ATTACHMENT C: TESTING AND MONITORING PLAN
40 CFR 146.90

CTV III

Facility Information

Facility Name: CTV III

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Well location: [redacted]

This Testing and Monitoring Plan describes how CTV will monitor the project site pursuant to 40 CFR 146.90. The monitoring data will be used to demonstrate that the wells are operating as planned, the carbon dioxide plume and pressure front are moving as predicted, and that there is no endangerment to USDWs. In addition, the monitoring data will be used to validate and adjust the computational model used to predict the distribution of the CO_2 within the storage zone, supporting AoR re-evaluations 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.

Quality assurance procedures

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

Reporting procedures

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

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

CTV 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). Samples will be collected and analyzed quarterly, starting three months after the start of injection and every three months thereafter.

CTV is evaluating several sources of CO_2 as injectate for the project. Notification will be sent to the EPA prior to switching or adding CO_2 sources, at which time the sampling procedures can be reassessed.

Sampling location and frequency

CO_2 injectate samples will be taken between the final compression stage and the wellhead. Sampling will take place three months after the date of authorization of injection and every three months thereafter.

CTV will increase the frequency and collect additional samples if the following occurs:

1. Significant changes in the chemical or physical characteristics of the CO_2 injectate, such as a change in the CO_2 injectate source; and

2. Facility or injector downtime is greater than thirty days.

Analytical parameters

CTV will analyze the water content and injectate the constituents identified in Table 1 using the methods listed. An equivalent method may be employed with the prior approval of the UIC Program Director.

Table 1. Summary of analytical parameters for CO_2 stream.

Parameter	Analytical Method(s)
Oxygen, Argon and Hydrogen	ISBT 4.0 (GC/DID) GC/TCD
Nitrogen	ISBT 4.0 (GC/DID) GC/TCD
Carbon Monoxide	ISBT 5.0 (Colorimetric) ISBT 4.0 (GC/DID)
Total Hydrocarbons	ISBT 10.0 THA (FID)
Ammonia	ISBT 6.0 (DT)
Ethanol	ISBT 11.0 (GC/FID)
Oxides of Nitrogen	ISBT 7.0 Colorimetric
Methane	ISBT 10.1 (FID)
Hydrogen Sulfide and Sulfur Dioxide	ISBT 14.0 (GC/SCD)
CO_2 purity	ISBT 2.0 Caustic absorption Zahm-Nagel ALI method SAM 4.1 subtraction method (GC/DID) GC/TCD
δ13C	Isotope ratio mass spectrometry

Sampling methods

CO_2 stream sampling will occur in the last compressor station prior to being sent to the injector. A sampling station will be installed to facilitate collection of samples into a container. Sample containers will have a chain of custody form and will be labeled appropriately.

Laboratory to be used/chain of custody and analysis procedures

Samples will be sent to, and analysis conducted by is a state certified laboratory. The current plan is to use Eurofins TestAmerica (Eurofins) at 880 Riverside Parkway in Sacramento, CA. The laboratory has all the necessary equipment, experience, and certifications to complete the analysis. The detection limit and precision can be found in the QASP, Table 3.

Eurofins has a chain of custody procedure that includes the following.

1. Sample date
2. Sample description
3. Sample type
4. Relinquished by and received by signature
5. Sampler name
6. Location information

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

CTV 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; the annulus fluid volume added; and the temperature of the CO_2 stream, as required by 40 CFR 146.88(e)(1), 146.89(b), and 146.90(b).

Monitoring location and frequency

CTV will perform the activities identified in Table 2 to monitor operational parameters and verify internal mechanical integrity of the injection well. All monitoring will take place at the locations and frequencies shown in the table.

Monitoring for the parameters, except for annulus fluid volume, will be continuous with a 10 second sampling and 30 second recording frequency for both active and shut-in periods. This will be adequate to monitor for changes in the wellbore and the reservoir.

Table 2. Sampling devices, locations, and frequencies for continuous monitoring.

