Underground Injection Control – Class VI Permit Application for Hummingbird Carbon Storage Project Injection Wells No. 01, No. 02, No. 03, No. 04, and No. 05

SECTION 5 – TESTING AND MONITORING PLAN

Hummingbird Carbon Storage Project
Allen Parish, Louisiana
ExxonMobil Low Carbon Solutions Onshore Storage, LLC
March 2025

SECTION 5 – TESTING AND MONITORING PLAN

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5.1 Introduction

Consistent with the requirements of Louisiana Administrative Code, Title 43 (LAC43): XVII **§3625.A**, ExxonMobil Low Carbon Solutions Onshore Storage, LLC (ExxonMobil) developed a comprehensive Testing and Monitoring Plan for the Hummingbird Carbon Storage (CS) Project (Hummingbird Project) using a risk-based approach. The data collection includes injectate monitoring; corrosion monitoring of the well tubulars, mechanical, and cement components; pressure falloff testing; seismic surveying; well logging; continuous monitoring of injection rate, pressure, and temperature; groundwater quality monitoring; and CO_2 plume and pressure front tracking. The data generated from implementation of the plan provides the basis to verify the confinement of the injectate in the permitted injection formations during the active injection phase of the project.

The post-injection phase of monitoring is provided in *Section 7 – Post-Injection Site Care and Site Closure*, consistent with the structure of the Underground Injection Control (UIC) Class VI permit application for this project. In conjunction with careful site selection and area of review (AOR) delineation, this plan will be a critical component of the successful operation, post-injection site care (PISC), and eventual closure of the Hummingbird Project.

A key feature of the Testing and Monitoring Plan is that the location and frequency of monitoring and surveillance data acquisition and analysis are designed to align with the injection operation plan and the identified site-risk elements that impact and determine CO_2 plume and pressure front migration. This plan presents a data collection plan to confirm that the injection is consistent with the permit requirements. The plan also includes a phased/triggered approach for the incremental implementation of testing and monitoring technology, consistent with the Environmental Protection Agency's (EPA) presentation of phased/triggered monitoring in their 2013 *UIC Program Class VI Well Testing and Monitoring Guidance*.[1]

Overall, the risk of underground source of drinking water (USDW) endangerment is mitigated (1) by balancing the increase in CO_2 plume and pressure front size and location with the collection and analysis of data to track migration in the subsurface; and (2) by implementing robust risk management processes to assess the potential for leaks through the upper confining zone (UCZ) throughout the life of the project.

ExxonMobil intends for the review process for the Testing and Monitoring Plan and subsequent iterations to continue throughout the life of the Hummingbird Project. An adaptive approach will be employed with respect to the monitoring frequency of select parameters, whereby the application of selected monitoring technologies may be decreased based on improved subsurface understanding and subsequent reduction of reservoir uncertainties. Monitoring results will be presented in semiannual reports, wherein data will be evaluated and any proposed monitoring frequency modification within the Testing and Monitoring plan justified. Baseline

[1] UIC Program Class VI Well Testing and Monitoring Guidance, EPA 816-R-13-001 (March 2013). https://www.epa.gov/sites/default/files/2015-07/documents/epa816r13001.pdf)

data will be collected prior to injection start-up, and time-lapse comparisons to the baseline data will be made during the operational period of the project. The adaptive approach will be applied if the data collected during the injection period shows results within the expected range of CO_2 behavior.

An ongoing dialogue between ExxonMobil and the Commissioner of Conservation (Commissioner) is envisioned, marked by tying the monitoring plan reviews and proposed modifications to the AOR reevaluation frequency. Consistent with the discussion of AOR reevaluation in *Section 3 – Area of Review and Corrective Action Plan*, a defined schedule is proposed to address situations where ExxonMobil may require a change in the AOR. A change to the AOR may also be considered if other unexpected changes are detected as discussed in *Section 3*.

Key to this is the efficient review process that is needed and contemplated, particularly where the AOR reevaluation confirms that the plan is appropriate as written. The defined schedule ensures an appropriate response to testing and monitoring data results that suggest potential corrective actions are needed and mitigation measures should be employed. The Emergency and Remedial Response Plan (*Section 8*) will be implemented as appropriate if the conditions indicate that it is triggered.

The following objectives were developed for the Testing and Monitoring Plan in alignment with LAC43: XVII **§3625.A**:

- Use site characterization data, the site geologic conceptual model, and the results of computational modeling to identify areas or risk elements of potential concern for the project.
- Consider how possible migration pathways and subsurface uncertainties in confining zone and injection zone properties could affect the AOR boundaries and include this uncertainty in the testing and monitoring strategy.
- Select testing and monitoring strategies and a cadence of technologies' implementation that are tailored to the site-specific risk profile in conformance with the requirements.
- Identify project-specific factors to consider or incorporate in evaluating the data collected from the Testing and Monitoring Plan, which may indicate the potential risk to or endangerment of the USDW, as well as deviations from permitted conditions.

