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9.2 Pre- and Post-Injection Pressure Differential

The maximum pressure plume shown in **Figure 9-1** occurs 12 years after the initiation of injection and represents the project AoR. A calculated pressure threshold of 66 psi is used to define the extent of the AoR. Details of the pressure threshold calculation can be found in the *AoR and Corrective Action Plan* of this application. Changes in pressure relative to initial reservoir conditions were calculated from simulation results to identify the project AoR, delineating the monitoring area. Predicted reservoir pressure, 0.465 pounds per square inch (psi) a foot mean ea level (MSL) prior to injection is considered the initial pressure. Reservoir pressure measurements taken prior to injection will be used to further refine the initial pressure measurement. Simulations were conducted for 12 years of injection in a single well at a rate of 1.2 million metric tons per year. Simulations were continued for a total of one hundred years after the cessation of injection to represent CO_2 plume and pressure front evolution. The pressure buildup in the reservoir is presented in the figures below. A maximum pressure buildup of 269 pounds per square inch (psi) occurred in layer fourteen of the model (**Figure 9-2**) at DTM-1 twelve years after the initiation of injection. After injection cessation, the pressure differential decreases exponentially falling below the project pressure threshold of 66 psi seven years after the cessation of injection (**Figure 9-3**). Simulation results show injection well pressure differentials dropping from 269 psi at cessation of injection to 5.6 psi 50 years post injection, well below the 66-psi pressure threshold.

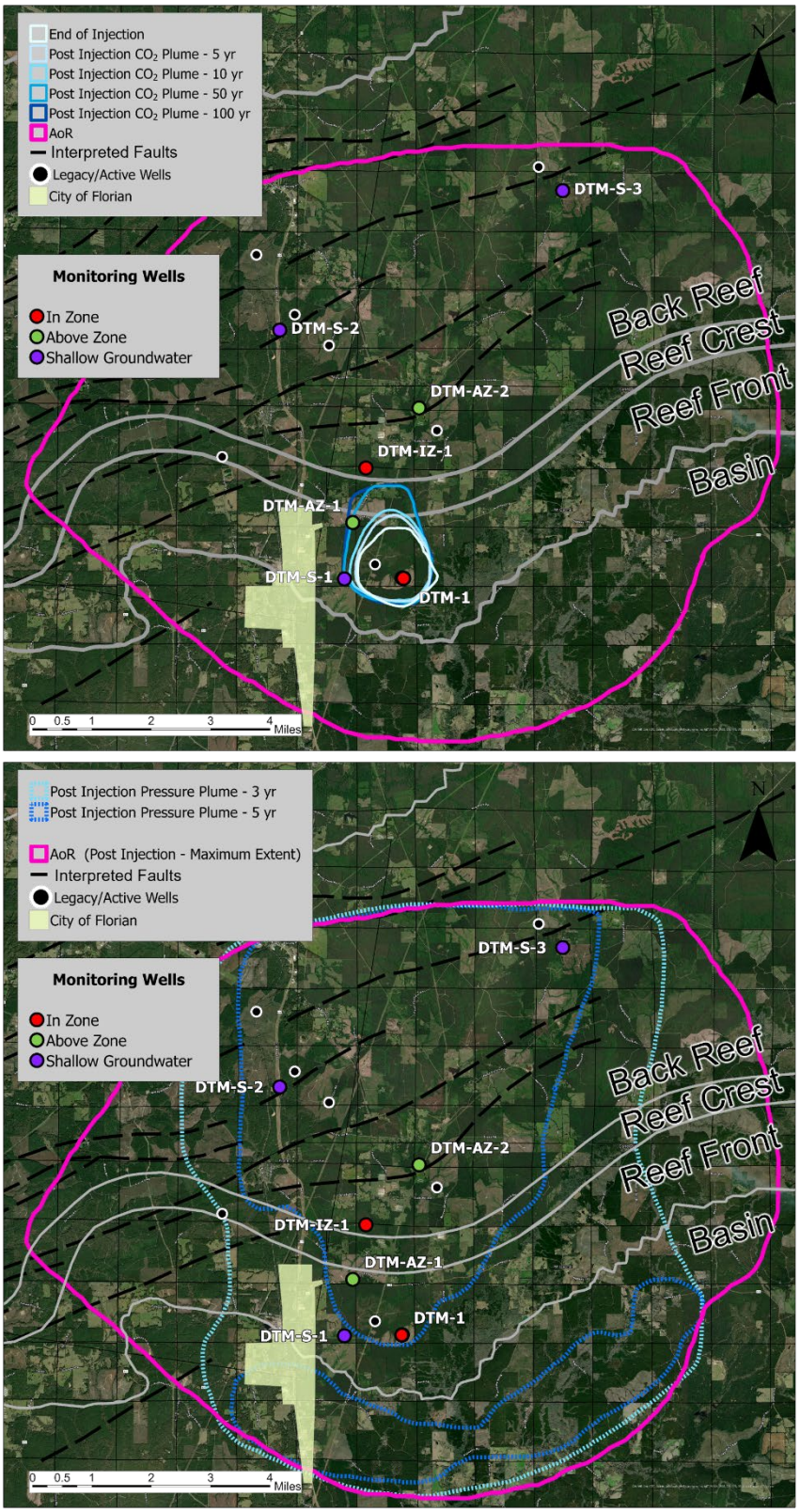

Figure 9-1. (Upper) CO_2 plume evolution post-injection. (Lower) Pressure plume evolution post injection

