Underground Injection Control
Carbon Sequestration
Class VI Permit Application

TESTING AND MONITORING PLAN
40 CFR 146.90
Section 8.0

Tallgrass High Plains Carbon Storage, LLC
Western Nebraska Sequestration Hub

January 2025

Prepared by:

Jessica Gregg (Director, Geoscience Compliance)
Tallgrass High Plains Carbon Storage, LLC
370 Van Gordon St
Lakewood, CO 80228

8.0 TESTING AND MONITORING PLAN

WESTERN NEBRASKA SEQUESTRATION HUB

FACILITY INFORMATION

Facility name: Western Nebraska Sequestration Hub
Conestoga I-1

Facility contacts:

Craig Spreadbury | Vice President, Carbon Capture & Storage
Tallgrass High Plains Carbon Storage, LLC
370 Van Gordon St
Lakewood, CO 80228
craig.spreadbury@tallgrass.com

Jessica Gregg | Director, Geoscience Compliance
Tallgrass High Plains Carbon Storage, LLC
370 Van Gordon St
Lakewood, CO 80228
jessica.gregg@tallgrass.com

Well location: Kimball County, Nebraska
[redacted]

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

A	
AoR	Area of Review
ASTM	American Society for Testing Materials
B	
BHL	bottomhole location
C	
CBL	cement bond log
CFR	Code of Federal Regulations
CO_2	carbon dioxide
D	
DTS	distributed temperature sensing
DAS	distributed acoustic sensing
E	
EOS	equation-of-state
EPA	U.S. Environmental Protection Agency
M	
MASIP	maximum allowable surface injection pressure
MIT	mechanical integrity test
MFL	magnetic flux log
N	
NRMS	normalized root mean square
P	
PEM	Petro-elastic modeling
PNL	pulsed neutron log
psi	pounds per square inch
psig	pounds per square inch, gauge
Q	
QASP	Quality Assurance and Surveillance Plan
R	
RCA	routine core analyses
S	
SCAL	special core analyses
SCADA	supervisory control and data acquisition
SP	spontaneous potential log
T	
TCS	triaxial compressive strength
TD	total depth
TEC	tubing encapsulated conductor
TVD	true vertical depth
TVDSS	true vertical depth subsea
U	
UIC	underground injection control
USDW	underground source of drinking water
USIT	ultrasonic imager tool
V	
VDL	variable density log

8.0 TESTING AND MONITORING PLAN [40 CFR 146.90]

This Testing and Monitoring Plan outlines Tallgrass High Plains Carbon Storage, LLC's (High Plains) approach to monitoring the Western Nebraska Sequestration Hub (WNS Hub, the "Project"), ensuring compliance with local, state, and federal regulations, including 40 CFR 146.82(a)(15) and 146.90. The plan is designed to demonstrate that the well is operating as intended, that the carbon dioxide (CO_2) plume and pressure propagation are progressing as expected, and no degradation of underground sources of drinking water (USDWs) occurs. Additionally, the monitoring data collected will be used to validate and refine the geological and dynamic simulation models that predict pressure and CO_2 distribution within the storage zone, supporting Area of Review (AoR) re-evaluations and the non-endangerment demonstration.

This plan incorporates *Section 11—Emergency and Remediation Response Plan* (ERRP), and the results of the testing and monitoring activities described below may trigger actions as outlined in the ERRP.

8.1 Overall Strategy and Approach for Testing and Monitoring

High Plains proposes drilling and completing a carbon sequestration injection well (Conestoga I-1) and monitoring well (Conestoga M-1), located [redacted] ft from the injection well, for the safe sequestration of carbon dioxide (CO_2) in southern Kimball County, Nebraska, [redacted]. High Plains' Juniper M-1 (API No. 49-021-29548) in Laramie County, Wyoming, is utilized as the Project's characterization well. The testing and monitoring plan outlined in this section is designed to meet the requirements of 40 CFR 146.82(a)15 and 146.90 and to provide data to confirm the Project is performing as predicted by the models and that USDWs are not adversely affected. Should deviations from the model predictions be observed, data collected in this plan will be used to update the plan and revise projections accordingly.