5.2 <u>Reporting Requirements</u>

The Testing and Monitoring Plan was developed to achieve two reporting objectives:

- Provide the necessary data to verify predictions of CO_2 plume and pressure front movement (LAC43: XVII **§3625.A.7**).
- Provide the basis for evaluating the model inputs, making necessary changes, and reevaluating the AOR (LAC43: XVII **§3625.A.10**).

In compliance with LAC43: XVII **§3629.A.1**, ExxonMobil will provide reports to the Commissioner in routine semiannual reports that document both the performance of the system and the CO_2 plume and pressure front tracking data. Relevant records in a digital format pertaining to the Class VI testing and monitoring program will be submitted to the Commissioner as well as the EPA. In addition, ExxonMobil will follow the prescribed notification requirements not only for deviation from permit conditions, in the event of an operational malfunction that may allow CO_2 or brine to migrate into or between USDWs—but also for other evidence of USDW endangerment.

The semiannual reports will include the data collected during each reporting period and a list of notifications triggered during a semiannual period, if any. The following information is proposed for the routine performance reporting:

- Monthly average, maximum, and minimum values of injection pressure, flow rate and volume, and annular pressure
- Monthly volume and/or mass of the CO_2 stream injected over the reporting period, and the volume injected cumulatively over the life of the Hummingbird Project
- Monthly annulus fluid volume added
- Results of CO_2 plume and pressure front tracking data analysis as described herein
- Any significant changes to the physical, chemical, and other relevant characteristics of the CO_2 stream from the proposed operating data that could impact plume migration or protection of USDWs
- A description of any event that triggered a shutoff device required according to LAC43: XVII **§3621** and the response taken
- A description of any event that exceeded operating parameters for annulus pressure or injection pressure specified in the permit

The semiannual reports will be submitted 30 days after the completion of the quality assurance and quality control (QA/QC) of the data for each reporting period. Table 5-1 describes the non-routine reporting triggers, contents, and schedule.

Table 5-1 – Summary of Triggering Events for Notification and Reporting Schedule

Triggering Event	Reporting Schedule
Planned well workover, stimulation activities, or other planned test of an injection well	Notification to the Commissioner, in writing, 30 days in advance of planned activity
Completion of well workover	30 days after completion of well workover
Any test of the injection well(s) conducted, if required by the Commissioner	30 days after completion of any testing required by the Commissioner
Evidence of potential non-compliance with a permit condition, or potential malfunction of the injection system that may cause fluid migration into or between USDWs	Verbal notification – reported within 24 hours of verification of non-compliance or malfunction

Triggering Event	Reporting Schedule
Primary evidence that the injected CO_2 stream or associated pressure front may cause an endangerment to a USDW	Verbal notification – reported within 24 hours of verification of endangerment
A failure to maintain mechanical integrity	Verbal notification – reported within 24 hours of verification of mechanical integrity test failure
A statistically significant change to the physical, chemical, and other relevant characteristics of the CO_2 stream from the composition described in the proposed operating plan	Written notification – reported within 72 hours of verification of composition change
An operational condition that exceeds operating parameters for annulus pressure or injection pressure as specified in the permit	• Verbal notification – reported within 24 hours of verification of non-compliance with permit conditions • Written notification – reported within 72 hours of verification of non-compliance with permit conditions
A shutoff device that is activated anywhere in the injection well system	• Verbal notification – reported within 24 hours of event • Written notification – reported within 72 hours of event

ExxonMobil will provide all reports, submittals, and notifications to the Louisiana Department of Energy and Natural Resources (LDENR) and retain records in accordance with LAC43: XVII **§3629.A.4** for a 10-year period after site closure. Additionally, injected-fluid data, including nature and composition, will also be retained for the 10-year period following site closure. Monitoring data will be retained for a minimum of 10 years post-collection, while well plugging reports, PISC data, and the site closure report will be retained for 10 years after site closure.

5.3 Testing Plan Review and Updates

In accordance with LAC43: XVII **§3625.A.10**, the Testing and Monitoring Plan will be reviewed and revised at a minimum of every 5 years to do one or more—or all—of the following:

- Identify Hummingbird Project-specific factors that may warrant revision to the plan.
- Incorporate information and changes necessary to monitor an increase in risk to or endangerment of USDWs.
- Account for any deviations from permitted conditions that require plan modifications.

ExxonMobil will incorporate the collected monitoring data that characterize the project-specific factors and the changes needed, if any, to monitor both increased potential risk to the USDW and overall plan compliance with the Commissioner's requirements. Plan amendments will be submitted within 1 year of an AOR reevaluation, following significant facility changes (e.g., the development of offset monitoring wells or newly permitted injection wells within the AOR), or as the Commissioner requires.

Table 5-2 summarizes the various measurements discussed in the Testing and Monitoring Plan and the frequency of measurements for data collection and reporting purposes.