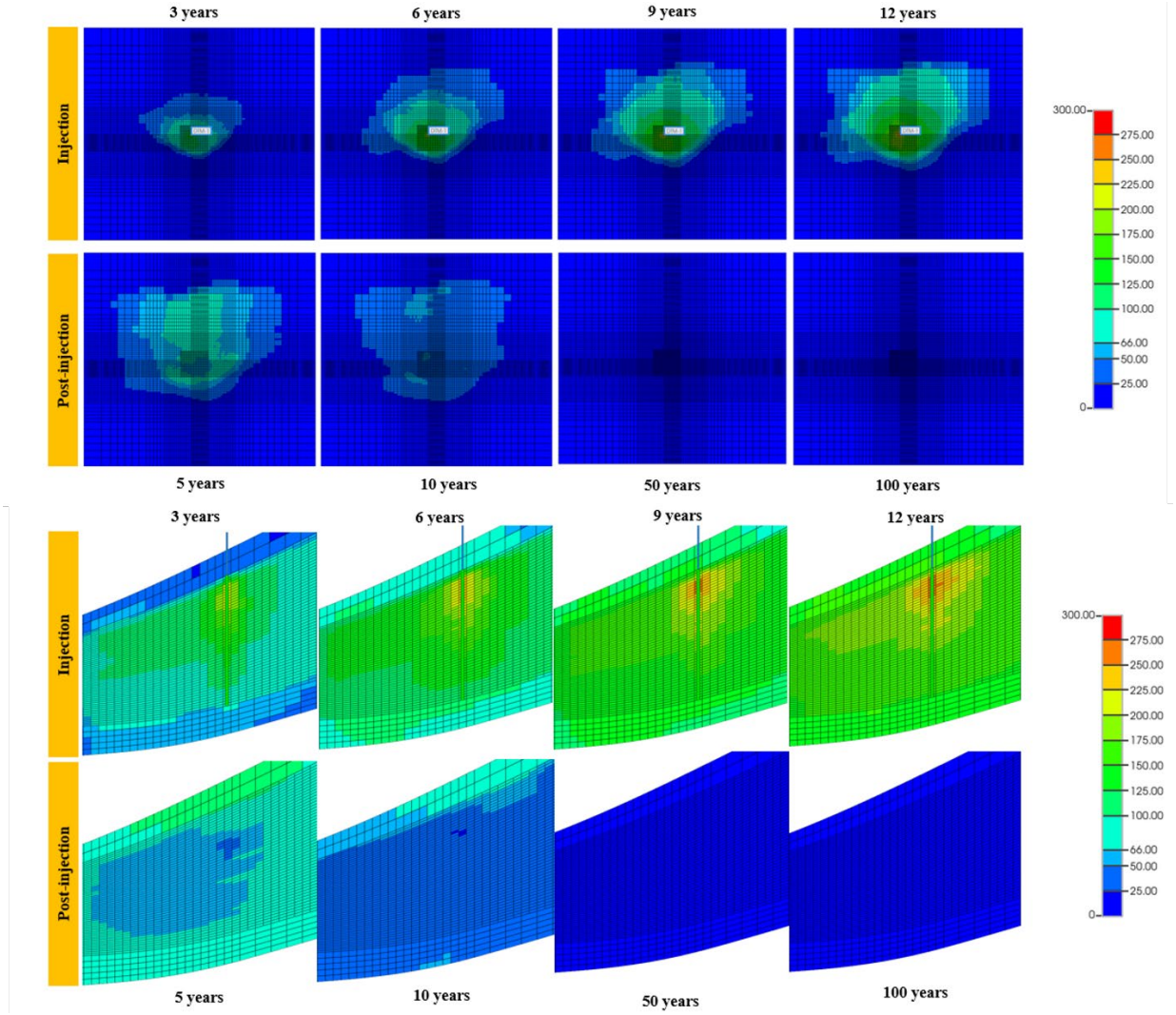

Figure 9-2. Pressure buildup in Middle Glen Rose at layer fourteen of model (upper) and in a S-N profile view through the injection well (lower). The scale bar displays the pressure differential from pre-injection in psi.