The injectate composition will be monitored to confirm its composition remains within the range of expected values and that contaminants such as water and sulfur compounds are absent or within design limits. Operational data, including pressure, temperature, flow rate, and volume (CFR §146.90[b]), will be continuously monitored during the active injection phase and into the post-injection site care (PISC) period. Corrosion levels will be monitored for all types and grades of metal that contact the injectate (CFR§146.90[c]). The groundwater quality of the first permeable zone above the confining zone will be monitored and compared with baseline data (CFR §146.90[d], §146.90[b]). Mechanical integrity testing of the injection well components will be conducted regularly and compared with baseline surveys to identify any areas of concern before they result in potential integrity failures (CFR §146.87[a][4], §146.89, §146.90[e], §146.92[a]). Pressure fall-off testing will be performed to measure any potential reduction in injectivity (CFR §146.90[f]). Direct monitoring of injection zone pressure will be conducted via pressure gauges in the injection zone of the Conestoga I-1 injection well. The lateral extent of the CO_2 plume will be indirectly monitored with periodic two-dimensional (2D) seismic surveys. Near-surface groundwater will be sampled periodically from a well(s) drilled on the injection well pad site, targeting the primary USDW accessed by water supply wells within the AoR.

All gathered surveillance data will be compared to baseline and previous surveillance logs and provide indicators of plume development. The results will then be compared to initial simulations to determine whether modifications to the static and/or dynamic models are warranted (CFR §146.90[g], §146.93[b]) or if leakage mitigation measures need to be initiated. **Table 8.1** summarizes the monitoring program, target, and frequency of data collection.

Table 8.1—Summary of the monitoring program, target, and frequency of data collection.

Regulatory Requirement	Monitoring Type	Monitoring Program	Monitoring Target	Frequency
146.90 (a)	CO_2 Injection Stream Composition	[redacted]		
146.90 (b)	Continuous Recording of Injection Pressure, Rate, and Volume			
146.90 (b)	Well Annulus Pressure Between Tubing and Casing			
146.90 (c)	Corrosion Monitoring			
146.90 (d)	Near-Surface Monitoring			
146.90 (d)	Above Confining Zone Monitoring			
146.90 (e)	Internal and External Mechanical Integrity			
146.90 (e)	Internal and External Mechanical Integrity			
146.90 (e)	Internal and External Mechanical Integrity			
146.90 (f)	Pressure Fall-Off Test			
146.90 (g)(1)	Direct Reservoir Monitoring			
146.90 (g)(2)	Indirect Reservoir Monitoring			

8.1.1 Quality Assurance Procedures

Once the final facility and equipment designs are approved, High Plains will provide an updated Quality Assurance and Surveillance Plan (QASP; *Section 8.11*) for all testing and monitoring activities according to CFR §146.90(k).

8.1.2 Reporting Procedures

High Plains will submit the results of all testing and monitoring activities to the U.S. Environmental Protection Agency (EPA) in compliance with the requirements under 40 CFR §146.91.

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

High Plains will continuously collect samples from the CO_2 injection stream and perform analysis to meet the requirements of 40 CFR §146.90(a). These analyses will provide data representative of the injectate stream's physical and chemical characteristics. The purpose of analyzing the CO_2 stream is to evaluate potential interactions of CO_2 and other components of the injectate. The CO_2 stream must meet High Plains' pipeline specifications and is expected to be approximately 95% CO_2. High Plains will conduct monthly comparisons of this data against baseline, predicted, and average values to detect any significant deviations. The CO_2 will be analyzed for the constituents identified in **Table 8.2** using the methods listed. Sampling frequency will be continuous, with records archived every year.

8.2.1 Sampling Location and Frequency

Following all appropriate QASP requirements, the CO_2 stream samples will be continuously collected from the CO_2 pipeline using a gas chromatograph on the flowline before the injection flowmeter, with records archived yearly. High Plains will compare this data to the baseline, predicted, and average values monthly to determine if any significant deviation from original values has occurred.

8.2.2 Analytical Parameters

High Plains will analyze the CO_2 stream for the constituents identified in **Table 8.2.** If additional lab testing is required, High Plains will select a certified lab and follow all required chain of custody and analysis procedures as outlined in the QASP.

Table 8.2—Summary of analytical parameters for the carbon dioxide stream.

Parameter	Analytical Method(s)
[redacted]	

8.2.3 Sampling Methods

High Plains will continuously analyze samples on-site with calibrated gas chromatographs. If additional lab testing is required, High Plains will select a certified lab and follow all required chain of custody and analysis procedures as outlined in the QASP.