Table 5-2 – Testing and Monitoring Plan Measurements and Frequency

Equipment / Measurement	LAC43: XVII Regulation	Objective	Frequency
Coriolis flow meter	§3625.A.2	Measure mass flow rate.	[redacted]
Corrosion coupon	§3625.A.3	Measure corrosion levels on the types of metal used in the project.	[redacted]
Injection stream sampling	§3625.A.1	Provide a more detailed analysis via periodic lab analysis of injection stream.	[redacted]
Central pad temperature gauge	§3625.A.1	Measure the temperature of the total injection stream at the pad before partitioning to injections.	[redacted]
Injection wellhead tubing gauge	§3625.A.1	Measure downstream of choke.	[redacted]
Injection wellhead annulus pressure gauge	§3625.A.2	Verify that the annulus pressure is maintained.	[redacted]
Injection annulus pressure test	§3627.A.2	Verify the absence of a leak in the annulus.	[redacted]
Injection well downhole pressure and temperature gauge for active/open injection interval	§3625.A.2	Measure downhole pressure and temperature (injection mass-to-volume conversion, verifying that it is not exceeding maximum pressure).	[redacted]
	§3625.A.6	Measure falloff of pressure immediately before abandoning injection stage and initiating injection in next stage above.	[redacted]
	§3625.A.7.a	Direct measurement of downhole pressure open to active injection zone.	[redacted]
Time-lapse surface seismic survey	§3625.A.7.b	Monitor CO_2 plume growth in the subsurface over time.	[redacted]

Equipment / Measurement	LAC43: XVII Regulation	Objective	Frequency
			[redacted]
[redacted]	§3625.A.5	Use temperature log to assess changes in the temperature profile due to migration of injected fluids.	[redacted]
Injection well casing inspection log	§3625.A.5	Use through-tubing log to detect loss of metal mass in casing due to corrosion.	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]			

5.4 Overall Strategy and Approach for the Testing and Monitoring Plan

The Class VI permit regulations (LAC43: XVII **§3625.A**) require various testing and monitoring activities to identify potential risks to, and the potential for endangerment of, USDWs during the injection phase of the Hummingbird Project. The site features that affect the degree of risk and potential for endangerment of a USDW include the following:

[redacted]

Of these features, the key risk factor that is most critical for the design of this plan is the potential for [redacted] ExxonMobil completed a variety of technical tasks, discussed in *Section 3 – Area of Review and Corrective Action Plan*, to identify and evaluate the potential for [redacted] Other potential risks associated with the project were deemed to be of a lower probability and consequence.

Therefore, a focused testing and monitoring approach was considered reasonable and appropriate to address the following risk scenarios:

[redacted]

Figure 5-1 presents a summary of the risk assessment process for the life cycle of the project.

[redacted]

As shown in Figure 5-1, the anticipated risk level is [redacted] The injection well locations and injection intervals were selected to provide separation from geologic features (e.g., faults) that could potentially contribute to CO_2 or brine crossflow between the injection zone and USDW. The maximum injection pressure will be maintained below the potential hydraulic fracturing or activation pressure of a natural fault, to mitigate the potential for CO_2/brine migration through one or more seals due to mechanical fracturing or migration of CO_2/brine along faults.

State-of-the-art construction and mechanical integrity testing will be employed to reduce the potential for the loss of external mechanical integrity, to prevent the potential release of CO_2. The composition of the injectate stream will be managed and monitored so that unexpected reactions with the potential to impact containment are mitigated. Monitoring and predictive reservoir modeling are being used to limit the potential for CO_2 plume and pressure front migration, to encounter artificial penetrations that have the potential for CO_2 or brine crossflow from the injection intervals to the lowermost USDW.

The Class VI permit testing and monitoring requirements (LAC43: XVII **§3625.A**) address the potential risk scenarios identified by ExxonMobil as warranting monitoring and testing. Scenarios that were found to have elevated risk will be the subject of corrective action prior to operations. [redacted]

An array of data collection technologies was screened to identify the most reasonable and appropriate methods for the Testing and Monitoring Plan. The screening criteria included: (1) selection of an appropriate direct-and-indirect mix of mature or commercially demonstrated monitoring technologies linked to identified risk scenarios; (2) cost benefit analysis of each technology to mitigate unexpected CO_2/brine migration potential; and (3) a mix of continuous and periodic schedules for implementing technologies. ExxonMobil recognizes mature technologies based on their Technology Readiness Levels (TRLs), as defined by the International Energy Agency in their report *Energy Technology Perspectives, 2020; Special Report on Carbon Capture Utilisation and Storage.* This scheme is applicable to any technology, including those described in Table 5-3 for implementation in the Hummingbird Project. As described in Figure 5-2, ExxonMobil considers mature technologies to be those at [redacted] and higher.

The selected mature monitoring technologies for the Hummingbird Project are designed to track the CO_2 and pressure plume growth in each of the four injection intervals, from bottom to top: [redacted] (Figure 5-3).

[redacted]

Table 5-3 provides a summary of mature technologies selected for tracking the CO_2 plume and pressure front. Consistent with the stated interests of the EPA, the Testing and Monitoring Plan is intended to be a flexible approach—using appropriate technologies and techniques that are refined and adapted based on site-specific information over time. ExxonMobil will continue to assess the feasibility of emerging technologies and conduct performance evaluations to continue to investigate large-scale applications and improve the performance of the testing and monitoring surveillance system.