Parameter	Device(s)	Location	Min. Sampling Frequency	Min. Recording Frequency
Injection pressure	Pressure Gauge	Surface and Downhole	10 seconds	30 seconds
Injection rate	Flowmeter	Surface	10 seconds	30 seconds
Injection volume	Calculated	Surface	10 seconds	30 seconds
Annular pressure	Pressure Gauge	Surface	10 seconds	30 seconds
Annulus fluid volume		Surface	4 hours	24 hours
Temperature	Temperature Gauge	Surface and Downhole	10 seconds	30 seconds
Temperature	DTS	Along wellbore to packer	10 seconds	30 seconds

Notes:

- 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 to digital format (such as a computer hard drive). For example, the data from the injection pressure transducer might be recorded to a hard drive once every minute.

Monitoring Details

Injection Rate and Pressure Monitoring

Injection pressure (gauge), temperature and flow rate (flow meter) will be continuously monitored and recorded by the CTV Central Command Facility (CCF). Injection rate and pressure

limitations will be implemented to ensure adherence to the maximum allowable bottomhole injection pressure of 90% of the injection zone's fracture pressure. Pressure and temperature gauges will be calibrated as shown in QASP Table 6.

Calculation of Injection Volumes

The volume of CO_2 injected into [redacted] will be calculated from the injection flow rate and CO2 density. Density of CO_2 injected into [redacted] will be calculated using PVTP, a fluid thermodynamics package, developed by Petroleum Experts Ltd. PVTP is an industry standard software package that has been used extensively in CO_2 EOR applications to accurately model and match CO_2 PVT properties over a wide range of temperatures and pressures.

Annular Pressure Monitoring

Annulus pressure is monitored continuously (every 10 seconds) with a surface pressure sensor to monitor for integrity of the casing, packer, and tubing. The annulus will be filled with a non-corrosive and incompressible aqueous packer fluid. Deviations in the annular pressure above certain thresholds may indicate a well integrity issue that will be investigated. Thresholds and alarms will be defined during pre-operational testing.

The surface pressure that will be maintained on the casing-tubing annulus for each injector is listed in Table 3 based on starting and ending injection conditions. The minimum surface pressure is 100 psi to ensure that any drop in pressure or annular fluid level is identified with the SCADA alarming system. The pressures are also found in the Appendix: Operating Procedure document with additional context.

Table 3. Injector Annulus Pressure Limits.

Well Name	Min Pressure (psi)	Max Pressure (psi)
C1	100	315
C2	100	605
E1	100	216
E2	100	396
W1	100	210
W2	100	449

Injection Rate

The injection rate will be monitored with a Coriolis flowmeter. The meter will be calibrated for the expected flow rate range using accepted standards and will be accurate to within 0.1 percent.

Corrosion Monitoring

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

Monitoring location and frequency

Monitoring will be conducted quarterly during the injection period, starting three months after injection begins and quarterly thereafter. Monitoring results will be documented and submitted to the EPA as per 40 CFR 146.91 (a)(7). CTV will continually update the corrosion monitoring plan as data is acquired.

Sample description

Samples of the materials used in the construction of the surface flowline equipment, wellheads, and injection and monitoring well tubulars that are exposed to CO_2 injectate will be monitored for corrosion using corrosion coupons. Representative materials (Table 3) will be weighed, measured, and photographed prior to installation. General construction materials for pipeline, tubing and wellhead are shown in Table 4. Updated materials will be provided prior to injection as part of pre-operational testing.

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

Equipment Coupon	Material of Construction
Pipeline	Carbon Steel
Casing (flow-wetted)	Chrome Alloy
Tubing	Chrome Alloy
Wellhead	Chrome Alloy

Monitoring details

The corrosion coupons will be located in the pipeline that feeds CO_2 injectate to the injectors. Quarterly the coupons will be sent to a lab and photographed, measured, visually inspected, and weighed to a resolution of 0.1 milligram. The samples will be handled and assessed in accordance with ASTM G1-03.

A detected corrosion rate of greater than 0.3 mils/year will initiate consultation with the EPA. In addition, a casing inspection log may be run to assess the thickness and quality of the casing if the corrosion rate exceeds 0.3 mils/year.