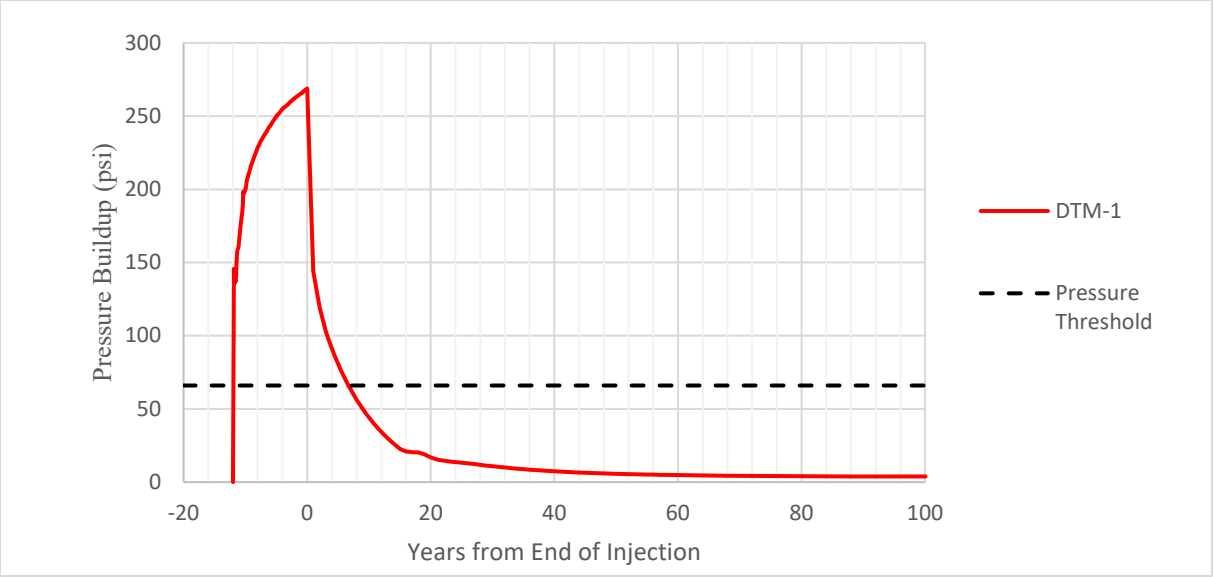

Figure 9-3. Graph illustrating the decline in pressure differential in the injection well following injection taken from the layer fourteen. At 50 years, the pressure differential is 5.6 psi.

9.3 Predicted Three-Dimensional Extent of the Free-Phase CO_2 Plume and Associated Elevated Pressure Front at Site Closure

Computational modeling was used to determine the predicted extent of the CO_2 plume and pressure front at site closure pursuant to 40 CFR 146.93(a)(2)(ii). Geochemical trapping is not expected to occur at the project timeframes and was not included in the modeling. The map in **Figure 9-1** is based on the final AoR delineation modeling results submitted pursuant to 40 CFR 146.84 and shows the furthest extent of the pressure plume at the time of cessation of injection after 12 years of injection.

Figure 9-2 and **Figure 9-3** show the magnitude of the pressure differentials in the injection well dissipating below the pressure threshold of 66 psi 7 years post-injection and down to 5.6 psi prior to site closure. Rapid pressure differential dissipation occurs in the reservoir with more gradual dissipation in the overlying Paluxy caprock. Pressure differentials in the overlying caprock at site closure max out at 147 psi, which translates to a reservoir pressure of approximately 3,959 psi. The difference between site closure and 100-year post-injection pressure differentials in the Paluxy is 2.88 psi, which is approximately 0.05 psi/year. The gradual decrease in the pressure differential after 50 years post-injection indicates a stable storage system with little to no endangerment to the USDWs. Additionally, planned post-injection monitoring described below will contribute to the non-endangerment demonstration required for site closure.

Figure 9-4 shows map and cross-section views of the modeled extent of the CO_2 plume during the injection and post-injection phases of the project. The simulated plume from site closure, 50 years after cessation of injection, to one hundred years after cessation of injection shows only a

5% difference in plume area. The rate of change in area for the CO_2 plume from site closure (50 years) to one hundred years post injection is 0.01%/year. **Figure 9-5** shows plume progression over the modeled period from start of injection to one hundred years post-injection. The graph shows a decreased rate of plume area after injection as expected with the plume area increase plateauing or stabilizing around 40 years post-injection.