ExxonMobil will communicate with the Commissioner on plans and the potential for modifications and updates to the Testing and Monitoring Plan, in case emergent technologies are deemed ready for adoption. Through the combination of proven and emerging technology implementation, an efficient testing and monitoring strategy will be maintained for the Hummingbird Project to ensure effective monitoring of CO_2 plume and pressure front migration paths in the subsurface, and to provide reliable data for risk management, mitigation strategies, and a potential reevaluation of the AOR model.

[redacted]

[redacted]

5.4.1 Use of Phased and/or Triggered Approach

The Testing and Monitoring Plan for tracking the CO_2 plume and brine pressure front uses the phased and/or triggered approach to scale the testing and monitoring network location and cadence within both the extent of the AOR and the site features that warrant monitoring as identified in the risk assessment evaluation. The goal of the approach is to provide the monitoring and surveillance data necessary to demonstrate that USDWs are protected from the potential migration of CO_2 or brine. The scaling aspect of the strategy is aligned with the multi-staged injection approach outline in *Section 2 – Plume Model*, which [redacted]

The initial monitoring network array is based [redacted] and what was deemed appropriate to track the CO_2 plume and brine pressure front growth based on our reservoir simulation. The regular AOR reevaluation process will be used to assess the adequacy of the testing and monitoring program to detect potential unexpected CO_2 or brine migration—should it occur—and make recommendations for changes and implementation of corrective measures, if necessary, to demonstrate the protection of USDWs.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

5.4.2 Mechanical Integrity Testing

5.4.2.1 Internal Mechanical Integrity Testing – Annulus Pressure Test

In accordance with LAC43: XVII **§3627.A.2**, ExxonMobil will assess the internal mechanical integrity of each injection well by performing annulus pressure tests after the well has been completed, prior to injection, and annually thereafter. During well construction and prior to the installation of the injection tubing and packer, the casing will also be pressure-tested to the maximum anticipated annulus-surface pressure to verify its integrity.

The annular pressure tests are designed to demonstrate the mechanical integrity of the casing, tubing, and packer. These tests will be conducted by pressuring the annulus and described in *Section 4 – Well Construction Plan and Operating Conditions*.

The injection tubing annulus pressure will be continuously monitored at the wellhead during all other times (LAC43: XVII **§3627.A.2**). The tubing annulus pressure will be recorded and reported in semiannual reports to the regulatory permitting authority, to demonstrate compliance with casing integrity requirements.

5.4.2.2 External Mechanical Integrity Testing

Following the requirements of LAC43: XVII **§3627.A.3**, ExxonMobil will use [redacted]

The procedures for acquiring a temperature log are as follows:

- Obtain a temperature log with gamma ray and a casing collar locator prior to injection activities, to establish baseline conditions and to identify any potential local temperature anomalies that may exist.
- Shut in the well for a minimum of 24 hours, targeting 36 hours of shut-in time, if possible, based on operational needs.
- Rig up the wireline company and perform the temperature log from surface to total depth.
- Pull the temperature tool out of hole. If anomalies are present, re-log the well at least 8 hours after the initial pass to reestablish sufficient conditions. If none are identified, rig down the wireline company.

Per the EPA's *Geologic Sequestration of Carbon Dioxide: UIC Program Class VI Well Testing and Monitoring Guidance* (March 2013), any temperature logs will be evaluated by comparing the relative differences of the log to a baseline log. If the log is comparable to the baseline log, it is considered a successful demonstration of mechanical integrity. If log data is inconclusive or anomalies are detected, additional logs such as an oxygen activation or pulsed neutron log may be run to further investigate the MIT.

5.4.2.3 Reporting Results of the MIT

Annulus pressure test (i.e., internal MIT) results will be submitted to the appropriate regulatory permitting authority within 30 days of completion. The logs recorded during the external MIT will be submitted to the appropriate regulatory permitting authority (e.g., the Commissioner) within 30 days of the verification that the logging results are representative and acceptable.

5.4.3 Pressure Falloff Testing

Required pressure-transient falloff testing will be conducted [redacted] The objective of periodic testing is to monitor for any changes in the near-wellbore environment that may impact permeability and reservoir pressures during active injection. A report containing the pressure falloff data and interpretation of the reservoir pressure will be submitted to the EPA within 30 days of the conclusion of the test. Although test procedures or methods may be changed based on the request of the permittee and approval by the Commissioner, the following procedure is expected to be typical for such periodic monitoring.

5.4.3.1 Testing Method

The procedures to conduct a pressure falloff test are as follows:

- Record data regarding the test well injection at typical operating conditions (constant rate plus or minus 10%). Rate vs. time data will be recorded during the injection period. Cumulative injection volume will also be recorded. Continue the injection for a time equivalent to the projected duration of the falloff necessary to observe analyzable radial flow. Note that significant rate variations may require more complicated analysis techniques.
- Verify the operation of the permanent monitoring equipment or rig up downhole the memory pressure gauge and run in the well to a datum depth approved by the regulators.
- For pressure transient falloff, obtain the final stabilized injection rate and pressure for a minimum of [redacted] Ensure that the injectate temperature has stabilized.
- Cease injection and monitor the pressure falloff. Continue monitoring pressure for a time sufficient to observe reservoir behavior. Wellbore pressure gradients will be obtained to establish the fluid gradient.
- Stop the test-data acquisition, rig down, and release the equipment.

