ATTACHMENT C: TESTING AND MONITORING PLAN
[40 CFR 146.90]
CTV III

Document Version History

Version	Revision Date	File Name	Description of Change
1	5/03/2022	Att C - CTV III TM	Original submission
2	2/14/2025	Att C - CTV III TM_V2_RtC	Response to October 31, 2024 EPA Comments
3	8/20/2025	Att C - CTV III TM_V3_RtC	Response to May 19, 2025 EPA Comments

<u>Facility Information</u>

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Well location: Project Area, San Joaquin County, CA
37.89 / -121.53

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 as **Appendix 11: Quality Assurance and Surveillance Plan (Appendix 11)**.

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 C-1** using the methods listed. An equivalent method may be employed with the prior approval of the UIC Program Director.

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 Airborne Labs International, which is located at 22C World’s Fair Drive, Somerset, New Jersey. The laboratory has all the necessary equipment, experience, and certifications to complete the analysis. The detection limit and precision can be found in **Appendix 11**, Table 3.

Airborne Labs International 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

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

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 C-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.

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 **Appendix 11**, Table 6. In the event of any unexpected pressure or temperature deviations, the system will deliver alarms to indicate that there is an issue, and CTV will take the appropriate steps as defined in the Injection Well Monitoring Equipment Failure section **of Attachment F: Emergency and Remedial Response Plan (Attachment F)** to ensure that the injector resumes operating within acceptable injection rate and pressure ranges.

Calculation of Injection Volumes

The mass of CO_2 injected into the Mokelumne River Formation will be calculated from the injection flow rate and CO_2 density. Density of CO_2 injected into the Mokelumne River Formation 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 C-3** based on starting and ending injection conditions. The casing-tubing annulus for injection wells will be maintained on average with 100 pounds per square inch (psi) at surface, as stated in **Appendix 4: Operational Procedures (Appendix 4)**. Any decrease in pressure less than 100 psi or annular fluid level will be identified with the supervisory control and data acquisition (SCADA) alarming system. The pressures are also found in **Appendix 4** with additional context.

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. The corrosion coupons will be installed in the pipeline that feeds CO_2 injectate to the injectors. The baseline mass of a corrosion coupon is recorded at installation. Subsequent measurements are relative to the baseline mass.

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 C-3**) will be weighed, measured, and photographed prior to installation. General construction materials for pipeline, tubing and wellhead are shown in **Table C-4**. Updated materials will be provided prior to injection as part of pre-operational testing.

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 2,300 to 2,340 feet measured depth (MD) in the USDW monitoring wells.

2. Domengine Formation – between the confining layer and USDW from 5,240 – 5,400 feet MD in D1.

Monitoring location and frequency

Table C-5 shows the planned monitoring methods, locations, and frequencies for ground water quality and geochemical monitoring above the confining zone. **Figure C-1** shows the location for the monitoring well locations with respect to the AoR and CO_2 plume. 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 in 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 wells. 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.

If CTV detects evidence of USDW endangerment the Emergency and Remedial Response Plan will be implemented (**Attachment F**). CTV will, in consultation with the UIC Program Director, determine appropriate types of monitoring to be performed.

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

1. Domengine Formation monitoring well indicates increased pressure due to Mokelumne River Formation CO_2 injection.

2. Lowermost USDW aquifer pressure or composition changes due to Mokelumne River Formation CO_2 injection.

<u>Domengine Formation</u>

The Domengine Formation has permeable sands and is observed between the confining zone and Undifferentiated Non-marine lowermost USDW with the capacity to dissipate CO_2 injectate as a secondary storage reservoir. The Domengine will be monitored continuously for pressure and temperature changes and quarterly via fluid sampling within a continuous sand. Leakage from the Mokelumne River Formation to the Domengine Formation will increase the reservoir pressure and decrease the temperature of the Domengine. This is the first porous interval above the sequestration reservoir.

The Domengine zone is continuous across the AoR. As such, D1 (**Figure C-1**) will adequately monitor for pressure and temperature changes.

Prior to injection, baseline water analysis will be acquired for the Domengine Formation monitoring zone.

Analytical parameters

Table C-6 identifies the parameters to be monitored and the analytical methods CTV will use. Detection limits and precision are shown in **Appendix 11**, Table 3.

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 **Appendix 11**, 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

Data Interpretation

Consistent with the EPA *Class VI Testing and Monitoring Guidance*, trends indicative of potential fluid leakage are listed below. If two or more of these trends (as compared to baseline data) are noted over a period of three or more sampling events CTV will initiate further coordination with EPA to assess the potential for fluid leakage above the confining zone.