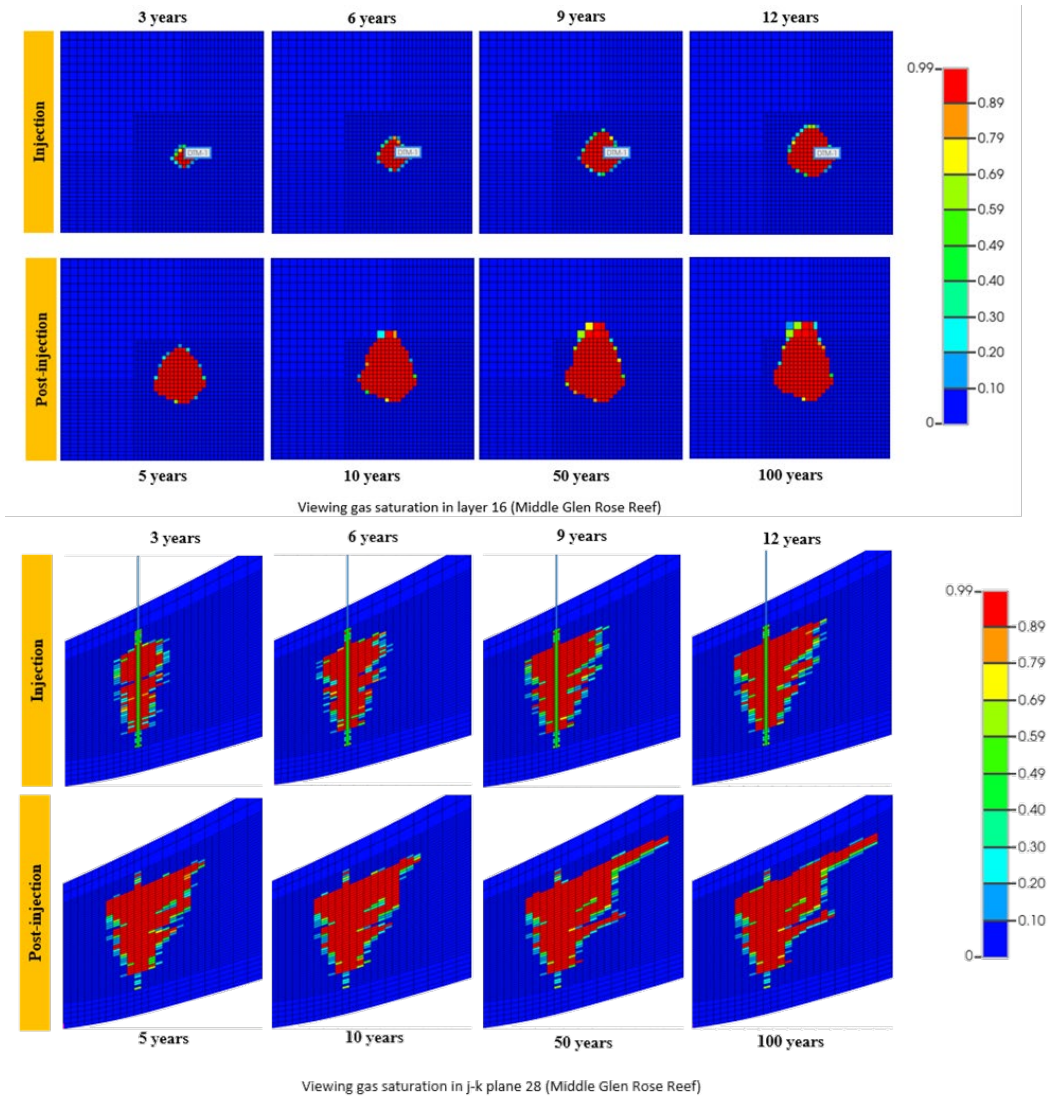

Figure 9-4. Gas saturation in layer 16 (Mooringsport) during and following injection in map view (Upper) and a S-N (left to right) profile view (Lower). The scale describes CO_2 saturation from 0% (blue) to 100% (red).