5.4.3.2 Analytical Methods

Near-wellbore conditions, such as the prevailing flow regimes, well skin, reservoir properties, and boundary conditions, will be assessed using standard pressure-transient diagnostic plotting and well test simulators, as required. This assessment will be accomplished from analysis of observed pressure changes and pressure derivatives on standard diagnostic log-log and semi-log plots. Significant changes in the well or reservoir conditions will be identified by comparing pressure falloff tests performed prior to initial injection with later tests. These well parameters resulting from falloff testing will be compared against those used in AOR determination and site computational modeling. Notable changes in reservoir properties may dictate that an AOR reevaluation is necessary.

The pressure falloff test results will be submitted to the Commissioner within 30 days of completion of the QA/QC verification of the pressure data.

5.4.3.3 Quality Assurance/Quality Control

The surface field equipment will undergo inspection and testing prior to operation, and the pressure gauges will be calibrated prior to installation per manufacturer instructions. Documentation certifying proper calibration will also be enclosed with the test results.

5.4.4 Monitoring of CO_2 Stream

Consistent with LAC43: XVII **§3625.A.1**, ExxonMobil will install and use measurement devices to analyze the chemical composition of the injection stream, to assess the potential for interactions between CO_2 and other injectate components—and compatibility with the well-completion materials. Temperature and pressure will also be measured at the sample collection point.

5.4.4.1 Sampling Frequency

[redacted]

5.4.4.2 Sampling Methods

The quarterly measurements will be obtained by collecting representative samples of CO_2 at a sample port on the project's central pad, beyond the last stage of compression in the compression build or similar point. Sufficient mixing and residence time in the system will have occurred at this sampling point for the sample to be representative of the injected CO_2 stream. The sampling station will be equipped with the ability to purge and collect a gas sample into a sealed container.

The central pad is the connection point between the CO_2 pipeline and the sequestration field's distribution system.

Sampling activities will be conducted at the direction of site representatives—in accordance with the certified or accredited analytical laboratory procedures—and will meet the minimum current standard EPA procedures. A sample will be collected by depressurizing the liquid stream and sampling the CO_2 as a gas in either a Tedlar® bag, a Summa cannister, or a laboratory-approved alternate. The grab sample will be sent to an independent contract laboratory for analysis.

Each sample will be accompanied by a facility or contract laboratory chain-of-custody (COC) form that provides a record of sample handling—starting with sample acquisition and documenting the sample transfer process up to the laboratory analysis. Samples taken are to be logged in the field using the COC form. Sample transfer containers (e.g., coolers) will be sealed and delivered to the laboratory with a COC form, which will provide the following items recorded by the sampler:

- Sample ID including code or name, in addition to date and time
- Name of sample collector (sampling company name to be included if not site personnel)
- Sample collection method
- Sample collection date
- Sample collection point
- Sample presentation technique, as applicable
- Standard laboratory COC forms that document the times and dates of all personnel handling the sample—along with standard labels and container seals sufficient to distinguish between samples and to prevent tampering—will be acceptable.
- The sample COC will be followed at all times during the sampling and subsequent analysis and will be used to document the handling and control necessary to identify and trace a sample from collection to final analytical results.

5.4.4.3 Analytical Plan

Table 5-4 presents the test parameters, analytical methods, and sample frequency for each test parameter.

[redacted]

[redacted]	[redacted]		[redacted]
[redacted]	[redacted]		[redacted]
[redacted]	[redacted]		[redacted]
[redacted]	[redacted]		[redacted]
[redacted]	[redacted]		[redacted]
[redacted]	[redacted]		[redacted]
[redacted]	[redacted]		[redacted]
[redacted]	[redacted]		[redacted]
[redacted]	[redacted]		[redacted]
[redacted]	[redacted]		[redacted]
[redacted]	[redacted]		[redacted]

[redacted]

5.5 Monitoring Programs

5.5.1 Continuous injection Stream Physical Monitoring

ExxonMobil will install and use continuous measurement devices to monitor the injection pressure, rate, and mass injected; the pressure on the annulus between the tubing and the long string casing; and the temperature of the CO_2 stream, as required under LAC43: XVII **§3621.A.6.a**, **§3627.A.2**, and **§3625.A.2**. Data will also be collected to document the addition or removal of any fluid from the annulus system. For equipment that is not linked directly to a data management system or suitable equivalent, data interfaces will be created and integrated into a unique surveillance platform.

In the monitoring program, the sensors, transducers, and controllers will be connected in a central platform to monitor the operating conditions, set alarms for alerting operations of malfunction, and establish safety protocols in case of abnormal conditions. Alarms will additionally be set for pressures outside of described tolerances (generally 90% of the fracture gradient and prescribed wellhead pressures), and changes in annular pressure and fluid.