- Changing TDS: An increasing TDS trend may indicate that native brines have migrated from the injection zone, or an intervening zone, into the monitored zone. A change in the overall TDS trend may indicate fluid exchange between adjacent formations.
- Changing signature of major cations and anions: A change in the signature of dissolved ground water constituents in the monitored zone as compared to that of the injection zone or confining zone may indicate leakage. The anion/cation signature may be evaluated through the construction and use of ion diagrams, including piper and stiff diagrams.

- Increasing CO_2 concentration: An increase in the concentration of dissolved CO_2 may indicate leakage of the dissolved-phase plume into the monitoring zone. Increasing CO_2 concentrations may also be observed due to other factors, including increasing groundwater recharge. These other factors may be evaluated to ascertain if the observed increasing CO_2 concentrations are due to migration from the injection zone.
- Decreasing pH: A decreasing pH trend may indicate migration of carbonic acid and other fluids into the monitoring zone. Similar to increasing CO_2 concentrations, other factors may be evaluated that would cause an observed decrease in pH.
- Increasing concentration of injectate impurities: An increase in the concentration of any impurities in the injectate may be indicative of injectate migration into the monitoring zone.
- Increasing concentration of leached constituents: The presence of CO_2 may leach certain inorganics from the formation matrix due to lowered pH (**Appendix 3: Geochemical Modeling**). Increasing trends may be indicative of fluid migration.
- Increased reservoir pressure and/or static water levels.

Mechanical Integrity Testing

CTV will conduct mechanical integrity testing on each injection and Mokelumne monitoring well at least once per year to demonstrate external mechanical integrity using an approved test method per 40 CFR 146.89(c). **Table C-7** shows testing methods that may be used for MIT on injection and monitoring wells associated with this project. 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

Distributed Temperature Sensing (DTS)

DTS is a fiber optic continuous temperature monitoring system that will measure the injection 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 the Capay Shale base 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 as 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.

A baseline temperature survey will be pulled while injecting at a constant rate and subsequent surveys pulled through time, post shut-in. The premise of temperature logging is that the wellbore fluid should warm back to a (constant) geothermal temperature gradient over time. Depending on the fluid profile behind pipe, the temperature could increase or decrease due to a hole in the casing. Any temperature anomalies will be analyzed to determine if it could be indicative of a failure in casing integrity. If analysis is inconclusive, then additional surveys could be prescribed.

Pressure Fall-Off Testing

CTV will perform pressure fall-off tests once prior to injection operations and 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 performed on the injection wells 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 C-8 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 C-9**. Quality assurance procedures for these methods are presented in Section B – Data Generation and Acquisition of **Appendix 11**.

Figure C-2 shows the location of the wells that will monitor the CO_2 plume directly in the targeted Mokelumne River zone. 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. Phased monitoring well installation and additional monitoring well(s) may be considered during AoR reevaluation at a minimum of once every five years, consistent with the T&M guidance Section 4.1.3. If CTV detects evidence of USDW endangerment, CTV will implement the Emergency and Remedial Response Plan (**Attachment F**). Determination for plume monitoring changes will be made in consultation with the UIC Program Director and would trigger an AoR reevaluation, per **Attachment B: AoR and Corrective Action Plan (Attachment B)**.

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 CO2 content/concentration of the plume. The parameters to be analyzed for fluid sampling are presented in **Table C-9**.

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

As discussed in Section 2.1 of **Attachment B**, 83 percent 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.

The pulse neutron spectral carbon-oxygen logging technique has numerous applications for subsurface characterization, including time-lapse reservoir saturation monitoring. As a nuclear logging device with a relatively shallow depth of investigation, near wellbore conditions and proper calibration of the equipment prior to wireline deployment are essential for collecting accurate data and subsurface measurements. The standard operating procedure of the selected PNL tool's manufacturer will be followed in the field. A generalized procedure for a PNL run is as follows:

1. Pre-Logging Preparation
    - Well Integrity: Confirm integrity of the wellbore and casing.
    - Confirm Run Details: Verify logging depths and scope of work.
    - Reservoir Parameters: Review the reservoir properties (e.g., lithology, porosity, permeability) of the formations of interest.
    - Tool Calibration: Ensure the tool is calibrated properly for accurate data and results. Thermal absorbers such as chlorine in brine increase the sensitivity of the PNL tool towards CO_2. Verify proper calibration to connate reservoir salinity and geochemical properties of drilling mud.
1. Logging Procedure
    - Tool Deployment: Lower the pulse neutron tool into the wellbore and position the tool string at the base of the target depth range.
    - Neutron Source Activation: Activate the neutron source to emit neutrons into the formation.