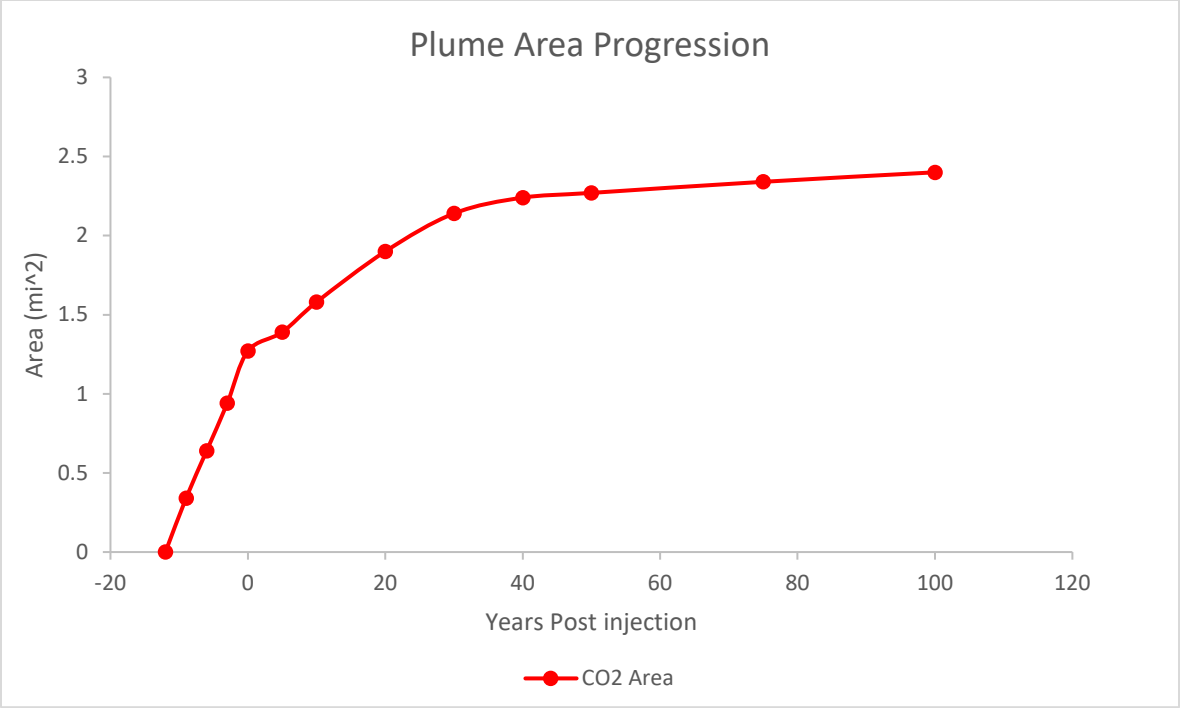

Figure 9-5: CO_2 Plume Area Progression from start of injection to one hundred years post-injection.

9.4 Post-Injection Monitoring Plan

Following the cessation of injection, the injection well (DTM-1) will be converted to a monitoring well and will continue to contribute monitoring data as it did during the injection phase of the project (**Figure 9-1**). No monitoring technologies will be added during the PISC phase of the project. The post-injection phase monitoring will include external mechanical integrity testing, multi-spectral remote sensing vegetative stress surveys, groundwater sampling, direct pressure and temperature measurements, and indirect and direct plume tracking. Every five years during the post-injection phase of the project, the monitoring data will be incorporated into computational models and the monitoring plan will be reviewed and updated, if needed, based on modeling results. Details on the specific technologies utilized and frequency for monitoring strategies pursuant to 40 CFR 146.93(a) (iii) is provided in **Table 9-1** below. Please refer to the *Testing and Monitoring Plan* for more detailed information on the testing and monitoring technologies.

A *Quality Assurance and Surveillance Plan* (QASP) for all testing and monitoring activities is provided in the appendix to the *Testing and Monitoring Plan*. DTM plans to secure options for rights to surface access for all proposed monitoring technologies (monitoring wells and injection well) during the pre-operation, operation, and post-injection phases of the project. In-well monitoring technologies will be implemented until the start of each well's plugging and

abandonment procedure. All PISC monitoring technologies will be implemented for a minimum of 50 years or according to the Director approved alternate post-injection site care timeframe as proposed below.

Table 9-1. PISC Monitoring Strategy & Frequency.

Monitoring Category	Monitoring Method		Post-Injection Frequency (50 years)	Location
Monitoring Plan Update	Reviewed every 5 years. Updated as required		As required	NA
Mechanical Integrity Testing	*External*	Distributed Temperature Sensing	Continuous *1 analysis every 5 years*	DTM-1 DTM-IZ-1 DTM-AZ-[1-2]
Surface Monitoring	Multispectral Remote Sensing Vegetative Stress Surveys		1 per every 5 years*	Within all of AoR
Groundwater Quality and Geochemistry Monitoring	Above-Zone and Shallow Groundwater Fluid Sampling		1 per every 2 years*	DTM-S-[1-3] *(Wilcox, Sparta, Cockfield aquifers)*
	Pressure and Temperature *DTS & P/T Gauges*		Continuous	DTM-AZ-[1-2] *(Ozan Sandstone)*
Direct Pressure Monitoring	Electronic P/T gauges		Continuous	DTM-1 DTM-IZ-1 DTM-AZ-[1-2]
Indirect Plume Monitoring Techniques	*Fiber/Wireline*	DTS	Continuous	DTM-1 DTM-IZ-1 DTM-AZ-[1-2]
		PNC Logging	1 per every 5 years**	DTM-1**
	Seismic	Timelapse 3D DAS-VSP Surveys OR Repeat 3D Seismic Surveys	1 per every 5 years	DTM-1 DTM-IZ-1 DTM-AZ-1 OR Coverage of 50-year post-injection plume

*Frequency to be reduced based on baseline and injection phase results and project specific benchmarks
**Run Pulsed Neutron Capture (PNC) log every five years in any well with detected CO_2 breakthrough.

9.4.1. Mechanical Integrity Testing

Continuous external mechanical integrity testing or equivalent will continue to be implemented using DTS as outlined in the *Testing and Monitoring Plan*. DTS data or equivalent data will continue to be recorded in DTM-1, DTM-IZ-1, DTM-AZ-1, DTM-AZ-2 until the start of each well's pugging and abandonment procedure. An analysis of the DTS data will be run once every five years to ensure external mechanical integrity of the wells. Should the DTS malfunction or

not operate as needed to run mechanical integrity tests then DTM will run temperature logs or equivalent in the wells to confirm external mechanical integrity. The first external well integrity analysis will occur in the above- mentioned wells 5 years after the cessation of injection or in a well where continuous DTS data suggests compromised external mechanical integrity.