8.2.4 Laboratory to be Used/Chain of Custody and Analysis Procedures

High Plains will analyze samples on-site with calibrated gas chromatographs. If additional lab testing is required, High Plains will select a certified lab and follow all required chain of custody and analysis procedures as outlined in the QASP.

8.3 Continuous Recording of Operational Parameters [40 CFR 146.88(e)(1), 146.89(b) and 146.90(b)]

High Plains will install and operate continuous recording devices to monitor injection pressure, rate, and volume; the pressure on the annulus between the tubing and the long casing string; the annulus fluid volume added; and CO_2 stream temperature, as required at 40 CFR 146.88(e)(1), 146.89(b), and 146.90(b). The owner or operator will report the monthly average, maximum, and minimum values of injection pressure, flow rate, and volume to the UIC Program Director in semi-annual reports as required by CFR 146.91(a)(2).

8.3.1 Monitoring Location and Frequency

High Plains will perform the activities identified in **Table 8.3** to monitor operational parameters and verify the injection well's internal mechanical integrity. All monitoring will occur at the locations and frequencies shown in the table.

Table 8.3—Sampling devices, locations, and frequencies for continuous monitoring.

Parameter	Device(s)	Location	Min. Sampling Frequency	Min. Recording Frequency
Injection Pressure	[redacted]			
Injection Rate				
Injection Volume				
Annular Pressure				
Annulus Fluid Volume				
CO_2 Stream Temperature				

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

8.3.2 Monitoring Details

Injection stream parameters will be monitored initially at the flowline between the supply pipeline and the wellhead for quality, pressure, and temperature. The supervisory control and data acquisition (SCADA) system at the Conestoga I-1 injection site will track injection volume. A pressure gauge will monitor the annular pressure of the Conestoga I-1 injection well at the wellhead, and reservoir pressure monitoring will take place with a downhole pressure gauge in the injection zone. Details on instrumentation, calibration standards, and conversion formulas will be provided as instrumentation details are finalized.

8.4 Corrosion Monitoring

To comply with the 40 CFR 146.90(c) requirements, High Plains will monitor well materials during the operational period for loss of mass, thickness, cracking, pitting, and other signs of corrosion, ensuring that well components maintain the minimum standards for material strength and performance.

The specified composition of the injectate stream is shown in **Table 8.4**. The final injectate stream will have impurities within the limits shown. The injection formation fluids will be considered to determine the appropriate metallurgy for the tubing and long casing string. Additionally, cement and packer fluids resistant to CO_2 corrosion will be used to minimize corrosion in the injection well.

Table 8.4—Composition of the injectate stream.

Constituent	Limit
[redacted]	

High Plains will monitor corrosion coupons and collect samples according to the methods described in the following subsections. This monitoring will occur quarterly, as described in *Section 8.4.1*.

In addition to routine coupon inspection, casing inspection logs, annulus pressure tests, and temperature logs will be run, as outlined in *Section 8.6*.

8.4.1 Monitoring Location and Frequency

To ensure that samples are exposed to representative conditions, corrosion coupons made of the same material as the production casing and injection tubing will be placed upstream of any processing equipment in the CO_2 injection pipeline. The coupons will be removed quarterly by the following dates each year:

- Three months after the start of injection
- Six months after the start of injection
- Nine months after the start of injection
- Twelve months after the start of injection

8.4.2 Sample Description

Table 8.5 includes a list of materials that will be monitored for corrosion. Baseline mass and imagery of all coupon samples will be recorded for comparison with appearance and mass during quarterly checks.

Table 8.5—List of equipment and construction materials.

Equipment Coupon	Material of Construction
Pipeline	[redacted]
Production Casing	
Stainless Production Casing	
Tubing	

8.4.3 Monitoring Details

The corrosion coupons will be removed from the upstream CO_2 pipeline and inspected visually for any signs of corrosion, including pitting. The weight and size of the coupons will be measured each time they are removed. They will be assessed for corrosion using American Society for Testing and Materials (ASTM) standards at a certified laboratory. The corrosion rate will be calculated using a weight loss method, where the rate equals the weight lost during the exposure period divided by the duration of the period. Baseline mass and imagery of all samples will be recorded for comparison with appearance and mass during quarterly checks. Should any deviations in the corrosion rate be identified, the quarterly monitoring will be supplemented with additional samples collected based on forecasted injection volumes.