- Gamma Ray Detection: The tool detects gamma rays emitted as neutrons interact with the formation. Log signature responses vary based on the fluid type encountered (CO_2, water, etc.) and geochemical properties of the logged formation.
- Fluid Differentiation: The PNL tool differentiates CO_2 from other fluids by analyzing the energy spectrum of the gamma ray emissions. Due to its low hydrogen content, CO_2 produces a distinctive response compared to water.
- CO_2 Saturation Assessment: Based on the neutron flux and gamma ray data, the tool calculates CO_2 saturation by measuring the hydrogen content in the formation and applying fluid identification models.

2. Post-Logging Data Processing
   - Data Review: Inspect the data for depth inaccuracies, signs of tool malfunctions, and verify the overall quality of the data. Relog any intervals that need relogging.

Interpretation: Use logging results to monitor and interpret CO_2 distribution in the aquifer. Use in conjunction with other well data (e.g., other logs & seismic data) for further validation.

Scalable, Automated, Semipermanent Seismic Array (SASSA)

CTV will implement a time-lapse SASSA solution (Burnison et al., 2016, Livers 2017, Richards et al., 2022) for indirect plume monitoring to confirm consistency of the plume development with computational modeling results. This SASSA design will consist of sparse 5Hz geophones located at the near surface to monitor for plume growth based on subsurface mid-point modeling. The array will be setup to validate the expansion of the plume by monitoring in multiple azimuths including toward monitoring well locations (**Figure C-2**). Direct and indirect plume monitoring activities at these well locations will be used to confirm the SASSA observations of plume growth.

The seismic source for the SASSA will be a Surface Linear Vibrator (SLV) developed by Green Products USA (GPUSA). Confirmation of the effectiveness of the source will be made during pre-operational testing but proprietary testing performed by CTV with GPUSA shows highly promising results. A vibroseis source would be the backup in the unlikely event this is necessary.

As discussed in the EPA guidance summarizing the work of Lumley et al. (2008) there is a challenge to invert any seismic data to accurately estimate carbon dioxide saturations. However seismic data are excellent for detecting the early presence of carbon dioxide. The phenomenon of carbon dioxide injection creating a strong time-lapse negative impedance change is well documented (e.g. Vasco et al., 2019). The SASSA method to be implemented here will monitor for the plume front onset, and once confirmed, the semipermanent sources and receivers for the experiment will be moved as appropriate to monitor for continued plume expansion. Observations of plume expansion will be confirmed at monitoring well locations (**Figure C-2**) using the direct and indirect monitoring activities described in **Table C-8**.

Richards et al. (2022) detail the advantages of a SASSA including for data processing and turnaround. CTV plans to activate the SLV seismic source and collect time-lapse data on at least a quarterly basis during the injection phase. The results will be aggregated into an annual report. A baseline survey will be collected during the pre-operational and/or construction phases. Once the geophone array is laid out it will also be used for seismicity monitoring as discussed in the Induced Seismicity and Fault Monitoring section.

Pressure-front monitoring location and frequency

Table C-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 **Appendix 11**.

The pressure front will be monitored with 2 wells within the CO_2 plume (M1 and M2), and an additional well to the East of the project outside of the AoR (SONOL SECURITIES 2) 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 C-3**.

Monitoring well pressure development based on computational modeling is shown in **Figure C-4**. Note that the pressure at Monitoring well location M2 drops below 2950 psi roughly 14 years after the end of injection and drops down back to initial conditions roughly 50 years after the end of injection.

Pressure-front monitoring details

Direct pressure monitoring of the plume will be achieved through installation of pressure gauges in monitoring wells M1, M2 and SONOL SECURITIES 2. 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.

Induced Seismicity and Fault Monitoring

CTV will monitor seismicity with a network of surface and shallow borehole seismometers. This network will be implemented to monitor seismic activity near the project site. Direct pressure monitoring of the storage reservoir will be used in conjunction with the passive seismic monitoring to demonstrate that there are no seismic events affecting CO_2 containment. 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.

Specifications of the network are as follows:

- Sensor locations to be determined in the field (shallow borehole and/or near surface) with high-sensitivity three-component geophones in shallow boreholes to complement SASSA geophone array

- A velocity model will be derived from vertical seismic profiles (VSPs), sonic well logs, and check shots.
- The system will be designed with capability of detecting and locating events >M_w 0.0.

Baseline Analysis

The monitoring network will be installed during the construction phase. Baseline seismicity data will be collected from the seismic monitoring network for at least 12 months prior to first injection to establish an understanding of baseline seismic activity within the area of the project. Historical seismicity data from the NCEDC will be reviewed to assist in establishing the baseline. These data will help establish historical natural seismic event depth, magnitude, and frequency to distinguish between naturally occurring seismicity and induced seismicity resulting from CO_2 injection.