9.4.2. Monitoring Above the Confining Zone

The Ozan Sandstone, Wilcox aquifer, and other shallow Eocene aquifers will be monitored to ensure protection of the USDWs within the AoR. Monitoring the Ozan Sandstone, the first permeable unit above the confining zone, will provide early detection of any out-of-zone CO_2 movement prior to reaching the lowermost USDW aquifer. Additional monitoring in the Lowermost and shallow USDWs will allow for detection of a shallower leak should one occur above or not be detected within the Ozan Sandstone. Monitoring and testing of above-zone formations will include Pressure and temperature monitoring and groundwater sampling and analysis. Permanent pressure/temperature gauges and Distributed Temperature Sensing (DTS) will occur in the Ozan Sandstone in the DTM-AZ-1 and DTM-AZ-2 monitoring wells. Groundwater sampling and analysis will occur in the shallow groundwater wells DTM-S-[1-3]. The aquifers mentioned in this section are the predicted aquifers present below the above-zone and shallow groundwater monitoring well surface locations. The pre-operation phase of the project will collect data that will be useful in confirming the presence and depths of these aquifers.

Groundwater sampling and analysis during the post-injection phase of the project will be conducted in the lowermost USDW (Wilcox Aquifer), and shallow ground water aquifers (Sparta and Cockfield aquifers). Groundwater sampling and testing in the wells will occur once every two years after cessation of injection. A reduced sampling frequency will be implemented based on baseline and injection phase fluid sampling results and project benchmarks not to exceed one sample every 5 years. The first PISC groundwater fluid samples will be taken in DTM-S-1, DTM-S-2, and DTM-S-3 six months after cessation of injection and the last samples will be taken prior to well plugging and abandonment. The samples will be analyzed for water quality and indicators of CO_2 or brine movement. Should monitoring data suggest a subsurface leak, groundwater fluid samples will be considered in the affected area to help verify or confirm a leak has occurred and the potential source of the leak. See the *Testing and Monitoring Plan* and the *QASP* for more details on the groundwater monitoring plan.

Direct pressure and temperature data as well as indirect temperature data will be collected in the Ozan Sandstone in the above-zone wells (DTM-AZ-1 and DTM-AZ-2). Direct measurements of pressure and temperature within the Ozan Sandstone will be conducted using Baker Hughes SureSENS QPT Elite permanent downhole pressure/temperature gauges or equivalent and will be installed above the packer to detect out-of-zone brine or CO_2 migration. DTS will also be installed on the outside of the long string casing to continuously record temperature along the

well and down into the Ozan Sandstone. Should a leak be detected and verified in the above-zone Ozan Sandstone a Pulsed Neutron Capture (PNC) log will be run to help quantify the vertical concentration of the CO_2 within the well it was detected and/or identify changes in the fluid total dissolved solid concentrations. This log will help confirm a change in the reservoir fluid chemistry due to increased brine or CO_2. If the PNC log confirms an increased brine or CO_2 concentration, DTM will consider a study that includes fluid sampling in the Ozan Sandstone to attempt to identify the source of these changes.

Table 9-2 presents the monitoring methods, locations, and frequencies for monitoring groundwater quality and geochemistry above the confining zone. The fluid sampling will be conducted in the manner described in the *Testing and Monitoring Plan* with sample analytes removed or added based on baseline and injection phase groundwater monitoring results. More explicit detail for the groundwater analytical parameters is presented in the *Testing and Monitoring Plan* and *QASP* sections of this permit.

Table 9-2. Monitoring of groundwater quality and geochemical changes.

Monitoring Activity	Target Formation	Monitoring Location(s) feet MD)	Frequency
Fluid Sampling	Shallow Middle Eocene Aquifers	DTM-S-1 - TBD DTM-S-2 - TBD DTM-S-3 - TBD	1 per every 2 years*
	Lowermost USDW	DTM-S-1 - TBD	
P/T Gauges	Ozan Sandstone	DTM-AZ-1 – 4,710 DTM-AZ-2 – 4,110	Continuous
DTS	Ozan Sandstone	DTM-AZ-1 - Surface to 5,200 DTM-AZ-2 - Surface to 4,520	Continuous
PNC	Ozan Sandstone	DTM-AZ-1 – Ozan SS DTM-AZ-2 – Ozan SS	If leak detected

*Frequency to be reduced based on baseline and injection phase results and project specific benchmarks.

9.4.3. Carbon Dioxide Plume and Pressure Front Tracking

DTM will employ direct and indirect methods to track the extent of the carbon dioxide plume and the presence or absence of elevated pressure and demonstration that no leakage of CO_2 is occurring, as specified in the Testing and Monitoring Plan, pursuant to 40 CFR 146.93(b). Table 9-1 describes the monitoring methods and frequencies DTM will implement in the post-injection phase of the project. Locations of monitoring technologies as presented in the *Testing and*

Monitoring Plan will remain the same with additional monitoring technology detail presented in the QASP.

In-zone pressure, temperature, and saturation measurements will be recorded during the post-injection phase of the project using Baker Hughes SureSENS QPT Elite permanent downhole pressure and temperature (P/T) gauges, Silixa's DTS fiber optic cable, and Schlumberger's PNC logging suite or equivalents.