Instrument calibration standards, precision, and tolerances will be determined based on manufacturer recommendations. The automated control system data will be visually monitored on a regular basis for anomalies. Average values will be compared to baseline and predicted values to determine if there are any significant deviations relevant to integrity or containment. The operating parameters, monitoring values, laboratory results, reports, and surveillance documents for the Hummingbird Project will be stored in a database to support AOR reviews, QA/QC review programs, and routine reporting.

Table 5-5 provides a summary of the typical sampling devices, locations, and data storage frequencies for the continuous monitoring program. Paper records may be substituted, as necessary, for digital records—at the discretion of the operator. Suitable equivalent devices may be used as technology availability and maintenance dictate.

Table 5-5 – Sampling Devices, Locations, and Data Frequencies for Continuous Monitoring

Parameter	Device(s)	Location	Estimated Min. Sampling Frequency	Estimated Min. Recording Frequency
Surface injection pressure	Wellhead pressure logger	Surface, injection well piping	5 seconds	5 minutes
Downhole pressure gauge	Pressure gauges	Injection unit	5 seconds	5 minutes
Injection rate	Coriolis flow meter	Central pad piping	5 seconds	5 minutes

Parameter	Device(s)	Location	Estimated Min. Sampling Frequency	Estimated Min. Recording Frequency
Injectate density	Coriolis flow meter	Central pad piping	5 seconds	5 minutes
Total mass injected	Coriolis flow meter	Central pad piping	5 seconds	5 minutes
Annular pressure	Pressure gauge	Wellhead	5 seconds	5 minutes
Annulus fluid volume	Pressure gauge	Annulus system tank	5 seconds	5 minutes
CO_2 stream temperature	Coriolis flow meter/wellhead pressure logger	Wellhead, injection well flowing	5 seconds	5 minutes

5.5.1.1 <u>Continuous Monitoring of Injection Rate and Volume</u>

ExxonMobil will collect continuous measurements necessary to calculate and report the injection mass flow rate and volume in compliance with LAC43: XVII **§3625.A.2**. A data management system or suitable equivalent will be used to facilitate the continuous collection of intake pressure at the central pad transfer point, the distribution system to each injection well, and the wellhead of the proposed injection wells.

A Coriolis flow meter will be used to measure the flow rate at the central pad and compute flow rates for each injection well. The meter directly measures the mass flow rate of the injected fluid. Analytical methods will be conducted at a periodic interval to determine the mass percentage concentration of CO_2 and carbon monoxide (CO). The mass percentage concentration of CO_2 and CO is multiplied by the total mass flow reading from the Coriolis flow meter, to estimate the total mass of captured CO_2 and CO for a given period. The meter will be placed directly at the point of injection and calibrated to manufacturer specifications.

[redacted]

ExxonMobil will review and interpret the continuously monitored parameters to validate that they are within permitted limits. The data review will also include an examination of trends to help assess the need for equipment maintenance or calibration. Semiannual reports of the monitoring data will be submitted to the regulatory permitting authority.

5.5.1.2 <u>Continuous Monitoring of Injection Temperature and Pressure at the Injection Wells</u>

ExxonMobil will perform continuous monitoring of the injection pressure, temperature, mass flow rate, and injection annulus pressure in compliance with LAC43: XVII **§3625.A.2**. The injected CO_2 stream pressure will be continuously monitored in the CO_2 flowline near the wellhead interface. The annulus pressure will also be continuously recorded. The combined wellhead and downhole monitoring data will be used to continuously characterize the injection stream in detail.

ExxonMobil will review and interpret the monitoring data to confirm compliance with the operational limits of the injection permit for each well. The data review will include an analysis of trends for operational performance evaluation and routine maintenance. Periodic reports of the monitoring data will be submitted to the Commissioner.

5.5.1.3 Continuous Monitoring of Injection Temperature and Pressure in the Reservoir

Reservoir temperatures and pressures will be measured using a downhole gauge that will be installed in the tubing above the production packer. (*Section 4 – Well Construction Plan and Operating Conditions* contains the well diagrams.) The wellhead pressure logger will also continuously measure the temperature.

5.5.1.4 Continuous Monitoring of Annular Pressure and Volume (Tank Level)

The annular pressure between the tubing and the injection casing string will be monitored on a continuous basis. The pressure gauge on the annulus will be tied into the data management system or a suitable equivalent system and set to alarm if the pressure or volumes move outside set tolerances. The annulus tanks in the well systems will be maintained with sufficient volumetric capacity to accommodate the anticipated volume fluctuations due to temperature and pressure variations. The annulus tanks are to be equipped with a level transducer or an armored reflex sight glass and an independent liquid-fill nozzle. If any annulus fluid is added or removed, it will be recorded. An annulus tank level is to be recorded on any day when injection occurs.

5.5.1.5 Positive Annular Pressure

Per LAC43: XVII **§3621.A.4**, pressure will be maintained in the annulus at a value greater than the injection pressure. Per LAC43: XVII **§3621.A.3**, ExxonMobil will fill the annulus with a noncorrosive fluid approved by the Commissioner. A system will be set up to maintain pressure in the annulus using noncorrosive fluid or gas, and will be tied into the alarms or a suitable equivalent system designed to signal pressure drops below set points.