Above Confining Zone Monitoring

CTV 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). Monitoring above the confining zone will include the following:

1. Undifferentiated non-marine- lowermost USDW will be monitored between approximately [redacted] feet MD in the USDW monitoring wells.
2. [redacted].

Monitoring location and frequency

Table 4 shows the planned monitoring methods, locations, and frequencies for ground water quality and geochemical monitoring above the confining zone. Figure 1 shows the location for the monitoring well locations with respect to the AoR. The wells are located within the project boundary, and CTV has obtained surface access for the duration of the project.

Undifferentiated Non-Marine

CTV will monitor the lowermost USDW in the undifferentiated non-marine sediments. Monitoring will include pressure, temperature, and fluid sampling. Leakage to the lowermost USDW would increase the aquifer pressure and change the composition of the formation water (increased CO_2 concentration). Based on having groundwater less than 10,000 ppm TDS, the proposed monitoring zone is a USDW. However, the water supply wells in the AoR are completed at much shallower depths that are above the base of fresh water, which is at about 1,000 ft MD. Monitoring of the lowermost USDW is more protective than monitoring the freshwater aquifers because impacts would occur in the lowermost USDW before the freshwater aquifers.

The locations of groundwater monitoring wells are often based on the local groundwater gradient. There are very few groundwater supply wells in this area because there is a plentiful supply of surface water. Therefore, groundwater gradient maps don't show any water level elevations this area. Thus, groundwater gradients are not expected to be significant due to the lack of pumping. The locations of the two monitoring wells are planned on opposite sides of the CO_2 plume to the northeast and southwest within reasonable proximity to the injection wells and well identified as requiring a corrective action plan.

Prior to injection, an updated baseline analysis will be completed for the USDW monitoring well. Future results will be compared against these baseline results for significant changes or anomalies. In particular, pH will be monitored as a key indicator of CO_2 presence.

Additional groundwater monitoring wells will be drilled to assess and monitor the lowermost USDW if the following occurs:

1. [redacted].
2. Lowermost USDW aquifer pressure or composition changes due to [redacted].

[redacted] Formation

[redacted]. This is the first porous interval above the sequestration reservoir.

[redacted].

Prior to injection, baseline water analysis will be acquired for [redacted] monitoring zone.

Table 5. Monitoring of ground water quality and geochemical changes above the confining zone.

Target Formation	Monitoring Activity	Monitoring Location(s)	Frequency	Depth
Undifferentiated Non-marine	Fluid Sampling	USDW Monitoring Well	Quarterly	[redacted] MD/TVD
	Pressure/Temperature	USDW Monitoring Well	Continuously	
[redacted]	Pressure/Temperature	[redacted]	Continuously	[redacted] MD/TVD
	Fluid Sampling	[redacted]	Quarterly	

[redacted]

Analytical parameters

Table 6 identifies the parameters to be monitored and the analytical methods CTV will use. Detection limits and precision are shown in QASP Table 3.

Table 6. Summary of analytical and field parameters for water samples from the USDW monitoring well and [redacted] monitoring well.

Parameters	Analytical Methods
Undifferentiated Non-marine - Lowermost USDW	
Cations (Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Se, Zn, Tl)	ICP-MS EPA Method 6020
Cations (Ca, Fe, K, Mg, Na, Si)	ICP-OES EPA Method 6010B
Anions (Br, Cl, F, NO3, SO4)	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
δ13C	Isotope ratio mass spectrometry
Hydrogen Sulfide	ISBT 14.0 (GC/SCD)
Oxygen, Argon and Hydrogen	ISBT 4.0 (GC/DID) GC/TCD
Total Dissolved Solids	Gravimetry; Method 2540 C
Alkalinity	Method 2320B
pH (field)	EPA 150.1
Specific Conductance (field)	SM 2510 B
Temperature (field)	Thermocouple

Sampling methods

Samples will be collected using the following procedures:

1. Depth and elevation measurements for water level taken.
2. Wells will be purged such that existing water in the well is removed and fresh formation water is sampled.
3. Samples collected by lowering cleaned equipment downhole. Field measurements taken for pH, temperature, conductance, and dissolved oxygen.
4. Samples preserved and sent to lab as per chain of custody procedure.
5. Closure of well.