Monitoring Analysis

Throughout the injection phase, monitoring for natural and induced seismic activity will be performed continuously.

- Waveform data transmitted near real-time via cellular modem or other wireless means and archived in a database
- Event notifications to be automatically sent to required personnel to ensure compliance with CTV's Emergency and Remedial Response Plan

Additionally, CTV will monitor data from nearby existing broadband seismometers and strong motion accelerometers of the NCEDC. The EPA Director will be notified of seismic activity per **Attachment F**.

Network Design

The network design will be finalized during the pre-operational and construction phases of the project. The network will comprise of the 5Hz geophones used to collect SASSA data in near surface conditions. Once the locations of these geophones are finalized, the network will be infilled as necessary with shallow borehole (approximately 100 to 300 feet deep dedicated holes) three-component sensors. The basis of the infilling will be to meet the detection threshold requirements. All of the geophones and waveform data will feed in to a single monitoring solution to provide event notifications and compliance with the Emergency and Remedial Response Plan (**Attachment F**).

References

Burnison, S. A., Livers, A. J., Hamling, J. A., Slaako, O., and Gorecki, C. D., 2016, Design and implementation of a scalable, automated, semi-permanent seismic array for detecting CO_2 extent during geologic CO_2 injection: 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland, p. 3879-3888.

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Lumley, D., D. Adams, R. Wright, D. Markus, and S. Cole. 2008. Seismic Monitoring of CO_2 geo-sequestration: realistic capabilities and limitations. Society of Exploration Geophysicists Las Vegas 2008, November 9-14, 2008.

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Vasco, D. W., Alfi, M., Hosseini, S. A., Zhang, R., Daley, T., Ajo-Franklin, J. B., and Hovorka, S. D., 2019, The seismic response to injected carbon dioxide: Comparing observations to estimates based upon fluid flow modeling: JGR Solid Earth, v. 124, n. 7. P. 6880-6907.

