampling will be performed by trained or specialize personnel from the lab at the beginning of the operation, and the field operator will be trained in the process to be able to take samples and monitor gas compositions with handheld devices as routine operation. The samples are taken in specialized bags to collect the gas and will be sent to a third-party laboratory. Calibration of the field equipment will be performed by manufacturer protocol.

7.1.4 Laboratory to be used/chain of custody and analysis procedures

The samples will be analyzed by a third-party laboratory using standardized procedures for gas chromatography, mass spectrometry, detector tubes, and photo ionization. Analytic methods and chain of custody procedures will follow the laboratory protocol.

7.2 CO_2 sensors in injector and monitoring wellheads

The Bluebonnet Sequestration Hub, LLC will install infrared gas detectors close to the wellheads of the injector and monitoring wells. Theses sensors will interface with the surveillance system to set alarms and provide information on potential leaks at the surface. The final selection of the technology will consider the integration of all the sensors and transducers in a unique surveillance system. Calibration and maintenance protocols will be based on the manufacturer specifications and will be performed by specialized professionals. Table TM-28 shows referential technical specifications for the CO_2 leak detector.

Table TM-28—Infrared Gas Detector Parameters

Type of Sensor	[redacted]
Measurement Ranges	
Combustible	
CO_2	
Resolution	
Response Time	
Approval Classification	
Operating Ranges	
Relative Humidity	

Table TM-29—Atmospheric CO_2 Sensor in wellhead

Tool	Pre-Injection	Injection
[redacted]		

7.3 Induced seismicity monitoring

The Bluebonnet Sequestration Hub, LLC will deploy a seismometer monitoring network to determine the locations, magnitudes, and focal mechanisms of the injection-induced seismic events in case they are observed. This information will be used to address public concerns and identify features that may help to evaluate the plume and pressure front behavior.

7.3.1 Monitoring location and frequency for seismicity measurement

Table TM-30—Seismicity Monitoring Tools

Tool	Pre-Injection	Injection
[redacted]		

7.3.2 Traffic light system

While the historical seismicity of the project area indicates no measured earthquakes in the area, the operator intends to maintain a surface array for the duration of the project to ensure the safe operation of both the storage facility and adjacent infrastructure in the area. This seismic monitoring will be conducted with a surface array deployed to ensure detection of events above ML 2.0 with epicentral locations within 5.6 miles of the injection well covering an area of 100 square miles. This areal coverage was determined by referencing the Texas Railroad Commission's historic designation of Seismic Response Areas (SRA). SRAs are areas determined by RRC seismologists for which consistent identification and seismic response approach will be implemented after the occurrence of seismic events with a magnitude of 3.5 or greater (TRRC, January 2022). For example, after a magnitude 5.4 earthquake occurred in December 19, 2022, the RRC designated SRA with a radial area of 100 square miles (TRRC, December 2022). Out of an abundance of caution, the seismic monitoring area for this project is designed to preemptively cover an area equivalent to the RRC's post-event SRA coverage.

If an event is recorded by either the local private array or public national array to have occurred within 5.6 miles of the injection well, the operator would implement its response plan subject to detected earthquake magnitude limits defined below to eliminate or reduce the magnitude and/or frequency of seismic events.

- For events above ML 2.0 within 5.6 miles of the injection well, the operator will closely monitor seismic activity and may implement a pause to operations or continue operations at a reduced rate, should analysis indicate a causal relationship between injection operations and detected seismicity.
- For events above ML 4.0 within 5.6 miles of the injection well, the operator will reduce the injection rate by not less than 50%. A detailed analysis is conducted to determine if a causal relationship exists. Should a causal relationship be determined, a revised injection plan would be developed to reduce or eliminate operationally related seismicity. Such plans are dependent on the pressures and seismicity observed and may include, but not be limited to:
    1. Pausing operations until reservoir pressures fall below a critical limit,
    2. Continuing operations at a reduced rate and/or below a revised maximum operation pressure.
- For events above ML 4.5 within 5.6 miles of the injection well, the operator will stop injection as soon as safely practical. The operator will then immediately inform the regulator of seismic activity and inform them that operations have stopped pending a technical analysis. The operator will initiate an inspection of surface infrastructure for damage that may have resulted from the earthquake. A detailed analysis is conducted to determine if a causal relationship exists between injection operations and observed seismic activity. Should a causal relationship be determined, a revised injection plan would be developed to reduce or eliminate operationally related seismicity before resuming injection operations. Such plans are dependent on the pressures and seismicity observed, and may include, but not be limited to:
    1. Pausing operations until reservoir pressures fall below a critical limit,
    2. Continuing operations at a reduced rate and/or below a revised maximum operation pressure.

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