Laboratory to be used/chain of custody procedures

Samples will be sent to, and analysis conducted by is a state certified laboratory. The current plan is to use Eurofins TestAmerica (Eurofins) at 880 Riverside Parkway in Sacramento, CA. The

laboratory has all the necessary equipment, experience, and certifications to complete the analysis. The detection limit and precision can be found in the QASP, Table 3.

Eurofins has a chain of custody procedure that includes the following.

1. Sample date
2. Sample description
3. Sample type
4. Relinquished by and received by signature
5. Sampler name
6. Location information

Mechanical Integrity Testing

CTV will conduct at least one test periodically during the injection phase to verify external mechanical integrity as required at 146.89(c) and 146.90. MITs on the injectors and [redacted] monitoring wells will be performed annually, within 30 days of the commencement of the injection date, by one of two methods in Table 6. If CTV elects to conduct an alternate MIT, notification that includes the test and a description will be sent to the EPA for approval.

Testing location and frequency

Table 7. MITs.

Test Description	Location
Temperature (DTS)	Along wellbore via DTS
Temperature Log	Along wellbore via wireline well log

Distributed Temperature Sensing (DTS)

DTS is a fiber optic continuous temperature monitoring system that will measure the injector and monitoring wells annular temperature along the tubing. This will be used to assess the mechanical integrity of the well.

The following is procedures to utilize DTS for mechanical integrity analysis for an injector:

1. Establish baseline temperature profile that defines the natural gradient along the well.

2. During injection, record the temperature profile for 6 hours prior to shutting in the well. Stop injection and record the temperature for sufficient time to allow cooling.

3. Start injection and record the temperature profile for 6 hours.

4. Compare the baseline analysis to the time-lapse data for assessment of temperature anomalies that may indicate a well failure.

Temperature Logging Testing details

CTV will follow the following procedures for MIT temperature logging:

1. Stabilize injection for 24 hours prior to running the temperature log. If possible, the wireline speed will be limited to 20 feet per minute or less. The temperature sensor should be located as close to the bottom of the tool string as possible (logging downhole).

2. Run a temperature survey from 200 feet above [redacted] to the deepest point reachable in the well, while injecting at a rate that allows for safe operations.

3. Shut-in well and run multiple temperature surveys with 4 hours between runs.

4. Assess the acquired time lapse temperature profiles. As the well cools, the temperature profile is compared to the baseline. External integrity issues present themselves anomalies when compared to the baseline.

5. Evaluate data to determine if additional passes are needed for interpretation. Should CO_2 migration be interpreted in the topmost section of the log, additional logging runs over a higher interval will be required to find the top of migration.

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

CTV will perform pressure fall-off tests during the injection phase every five years as described below to meet the requirements of 40 CFR 146.90(f).

Testing location and frequency

The main benefit of pressure fall-off testing is to assess injectivity, reservoir flow boundary distances and reservoir pressures. The fall-off test will be done on the two injectors every five years.

Testing details

The following procedure will be followed:

1. Injection rate will be held constant prior to shut in. The injection rate will be high enough to produce a pressure buildup that will result in valid test data. The maximum operating pressure will not be exceeded.

2. The pressure falloff analysis will use several months of preceding injection data.

3. The test well should be shut-in at the wellhead to minimize wellbore storage and after-flow.

4. Upon shutting in the injector, surface and bottom-hole pressure and temperature measurements will be taken continuously every ten seconds. If there are offset injectors, rates will be held constant and recorded during the test.

5. The fall-off portion of the test will be conducted for a length of time sufficient that the pressure is no longer influenced by wellbore storage or skin.

6. Maintain accurate rate records for the test well and any offset wells completed in the same injection interval.

7. A report containing the pressure falloff data and interpretation of the reservoir pressure will be submitted to the EPA within 90 days of the test.