The in-zone monitoring wells (DTM-1 and DTM-IZ-1) will use P/T gauges, DTS, and PNC monitoring technologies to confirm the reservoir pressure does not exceed the 90% fracture pressure threshold, better constrain the in-zone pressure and temperature plumes in 3D, calibrate 3D geophysical saturation plume interpretations, and calibrate/update the static earth and computational models. The P/T gauges and DTS fiber optic cable will continuously record data that will be analyzed at a minimum of every 5 years during the post-injection phase for plume imaging and tracking or when monitoring data suggests loss of containment. The PNC logging tool will be run in DTM-1 (and in wells with detected CO_2 breakthrough) every 5 years. The DTM-1 and DTM-IZ-1 DTS fiber optic cables will record variations in formation temperature along the borehole to help track the vertical CO_2 plume within the reservoir and may help demonstrate CO_2 and brine containment in the reservoir through consistent formation temperature observations in the above-zone Ozan Sandstone. PNC logging in the DTM-1 well and any well with detected CO_2 breakthrough will detect the vertical saturation profile and changes in TDS in the well in the reservoir and the first permeable zone (Ozan Sandstone). These indirect temperature and saturation data will reveal the injection intervals within the reservoir that are taking fluid and will be used to update the static and computational model, if needed, every 5 years during the PISC phase of the project. See the *Testing and Monitoring* and *QASP* sections for details on the location of these in-zone monitoring technologies.

The technologies mentioned above will be implemented in the above-zone wells (DTM-AZ-[1-2]) to help demonstrate plume containment or, in the unlikely case of loss of containment, to help identify pressure perturbation into overlying zones and image and quantity the CO_2 plume should loss of containment occur. PNC logging will only be conducted in the DTM-AZ-[1-2] wells if monitoring suggests loss of containment at the well locations. See section *9.4.2. Monitoring Above the Confining Zone* above for more details.

Repeat 3D DAS-VSP CO_2 plume imaging or repeat 3D seismic surveys or equivalent will occur once every five years or when monitoring suggests and confirms loss of CO_2 plume containment to indirectly image 3D CO_2 plume extent. Well-based monitoring data will be used to calibrate and confirm geophysical CO_2 plume interpretation extents. The post-injection phase monitoring data will be incorporated into the computational model that will inform DTM of plume movement and demonstrate plume stabilization.

9.4.4. Schedule for Submitting Post-Injection Monitoring Results

Pursuant to 40 CFR 146.91(e), included is a proposed schedule for submitting post-injection site care monitoring results to the Program Director. All post-injection site care monitoring data and monitoring results collected using the methods described above will be submitted to the Program Director in reports submitted every five years. The data collection will be assembled and submitted to the Program Director by April 1st for the previous 5 years (ex. 2025 PISC monitoring data will be submitted by April 1st, 2030). The reports will contain information and data generated during the reporting period, i.e., well-based monitoring data, sample analysis, and the results from updated site models. See the *QASP* for more details on project reporting.

9.5 Non-Endangerment Demonstration Criteria

Prior to approval of the end of the post-injection phase, DTM will submit a demonstration of non-endangerment of USDWs to the UIC Program Director, per 40 CFR 146.93(b)(2) and (3). The owner or operator will issue a report to the UIC Program Director. This report will make a demonstration of USDW non-endangerment based on the evaluation of the site monitoring data used in conjunction with the project's computational model. The report will detail how the non-endangerment demonstration evaluation uses site-specific conditions to confirm and demonstrate non-endangerment. The report will include all relevant monitoring data and interpretations upon which the non-endangerment demonstration is based, model documentation and all supporting data, and any other information necessary for the UIC Program Director to review the analysis. The report will include the following sections:

1. Introduction and Overview
2. Summary of Existing Monitoring Data
3. Summary of Computational Modeling History
4. Evaluation of Reservoir Pressure
5. Evaluation of Carbon Dioxide Plume
6. Evaluation of Emergencies or Other Events

Below are brief descriptions of the contents that will be included in each section.

9.5.1. Introduction and Overview

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

9.5.2. Summary of Existing Monitoring Data

A summary of all previous monitoring data collected at the site, pursuant to the Testing and Monitoring Plan and this PISC and Site Closure Plan, including data collected during the

injection and post-injection phases of the project, will be submitted to help demonstrate non-endangerment. Data submittals will be in a format acceptable to the UIC Program Director [40 CFR 146.91€], and will include a narrative explanation of monitoring activities, including the dates of all monitoring events, changes to the monitoring program over time, and an explanation of all monitoring infrastructure that has existed at the site. Data will be compared with baseline data collected during site characterization [40 CFR 146.82(a)(6) and 146.87(d)(3)].