Figures

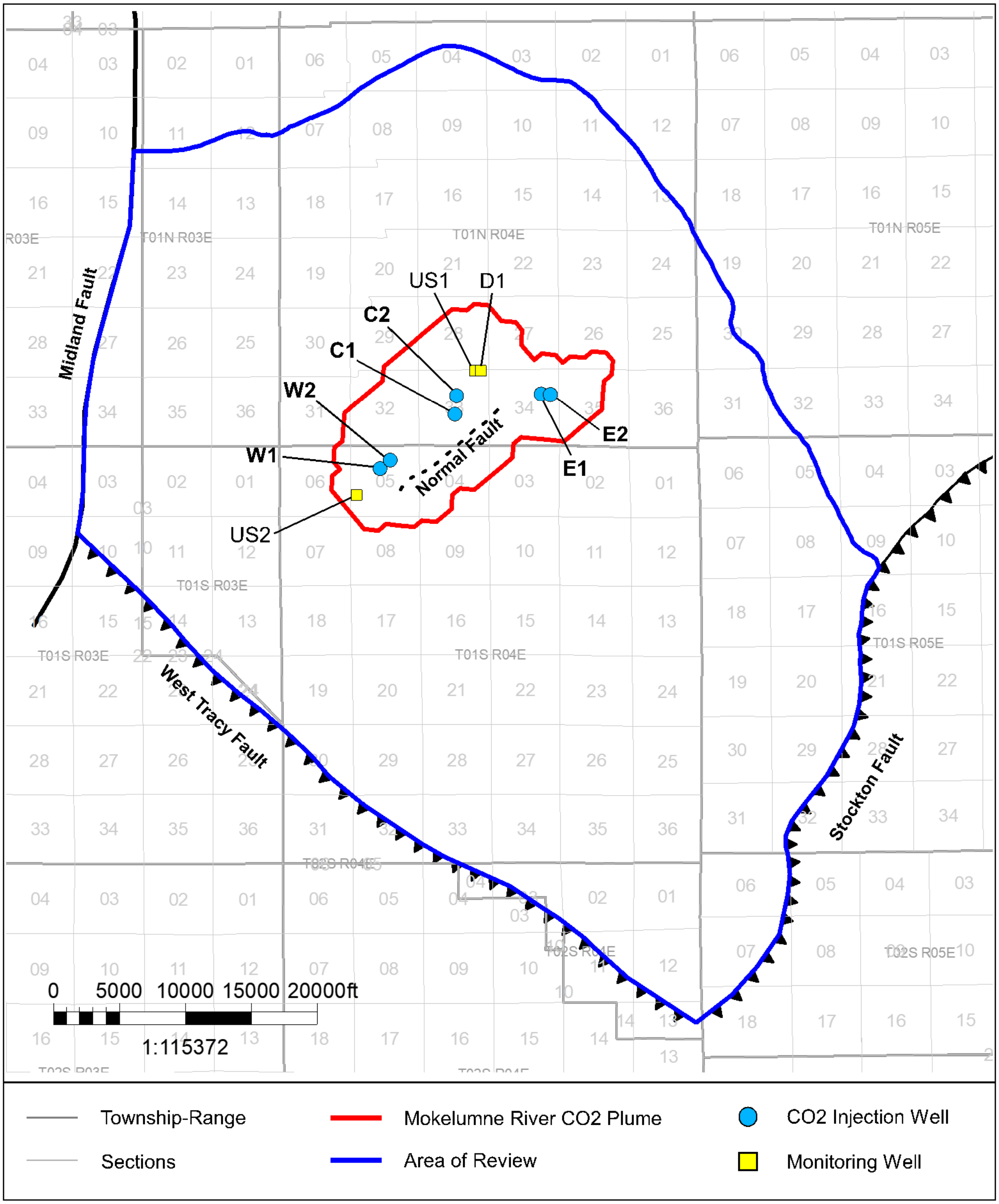

Figure C-1: Map showing the location of wells (yellow squares) that will monitor zones above the upper confining zone. These monitoring wells will monitor the USDW (US1, US2) and the Domengine (D1).