Pressure sensors used for this test will be the wellhead gauges and a downhole gauge for the pressure falloff test. Each gauge will meet or exceed ASME B 40.1 Class 2A that provides 0.5% accuracy. CTV will refer to EPA Region 9 UIC Pressure Falloff Requirements for additional procedures such as planning and evaluation.

Carbon Dioxide Plume and Pressure Front Tracking

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

Plume monitoring location and frequency

Table 6 presents the methods that CTV will use to monitor the position of the CO_2 plume, including the activities, locations, and frequencies. The parameters to be analyzed as part of fluid sampling in the injection zone and associated analytical methods are presented in Table 7. Quality assurance procedures for these methods are presented in Section B – Data Generation and Acquisition of the QASP.

Figure 2 shows the location of the wells that will monitor the CO_2 plume directly in [redacted]. These wells will actively monitor the development of the CO_2 plume upon the initiation of injection. If the plume development is not consistent with computation modeling

results, CTV will assess whether additional monitoring of the plume is necessary. Determination for plume monitoring changes will be made in consultation with the UIC Program Director and would trigger an AoR reevaluation, per the AoR and Corrective Action Plan.

[redacted]

Plume monitoring details

Fluid sampling (quarterly), pressure and temperature monitoring will be conducted for direct measurement of the plume. This will provide data on plume location but more importantly, the CO_2 content/concentration of the plume. The parameters to be analyzed for fluid sampling are presented in Table 9.

The DTS from the two monitoring wells will provide continuous temperature from packer to surface.

As discussed in the AoR and Corrective Action Plan, 83% of the post-shut-in injected CO_2 will remain as super-critical. Fluid samples will be taken, and CTV expects that there will be minor changes to pH, dissolved CO_2, and water density.

Indirect plume monitoring will include pulse neutron logs (PNL) to understand CO_2 saturation changes through time. Prior to injection, a pulse neutron log will be run as a baseline. A PNL will be run on the monitoring wells every two years during the injection phase.

Table 8. Plume monitoring activities.

DIRECT PLUME MONITORING				**Depths**
[redacted]	Fluid Sampling	[redacted]	Quarterly	[redacted]
[redacted]	Pressure and temperature	[redacted]	Continuously	
INDIRECT PLUME MONITORING				
[redacted]	Pulse Neutron Logging	[redacted]	Every two years from start of injection.	

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

Parameters	**Analytical Methods**
[redacted]	
Cations (Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Se, ZN, Tl)	ICP-MS EPA Method 6020
Cations (Ca, Fe, K, Mg, Na, Si)	ICP-OES EPA Method 6010B
Anions (Br, Cl, F, NO3, SO4)	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration ASTM D513-11
δ13C	Isotope ratio mass spectrometry
Hydrogen Sulfide	ISBT 14.0 (GC/SCD)
Oxygen, Argon and Hydrogen	ISBT 4.0 (GC/DID) GC/TCD
Total Dissolved Solids	Gravimetry; Method 2540 C
Alkalinity	Method 2320B
pH (field)	EPA 150.1
Specific Conductance (field)	SM 2510 B
Temperature (field)	Thermocouple

Pressure-front monitoring location and frequency

Table 10 presents the methods that CTV will use to monitor the position of the pressure front, including the activities, locations, and frequencies CTV will employ. Quality assurance procedures for these methods are presented in Section B – Data Generation and Acquisition of the QASP.

The pressure increase front defining the AoR boundary reaches its maximum extent 14 years into injection in the project. Pressure front will be monitored with 2 wells within the CO_2 plume, and an additional well to the East of the project outside of the AoR in order to track the pressure change in the reservoir and ensure it is similar to that predicted by computational modeling. Monitoring well locations with respect to plume development through time are shown in Figure 3.

[redacted]

Monitoring well pressure development based on computational is modeled in Figure 4. Note that the reservoir pressure after five years is stable. This is due to the high amount of CO_2 that remains super-critical and low quantity of CO_2 that will be soluble in either the oil or water phases.