To meet the 40 CFR §146.90 (c)(1) and (2) requirements, High Plains will also conduct corrosion monitoring of the well's pipeline materials using a corrosion coupon monitoring system. **Table 8.5** lists the materials that will be monitored for corrosion. This process will monitor for loss of mass and thickness, cracking, pitting, and other signs of corrosion to ensure that the pipeline components meet the minimum material strength and performance standards specified in 40 CFR §146.86 (b).

8.5 Above Confining Zone Monitoring

Above confining zone monitoring will be accomplished via the injection well (Conestoga I-1) and a monitoring well (Conestoga M-1), which will be located approximately [redacted] from the injection well, within the predicted extent of the plume. Conestoga I-1 will directly monitor pressure and temperature in the first permeable zone above the confining layer and indirectly monitor CO_2 saturation and temperature anomalies in permeable zones between the confinement zone and near surface. Conestoga M-1 will monitor pressure and temperature directly in the first permeable zone above the confining zone. Additionally, it will directly monitor temperature in permeable zones between the confining zone and near surface. Early detection of CO_2 migration outside the injection zone would allow time for mitigation measures to be implemented before it reaches a USDW.

The monitoring well network is provided in **Figure 8.1** showing the Conestoga I-1, Conestoga M-1 monitoring well, and the maximum plume extent (the AoR).