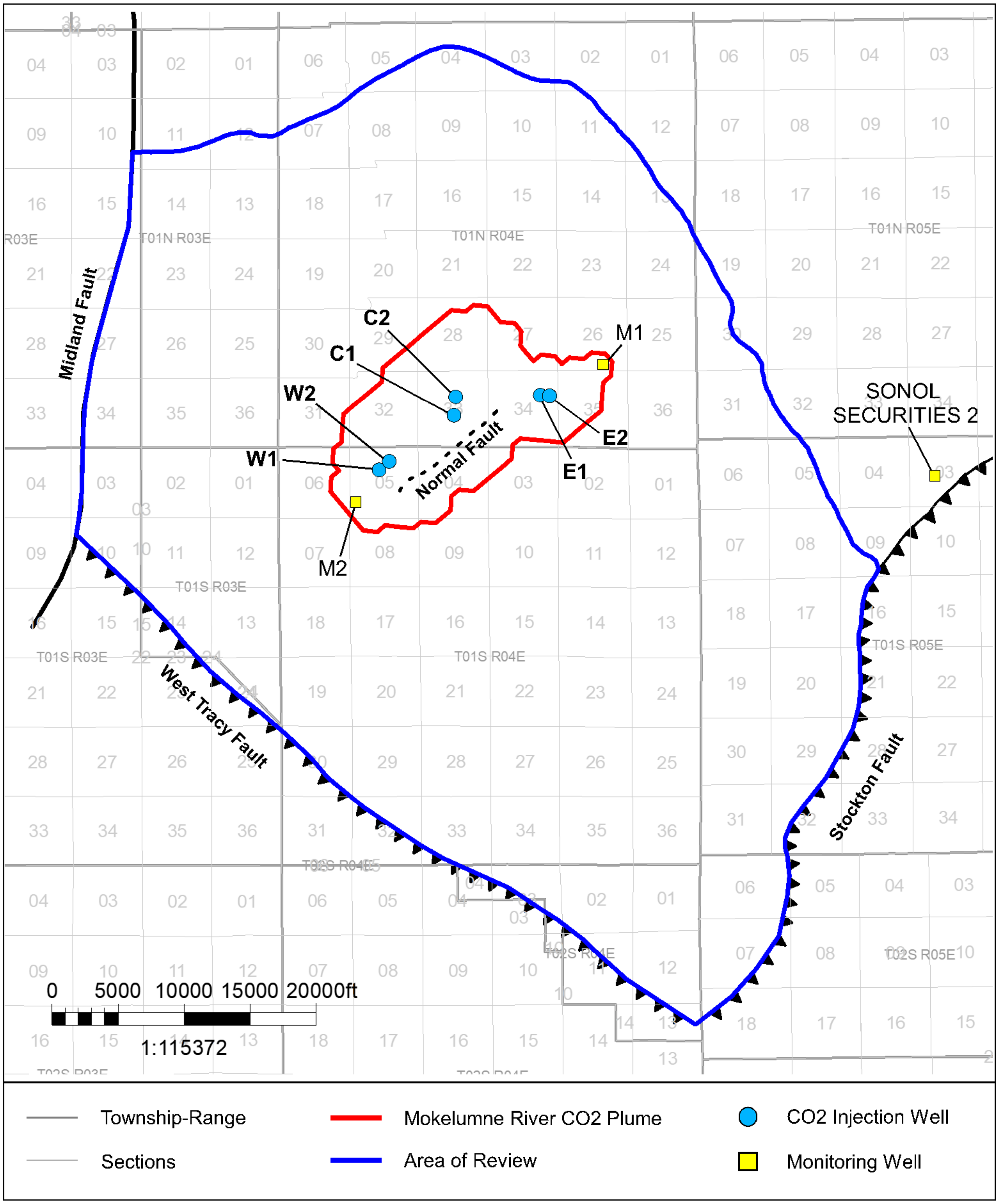

Figure C-2: Map showing the location of wells (yellow squares) that will monitor the injection reservoir.

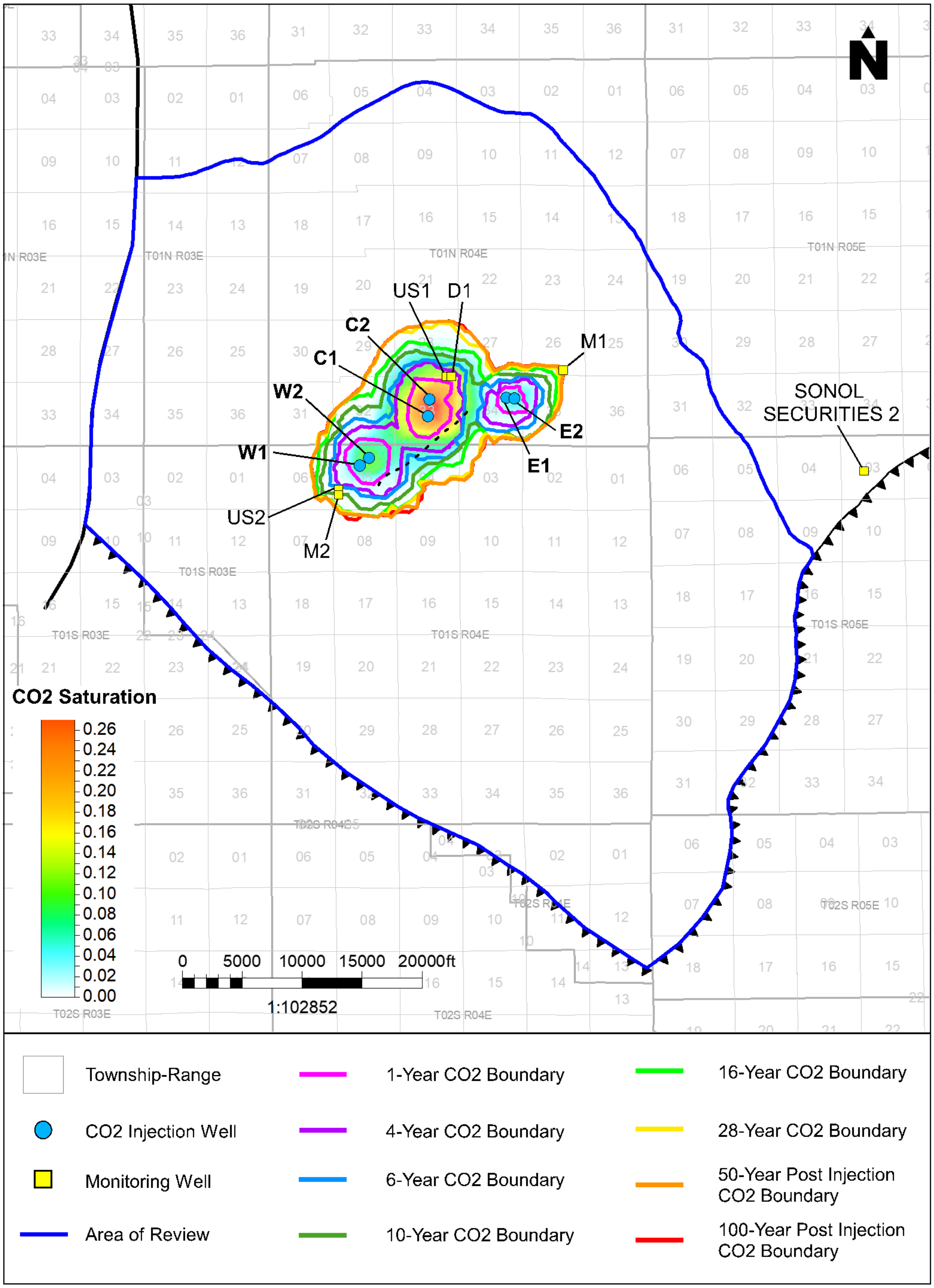

Figure C-3. **Map showing the location of monitoring wells and plume development through time from the computational model. Monitoring wells M1, M2, and Sonol Securities 2 monitor the injection interval, D1 monitors the dissipation zone, and US1 and US2 monitor the USDW.**