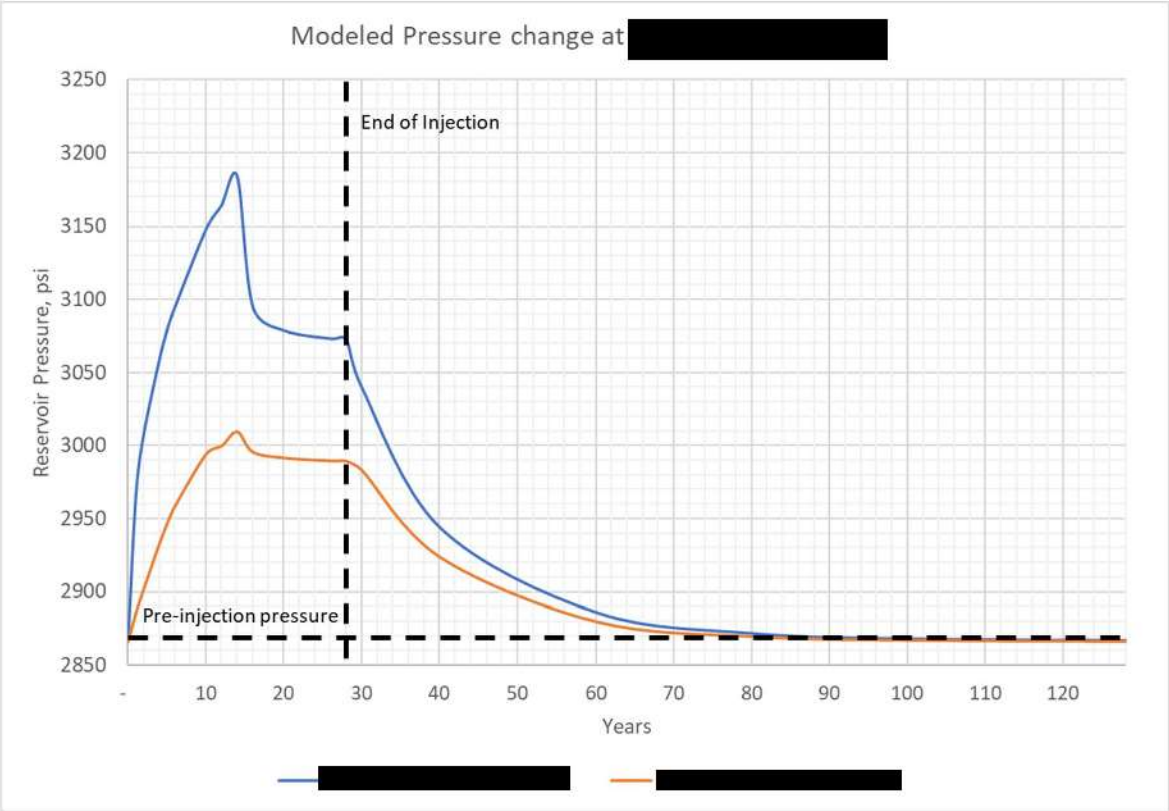

Figure 4: Modeled pressure at [redacted] during the injection period and 100 years post injection

Pressure-front monitoring details

Direct pressure monitoring of the plume will be achieved through installation of pressure gauges in monitoring wells [redacted] CTV will compare the pressure and rate increase from the computational model to the monitoring data to validate computational modeling results and identify operational discrepancies, ensuring suitable definition of the AoR and plume throughout the life of the project.

Table 10. Pressure-front monitoring activities.

Target Formation	Monitoring Activity	Monitoring Location(s)	Frequency
DIRECT PRESSURE-FRONT MONITORING			
[redacted]	Pressure and temperature monitoring	[redacted]	Continuous
INDIRECT PRESSURE-FRONT MONITORING			
All formations	Seismicity	AoR	Continuous

Induced Seismicity and Fault Monitoring

CTV will monitor seismicity with surface and shallow borehole seismometers in the AoR. The seismometers will be able to detect events with a magnitude 0 to 0.5 and will be installed one year prior to injection to provide baseline seismicity. In addition, CTV will monitor the Northern California Earthquake Data Center (NCEDC) network for seismic events. Historical seismicity within the area will be accounted for in the baseline assessment.