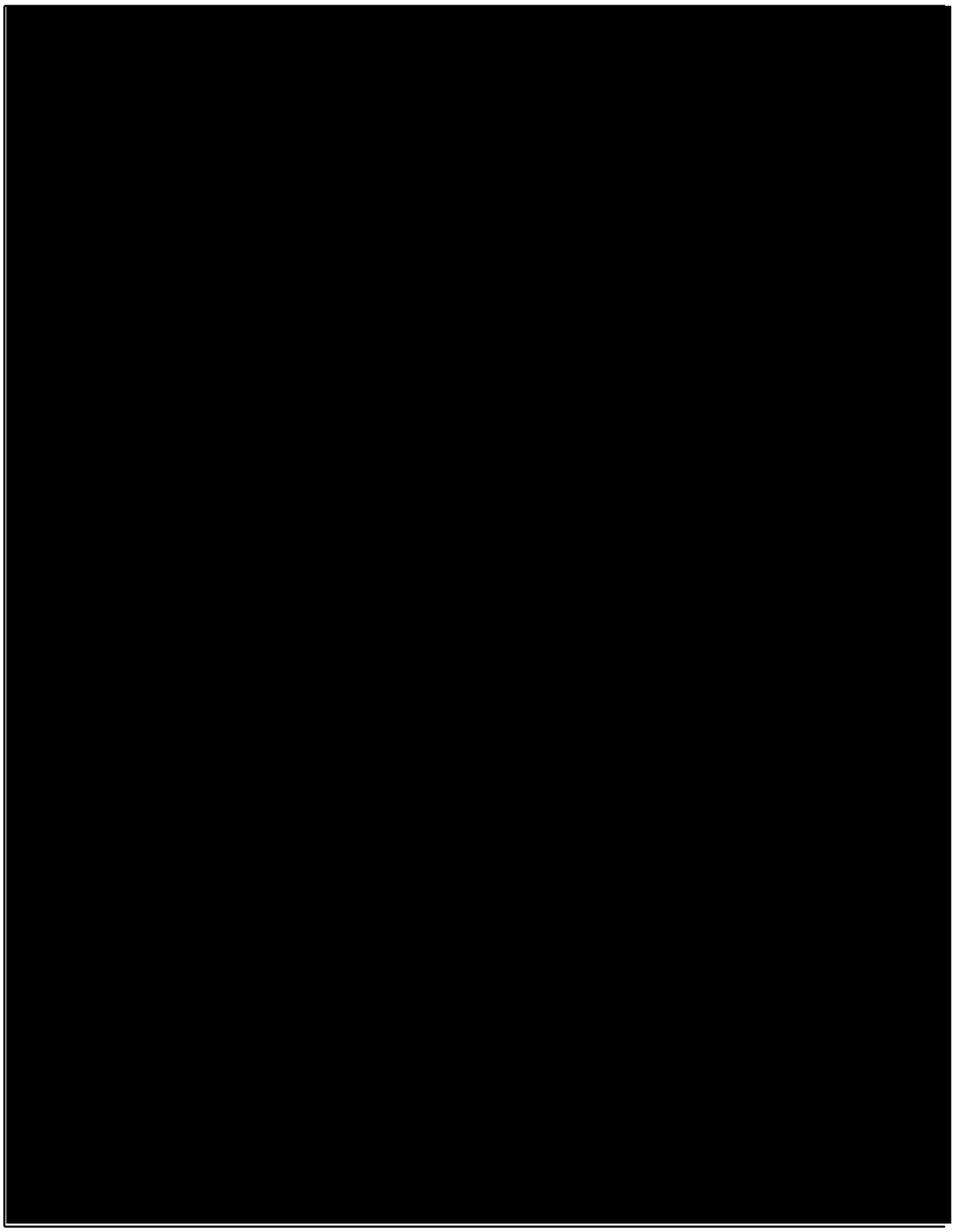

Figure 8.1—Monitoring well network.

8.5.1 Monitoring Location and Frequency

The methods described in this section include continuous monitoring and annual data collection events. As described in the QASP, pressure and temperature gauges will be installed on the tubing-encapsulated conductor (TEC) line outside the production casing. These gauges will continuously monitor for changes in pressure and/or temperature that would indicate the movement of formation fluids outside of the upper confining zone. The Conestoga I-1 gauges will be set in the injection zone (Lyons) and first permeable zone above the confining layer. The Conestoga M-1 will have a gauge in the first permeable zone above the confining layer.

A Distributed Temperature Sensing (DTS) and Distributed Acoustic Sensing (DAS) fiber optics system will be permanently installed behind the casing in the Conestoga M-1 to continuously monitor all zones above the upper confining zone. Due to the high-resolution nature of these technologies, this monitoring method will inform High Plains of any carbon dioxide or saline formation fluids migrating out of the injection zone.

A temperature log will be run annually in the Conestoga I-1 to monitor for potential leak indicators. The well will be shut in until the temperatures have stabilized, approximately 36 hours before running the temperature log. The temperature profile will be compared to previous surveys, and any anomalies will be investigated.

[redacted] to monitor for changes in the near-wellbore environment that could indicate out-of-zone migration of CO_2 based on observed changes in saturation from previous surveys (including a baseline survey).

Table 8.6 summarizes the methods and details of the above confining zone monitoring plan.

Table 8.6—Monitoring of groundwater quality and geochemical changes above the confining zone.

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
USDWs	[redacted]			
First permeable zone above the confining layer				
USDWs				

8.6 External Mechanical Integrity Testing

High Plains will conduct at least one of the tests presented in **Table 8.7** periodically, as listed, during the injection phase to verify mechanical integrity as required in §146.89(c) and §146.90.

Table 8.7—Mechanical integrity tests.

Test Description	Location	Frequency
[redacted]		

8.6.1 Testing Location and Frequency

Mechanical integrity tests (MITs) will be conducted annually at the injection well. Testing will occur annually within 45 days prior to the anniversary date of injection authorization and will continue until the well is abandoned.

8.6.2 Testing Details

The annular pressure test is designed to verify the mechanical integrity of the casing, tubing, and packer. This test involves pressurizing the annulus to a minimum of 500 psi or to the permitted maximum allowable surface injection pressure (MASIP), whichever is lower. Once the test begins, a block valve is used to isolate the test pressure source from the test pressure gauge, and all ports into the casing annulus will be closed except the one monitored by the gauge. Test pressure will be monitored and recorded for at least 30 minutes using a pressure gauge sensitive enough to detect a 10% loss. A lack of mechanical integrity is indicated if the test pressure drops by more than 10% within the 30-minute test period.

The pressure of the annulus between the long-string casing and the tubing will be continuously monitored. A significant change in the pressure may indicate a leak.

A temperature log will be run annually in the Conestoga I-1, as discussed in *Section 8.5.1*, to ensure no significant fluid movement into an underground source of drinking water through vertical channels adjacent to the injection wellbore. The well will be shut in until the temperatures have stabilized, approximately 36 hours before running the temperature log. The temperature profile will be compared to previous surveys, and any anomalies will be investigated.

[redacted]

8.7 Pressure Fall-Off Testing

High Plains will perform pressure fall-off tests during the injection phase, as described in the subsequent text, to meet the requirements of 40 CFR 146.90(f).