9.5.3. Summary of Computational Modeling History

A summary of the computational modeling conducted to determine the position of the pressure front and free-phase CO_2 plume during and following injection. Data used for modeling currently comes from nearby preexisting wells and well logs. The drilling and subsequent logging and coring will provide high-quality characterization of the storage reservoir and caprock which will inform static and computational modeling. Subsequent modeling for the non-endangerment demonstration will incorporate any additional site characterization data prior to injection and monitoring data up to the commencement of the non-endangerment demonstration. Throughout injection, CO_2 saturation and pressure plume monitoring data using PNC logging, repeat 3D DAS VSP or repeat 3D surface seismic, PT gauges, and DTS technologies will provide a wealth of data with which to history-match and update static and computational modeling. If there is a major disagreement between the computational modeling performed and the data acquired, re-evaluation shall take place to determine the discrepancies.

9.5.4. Evaluation of Reservoir Pressure

The reservoir pressure will be determined through baseline monitoring and will continuously collect data in the injection and monitoring well throughout the injection process and during PISC. Pressure gauges will directly measure the reservoir pressure. This data will be utilized to re-evaluate the model every 5 years.

9.5.5. Evaluation of Carbon Dioxide Plume

The carbon dioxide plume will be resolved through analyzing the data collected from PNC logging, repeat 3D DAS VSP or 3D surface seismic surveys, and DTS fiber optics. PNC logging and DTS data will be compared to modeled CO_2 plume extent locations to determine the vertical extent of the plume and predicted concentrations at the wellbores. Repeat 3D DAS VSP or 3D surface seismic surveys and the distribution of PNC logging and DTS data across the AoR will resolve the lateral extent of the plume throughout and following injection during PISC.

9.5.6. Evaluation of Emergencies or Other Events

In the unlikely event of an emergency, the extensive data collection through monitoring as outlined in the *Testing and Monitoring Plan* and above in the PISC Monitoring Plan will be utilized to identify, locate, and remediate the emergency. The depth and salinity of the USDWs and injection interval, pressure and temperature gauges, and modeling are all utilized to perform baseline analysis of reservoir conditions that can be compared to data acquired during and

following injection. Pressure and temperature data, PNC logging, and repeat 3D DAS VSP or 3D surface seismic surveys all will work in tandem to monitor the pressure front and plume migration. This information will all be used as part of the AoR re-evaluation.

9.6 Site Closure Plan

DTM will conduct site closure activities to meet the requirements of 40 CFR 146.93(e). Within 90 days of site closure, DTM shall submit a site closure report. This report must be retained at a location designated by the Program Director for 10 years.

9.6.1. Site Closure Procedure

DTM will notify the Program Director at minimum 120 days prior to site closure. Upon receiving authorization for site closure, all monitoring wells shall be plugged and abandoned (P&A) as outlined in the *Site Closure Plugging Program*. A final Site Closure Plan will be submitted to the Program Director for approval with the notification of the intent to close the site. The following steps are to be used as a general guide during site closure.

1. Notify the Program Director and all relevant local, state, and federal government agencies of intent to close the project site.
2. Decommission equipment.
3. P&A all monitoring and related project wells.
4. Complete and submit the Site Close Report to the Program Director within 90 days.

9.6.2. Equipment Decommissioning

The decommissioning of equipment will be completed in two stages: after the cessation of injection where equipment required to inject CO_2 is no longer necessary and at the end of the PISC period.

Step 1: After cessation of injection, surface equipment necessary to safely sequester CO_2 such as pumps, flowlines, flowmeter, annular pressure monitoring equipment, and piping and control equipment will no longer be necessary and shall be dismantled and removed from the DTMSS.

Step 2: After the PISC period, surface equipment related to the monitoring activities demonstrated in this plan and as part of the PISC period outlined in the Testing and Monitoring Plan will be decommissioned. This includes the plugging and abandonment of all project wells and removal of surface facilities,. The plugging and abandonment procedures are outlined below and are designed to ensure containment of the injected CO_2 and for protection of USDWs.

9.6.3. Site Closure Plugging Program

Once plume stabilization has been determined to have occurred, pursuant to 40 CFR 146.93(e), all CCS project wells will be abandoned following 40 CFR 146.92 of the Class VI Rule.

Abandonment shall be performed to not allow the movement of injection or formation fluids out of the storage complex that endangers a USDW.

Prior to well plugging, the mechanical integrity of the wells will be verified by the distributed temperature sensing (DTS) and distributed acoustic sensing (DAS) fiber optic systems emplaced in the monitoring wells. The well plugging and abandonment will follow the methodology described in the *Injection Well Plugging Program* for the converted injection well (DTM-1) and any other well with CO_2 breakthrough. The same well plugging methodology will be implemented for the monitoring wells except CO_2-resistant cement need not be utilized in wells that do not encounter CO_2 at depth. Refer to the *Injection Well Plugging Program* for the well plugging procedures.

9.6.4. Site Closure Report

Within 90 days of site closure, DTM shall submit a site closure report. This report will be retained at a location designated by the Program Director for 10 years. The report will contain at minimum the following information:

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

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

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

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

9.7 Quality Assurance and Surveillance Plan (QASP)

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