5.5.2 Corrosion Monitoring

To meet the requirements of LAC43: XVII **§3625.A.3**, the tubing and casing materials will be monitored during the operational period for loss of mass, thickness, cracking, pitting, and other signs of corrosion, to demonstrate that the well components continue to meet the minimum standards for material strength and performance. Monitoring based on well-specific conditions that are encountered will be conducted at least once per year.

5.5.2.1 Monitoring Location and Frequency

Corrosion coupons will be placed in continuous contact with the CO_2 stream in a selected location deemed representative of the five proposed injection wells. The samples will be exposed to the process stream conditions immediately prior to injection, using a recycle loop or sample retriever.

Exposure is to be representative of conditions at the top of the tubing. Initially, coupons will be tested quarterly. After establishing service life trends, coupon testing frequency may be reduced but will be conducted at a minimum of once per year.

Casing inspection logs (CILs) (e.g., ultrasonic imaging tool, electromagnetic, cement bond log, or caliper) will be conducted on the long string casing at a minimum frequency of once every 5 years at the time of permit renewal. [redacted]

5.5.2.2 <u>Monitoring of Corrosion Coupon</u>

Monitoring of well tubing and casing material corrosion will initially be conducted on a quarterly basis to evaluate the corrosion coupon monitoring system. After establishing service life trends, coupon testing frequency may be reduced but will be conducted at a minimum of once per year. A corrosion coupon station or rack will be provided as part of well-materials integrity monitoring. Any coupon in active use will be exposed to the stream composition to provide ongoing evaluation of material compatibility with the CO_2 stream. The results will be reported semiannually to the regulatory permitting authority, such as the Commissioner.

The coupons will be assessed for corrosion using American Society for Testing and Materials (ASTM) and Association for Materials Protection and Performance (AMPP) standards for evaluating corrosion tests (e.g., ASTM G1-03 (2017), Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens), or a suitable equivalent. When the coupons are removed, they will be inspected visually for signs of corrosion or pitting. The weight and size of the coupons will be measured each time they are removed. The rate of corrosion will be calculated using a weight loss method where the rate equals the weight loss during the exposure period divided by the duration of the period.

The initial baseline measurements of the coupons will follow the recommendations of AMPP National Association of Corrosion Engineers (NACE) SP0775-2023. Coupons will be prepared from the material used to construct the injection wells. A method of coupon preparation will be chosen that does not alter the properties of the metal. For example, grinding operations will be controlled to avoid high surface tensions/temperatures that could change the microstructure of the coupon. Coupons may be prepared by smooth grinding with 120-grit paper, by tumbling with loose grit, or by blasting with abrasive blasting material. A consistent finish may be obtained by blasting with glass beads. The abrasives will be free of metallic particles.

A permanent serial number will be etched or stamped on each coupon. ExxonMobil will machine or polish the edges of the coupon to remove cold-worked metal if the cold-worked edges adversely affect the data. ExxonMobil will dry the coupons, measure their length and width and thickness, and weigh them to within ±0.5 milligrams (mg)—then record the mass, serial number, and exposed dimensions, and calculate and record the surface area (including the edges). The areas covered by the coupon holder and shielded areas of flush-mounted coupons will be excluded.

5.5.2.3 Cement Evaluation and Casing Inspection Logs

As discussed in *Section 4 – Well Construction Plan and Operating Conditions*, a cement bond log will be run after the casing has been run and cemented, and sufficient cement curing has taken place. Logging will be conducted to assess the quality of the cement. A baseline CIL will establish the initial dimensions of the wall thickness of the long string casing after it is cemented. Following the installation of the completion equipment, including the tubing and packer assembly, an initial CIL will be run. The CIL will serve as the baseline survey for potential future repeat surveys with the objective of enabling the detection of possible loss of metal mass.

Repeat CILs will only be performed if other monitoring measurements create concern about the integrity of the casing of the wells, and the technical determination is made that a repeat CIL is most suitable to address those concerns. Examples include a loss of annulus pressure and temperature measurements using the gauges installed in the wells. Changes in the recorded electromagnetic response will be analyzed to identify and localize casing corrosion, addressing LAC43: XVII **§3627.A.4**.

5.5.3 Groundwater/USDW Quality Monitoring

To meet the requirements of LAC43: XVII **§3625.A.4**, ExxonMobil will monitor groundwater quality and geochemical changes above the confining zone during the period of operation.

5.5.3.1 Phased and/or Triggered Monitoring

The phased and/or triggered monitoring strategy (Table 5-6) was adopted for the installation of potential additional USDW monitoring wells, soil-gas monitoring wells, and air monitoring locations. The phased approach was deemed reasonable and appropriate based on the schedule of CO_2 injection for five injection wells—and the degree of protectiveness evident based on the geologic site characterization and demonstrated by the plume modeling. This type of approach allows the site-specific testing and monitoring strategies to be tailored to changes in predicted performance and in response to potential increased risks to USDWs identified or detected during injection.