A baseline pressure fall-off test on Conestoga I-1 will be conducted prior to commencing injection and every five years thereafter to estimate injectivity and any change to the near wellbore environment.

The time-lapse pressure fall-off tests will provide information regarding changes in reservoir pressure and injectivity by quantifying near-wellbore conditions that may hinder injection rates.

Two bottomhole pressure (BHP) gauges (primary and backup) will continuously monitor pressure with the well shut in. Monitoring will continue until radial flow conditions are observed on a semi-log plot of pressure versus time. The results will be submitted to the administrator within 30 days of testing.

8.7.1 Testing Location and Frequency

High Plains will perform a pressure fall-off test before the start of the injection phase and then every five years until the well is no longer used for injection and is ultimately abandoned or is converted to a monitoring well.

8.7.2 Testing Details

The data gathered from these tests will be used to monitor any changes in the permeability of the injection zone in the near wellbore environment that may impact injectivity. The pressure fall-off tests can also provide an additional indicator of injection zone pressure.

Two BHP gauges will also be used, as described in *Section 8.7*.

8.8 Carbon Dioxide Plume and Pressure Front Tracking

Per 40 CFR 146.90 (g), High Plains will use direct and indirect methods to track the extent of the CO_2 plume in the subsurface and monitor injection zone pressure during the operation period. Conestoga I-1 will be used to directly monitor pressure and plume growth within the AoR, and time-lapse 2D seismic will indirectly monitor plume growth.

8.8.1 Plume Monitoring Location and Frequency

[redacted]

Table 8.8 presents the methods that High Plains will use to monitor the position of the CO_2 plume over time, including the activities, locations, and frequencies that will be employed. Quality assurance procedures for these methods are presented in the QASP (*Section 8.11*).

Table 8.8—Plume monitoring activities.

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
DIRECT PLUME MONITORING				
[redacted]				
INDIRECT PLUME MONITORING				
[redacted]				

8.8.2 Plume Monitoring Details

Temperature and pressure gauges placed via the TEC line in the injection zone of the Conestoga I-1 will directly monitor the CO_2 plume. Measured changes in temperature and pressure within the injection zone enable the validation and calibration of the plume model by comparing observed data with predicted outcomes, while facilitating the tuning of future model runs.

[redacted]

[redacted]