Appendix: Quality Assurance and Surveillance Plan

See Quality Assurance and Surveillance Plan

TESTING AND MONITORING PLAN - FIGURES

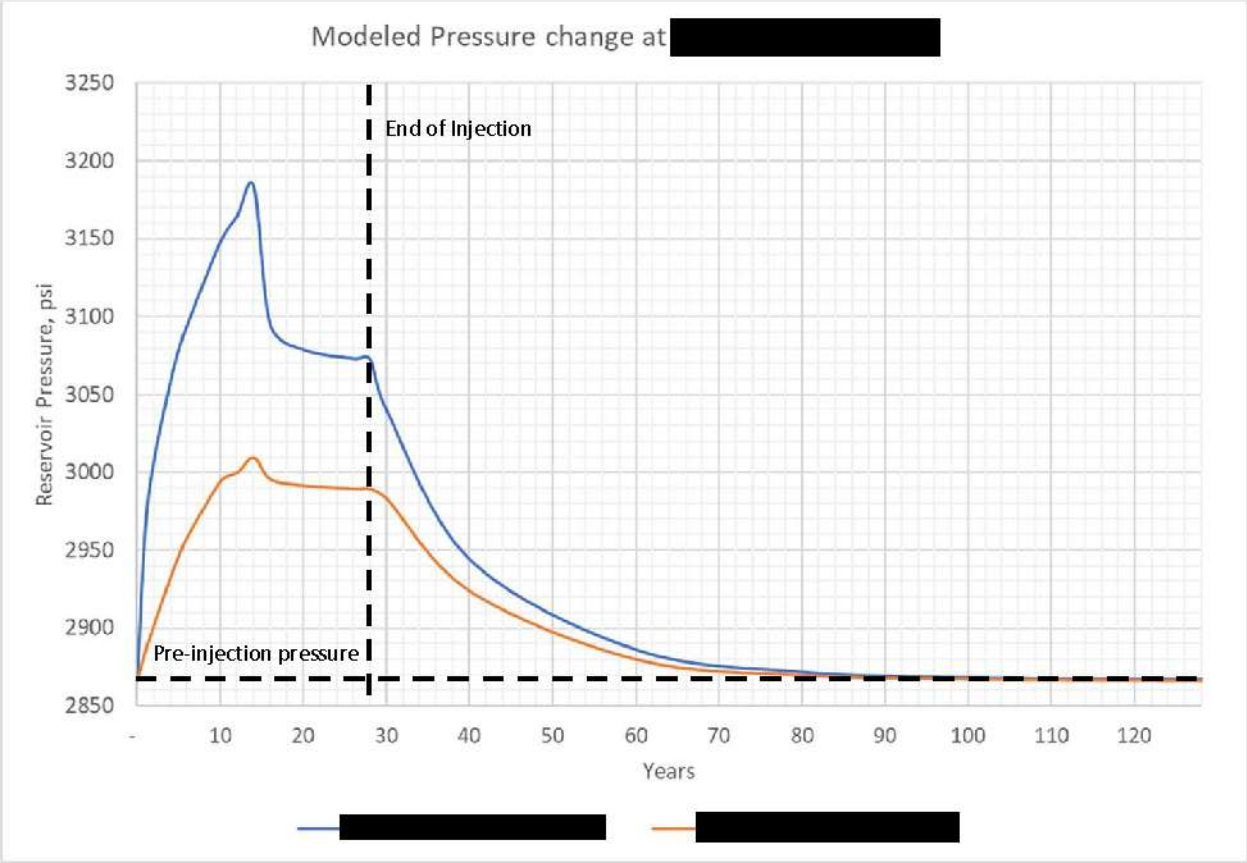

Figure 4: Modeled pressure at Monitoring well [redacted] during the injection period and 100years post injection