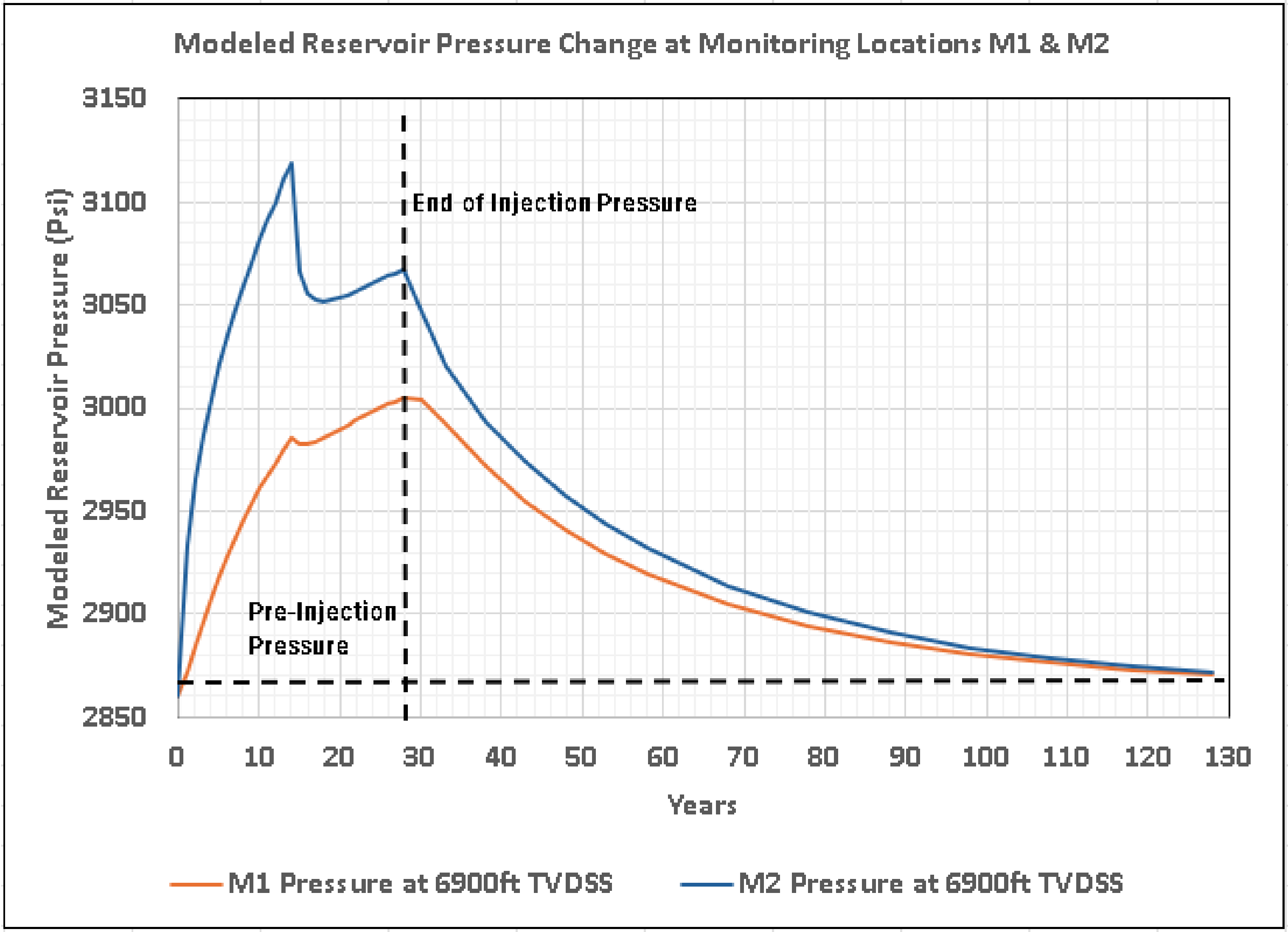

Figure C-4: Modeled pressure at monitoring well locations M1 & M2 at 6,920 feet TVDSS during the injection period and 100 years post injection.

Tables

Table C-1. Summary of analytical parameters for CO_2 stream.