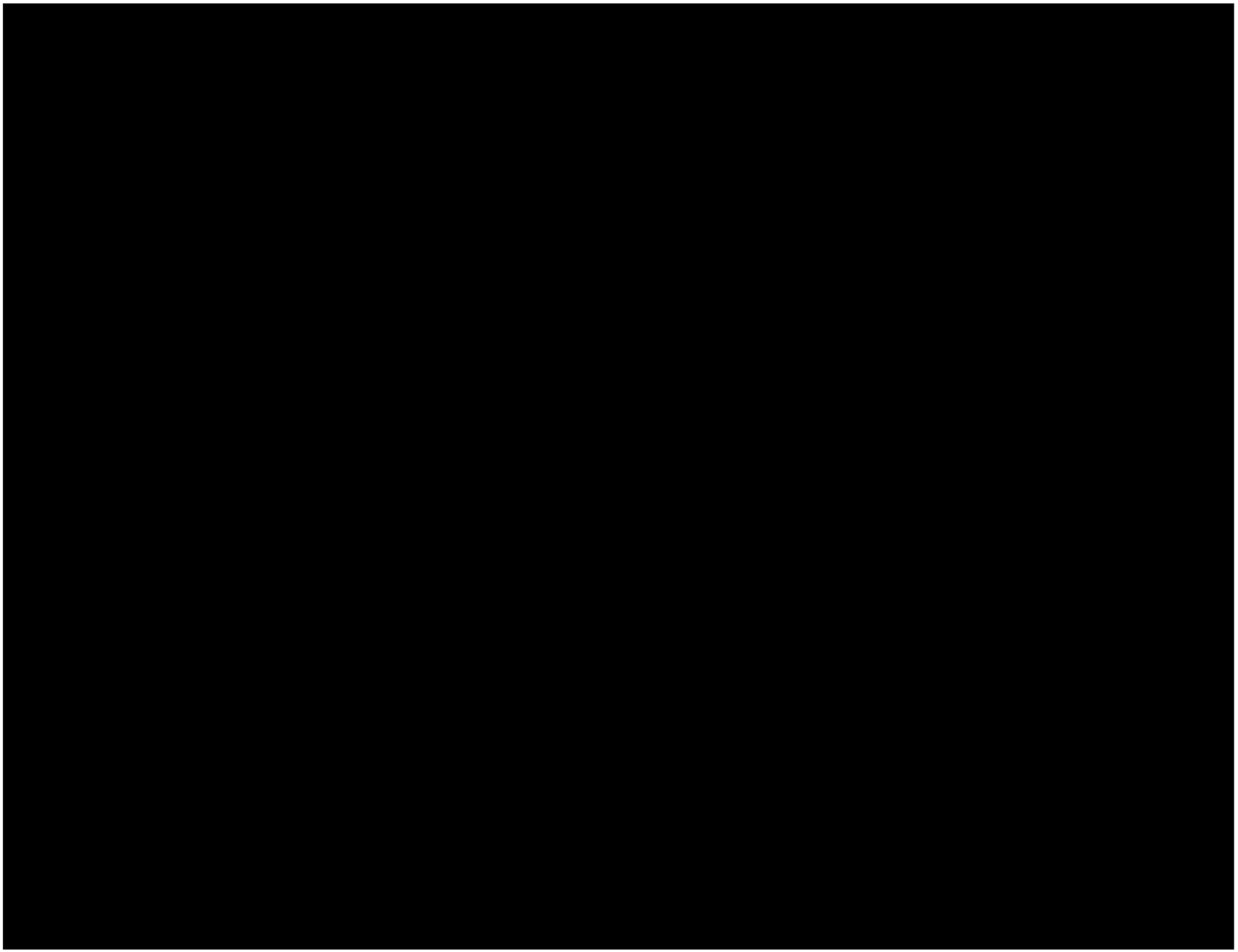

Figure 8.2—Approximate 2D seismic survey placement for plume monitoring.

8.8.3 Pressure-Front Monitoring Location and Frequency

While the Project is not anticipated to generate a critical pressure front—a zone where there is a pressure differential sufficient to cause the movement of injected fluids or formation fluids into a USDW—reservoir pressure will be continuously and directly monitored by pressure gauges placed via the TEC line in the injection zone of the Conestoga I-1.

Table 8.9 presents the methods that High Plains will use to monitor the pressures over time, including the activities, locations, and frequencies High Plains will employ.

Quality assurance procedures for these methods are presented in the QASP (*Section 8.11*).

Table 8.9—Reservoir pressure monitoring activities.

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
DIRECT PRESSURE-FRONT MONITORING				
Lyons Formation	Pressure Gauges	Conestoga I-1	Wellbore	Continuously

8.8.4 Pressure-Front Monitoring Details

Pressure gauges placed via the TEC line in the injection zone of the Conestoga I-1 will directly [redacted]

8.9 Soil Gas Monitoring/Other Testing and Monitoring

In addition to the CO_2 injector and deep monitoring well, High Plains proposes to conduct near-surface monitoring of utilized USDWs within the Project's AoR. A groundwater well [redacted] well, to facilitate fluid sampling from the primary USDW currently used for private and public purposes.

Baseline sampling and testing will be conducted prior to starting injection to establish the current levels of CO_2 and other critical compositional parameters in the groundwater. **Table 8.10** outlines the minimum parameters targeted for baseline testing.

After injection begins, groundwater will be sampled and tested annually and compared to baseline results to identify anomalies that may indicate the migration of non-native fluids associated with the Project. This sampling frequency will continue through PISC until the CO_2 plume has stabilized and the site is closed. If any monitoring method at the project site indicates an increase in the risk for out-of-zone migration of injection or reservoir fluids, the UIC Program Director can increase the frequency of groundwater sampling as necessary.

8.10 Testing and Monitoring Plan Review and Updates

This testing and monitoring plan will be reviewed and updated at least once every five years. High Plains will incorporate data collected as part of this plan and update the reservoir model accordingly. High Plains will submit an amended plan, if needed, or demonstrate that no amendments are needed.

Table 8.10—Summary of baseline analytical and field parameters for fluid sampling of the primary USDW.

Parameters	Analytical Methods	Detection Limit/Range	Typical Precisions	QC Requirements
[redacted]				

8.11 Quality Assurance and Surveillance Plan

The Quality Assurance and Surveillance Plan is provided in the standalone document **8.11_QASP_WNSHub_Conestoga_2024-08-30.pdf**.