Parameter	Analytical Method(s)
Oxygen, Argon and Hydrogen	ISBT 4.0 (GC/DID) GC/TCD
Water vapor	ISBT 3.0
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, Ethane, Ethylene	ISBT 10.1 (FID)
Hydrogen Sulfide, Sulfur Dioxide, Sulfur Trioxide [a]	ISBT 14.0 (GC/SCD)
CO2 purity	ISBT 2.0 Caustic absorption Zahm-Nagel ALI method SAM 4.1 subtraction method (GC/DID) GC/TCD
δ13C	Isotope ratio mass spectrometry

[a] Sulfur trioxide included if a component of the injectate stream.

Table C-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	TBD	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.
- TBD = to be determined

Table C-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

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

Equipment Coupon	Material of Construction
Pipeline	Carbon steel
Casing	N-80 Carbon Steel L-80 CRA
Tubing	Chrome alloy consistent with final well construction
Packer	Chrome alloy consistent with final well construction
Wellhead	Chrome alloy consistent with final well construction

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

Target Formation	Monitoring Activity	Monitoring Location(s)	Frequency	Depth (feet MD/TVD)
Undifferentiated Non-marine	Fluid Sampling	USDW Monitoring Wells: US1 US2	Quarterly	2,500 – 2,520
	Pressure	USDW Monitoring Wells: US1 US2	Continuous	5,080
	Temperature	USDW Monitoring Wells: US1 US2	Continuous	0 – 5,080
Domengine Formation	Fluid Sampling	D1	Quarterly	5,123 – 5,646
	Pressure	D1	Continuous	5,080
	Temperature	D1	Continuous	0 – 5,080

Note: The minimum sampling and recording frequency for above confining zone pressure and temperature data during active injection is 5 hours.

Table C-6. Summary of analytical and field parameters for water samples from the USDW monitoring well and the Domengine 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 CO2	Coulometric titration, ASTM D513-11
δ13C	Isotope ratio mass spectrometry
Hydrogen Sulfide	ISBT 14.0 (GC/SCD)
Total Dissolved Solids	Gravimetry; Method 2540 C
Oxygen, Argon, and Hydrogen	ISBT 4.0 (GC/DID GC/TCD
Alkalinity	Method 2320B
pH (field)	EPA 150.1
Specific Conductance (field)	SM 2510 B
Temperature (field)	Thermocouple

Table C-7. MITs.

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

Table C-8. Plume monitoring activities.

Monitoring Category and Class VI Rule Citation	Target Formation	Monitoring Activity	Monitoring Location(s)	Depths (feet MD)	Frequency (Baseline)	Frequency (Injection Phase)
Plume Monitoring [40 CFR 146.90(g)] DIRECT MONITORING	Mokelumne River Formation	Fluid Sampling	M1	5,744 – 7,668	Once	Quarterly
		Pressure		5,680	Baseline	Continuous
		Temperature		0 - 5,680	Baseline	Continuous
	Mokelumne River Formation	Fluid Sampling	M2	6,157 – 7,703	Once	Quarterly
		Pressure		6,110	Baseline	Continuous
		Temperature		0 – 6,110	Baseline	Continuous
	Mokelumne River Formation	Fluid Sampling	SONOL SECURITIES 2	5,731 – 5,792	Once	Quarterly
		Pressure		5,690	Baseline	Continuous
		Temperature		0 – 5,690	Baseline	Continuous
Plume Monitoring [40 CFR 146.90(g)] INDIRECT MONITORING	Mokelumne River Formation	Pulse Neutron Logging	M1	5,744 – 7,668	Baseline	Every two years from start of injection.
			M2	6,157 – 7,703	Baseline	Every two years from start of injection.
	Mokelumne River Formation	Scalable, Automated, Semipermanent Seismic Array (SASSA)	Plume Extents	N/A	Baseline	Quarterly, Aggregated Annually

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

Parameters	Analytical Methods
Mokelumne River Formation	
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 CO2	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

Table C-10. Pressure-front monitoring activities.

Monitoring Category and Class VI Rule Citation	Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage or Depth (feet MD)	Frequency (Baseline)	Frequency (Injection)
Pressure-Front Monitoring [40 CFR 146.90(g)] DIRECT MONITORING	Mokelumne River Formation	Pressure	M1	5744 – 7668	Baseline	Continuous
		Temperature			Baseline	Continuous
	Mokelumne River Formation	Pressure	M2	6160 - 7700	Baseline	Continuous
		Temperature			Baseline	Continuous
	Mokelumne River Formation	Pressure	SONOL SECURITIES 2	5731 - 5792	Baseline	Continuous
		Temperature			Baseline	Continuous
Pressure-Front Monitoring [40 CFR 146.90(g)] INDIRECT MONITORING	All formations	Seismicity	Seismic Monitoring Network	Two-mile radius from injector well	Baseline	Continuous