[redacted]

[redacted]

[redacted]

5.5.3.2 Design of the Monitoring Well Network

The monitoring well network includes the proposed monitoring wells that will be used to support compliance with the testing and monitoring requirements under the Class VI Rule. Combined with the monitoring of pressure buildup at each proposed injection well, the design of the monitoring well network was selected to provide a high degree of confidence in detecting vertical CO_2 migration through the confining zone, that may endanger the USDW. The relevant site data considered for the design of the monitoring well network included the phased injection depths, rate, and volume; the geology; and the presence of the legacy wells as required by LAC43: XVII **§3625.A.4.a** and **b**.

5.5.3.3 USDW Monitoring Well Construction

To comply with LAC43: XVII **§3625.A.4**, a phased approach to USDW monitoring well installation is proposed. Initially, [redacted] will be completed at the locations shown in Figure 5-4. These locations were selected to provide a baseline of geochemical data in the vicinity of the five injection wells and the in-zone monitoring well.

The Chicot aquifer is the primary USDW aquifer within the AOR, and its relatively shallow water-bearing zones are a target for the completion of freshwater wells, typically at depths ranging from approximately 60–400 feet below ground level (BGL) in the AOR, as reported in *Appendix C-4* [redacted]

[redacted]

5.5.3.4 Summary of Water Well Data for the AOR

Table 5-7 provides a summary of the [redacted] The well construction details for additional USDW monitoring wells (if constructed) will be consistent with the construction details in Table 5-7.

A total of [redacted] freshwater wells were identified in and near the AOR, as listed in *Appendix C-4*, from the Louisiana Strategic Online Natural Resources Information System (SONRIS). *Appendix C-3* illustrates the location of the water wells. The wells appear to be mostly drilled into the Chicot and Evangeline aquifers, with a maximum depth of [redacted], respectively. For planning purposes, the extent of the CO_2 plume and pressure front relative to the water wells will be reviewed after sufficient data have been collected to assess whether additional USDW groundwater monitoring is needed for situations of potential USDW endangerment.

[redacted]

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

Groundwater samples will be collected using decontaminated submersible pumps equipped with new dedicated, disposable sampling tubing capable of producing representative groundwater samples to the surface with the least pumping effort. The fluid sampling parameters and frequencies for the in-zone and USDW monitoring wells are shown in Table 5-8. Additional USDW monitoring wells will be added to assess the potential for USDW endangerment, if necessary. The USDW monitoring wells will be completed to collect groundwater samples at depths equivalent to public water supply usage.

5.5.3.5 Collection and Analysis of Groundwater Samples

Fluid samples will be taken periodically from the USDW monitoring wells and [redacted]. The USDW monitoring wells target the Chicot aquifer, which is the most-used aquifer in the AOR for potable and non-potable purposes. [redacted]

Table 5-8 summarizes the parameters analyzed and the planned sampling frequency, which apply to the USDW and in-zone monitoring wells. Anomalous measurements will trigger resampling and additional data analysis, including a more detailed evaluation of data using statistical comparisons approved by the EPA for detection monitoring programs. This analysis could also include geochemical modeling to compare the compositions of groundwater from before and during operations.

If warranted, other tests may be added to the evaluation if resampling and detailed analysis of the fluid samples do not satisfactorily rule out an undesired migration scenario.

[redacted]

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	
[redacted]		

Measurements are performed on gases collected from the fluid samples by depressurizing them to atmospheric conditions in a controlled laboratory environment.

ExxonMobil will test the fluid samples and maintain results for the parameters listed in Table 5-8. If results indicate the existence of impurities in the injection stream, the significance of these constituents relative to the protection of USDW will be assessed to determine if they should be included in the analysis of the water samples. Testing results will be stored in an electronic database.

Fluid chemistry data will be monitored for deviations from baseline, predicted, and average values. If a significant variance occurs, the numerical model will be reevaluated. Potential geochemical signs that fluid may be unexpectedly migrating from the uppermost injection interval may be detected upon observation of the following trends:

- Change in TDS
- Change in signature of major cations and anions
- Increase in CO_2 concentration
- Decrease in pH
- Increase in concentration of injectate impurities
- Increase in concentration of leached constituents

5.5.3.6 Laboratory to Be Used/Chain of Custody Procedures

The analysis of the fluid samples will be transported to an accredited and state-approved laboratory. ExxonMobil will observe standard COC procedures and maintain records to allow full reconstruction of the sampling procedure, storage, and transportation, including any problems encountered.

5.5.3.7 Quality Assurance and Surveillance Measures

ExxonMobil will collect replicate samples and sample blanks for QA/QC purposes. The samples will be used to validate test results, if needed. ExxonMobil is currently in the process of compiling the Quality Assurance and Surveillance Plan and will submit it as an update to the permit application.

5.5.3.8 Plan for Guaranteeing Access to All Monitoring Locations

The placement of the well locations is optimized to be accessible from roads.

5.5.4 Upper Confining Zone/Above-Zone Monitoring

5.5.4.1 [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

*MD – measured depth; subject to change based on as-drilled conditions

5.5.5 Plume and Critical Pressure Front Monitoring

[redacted]

5.5.5.1 Direct Monitoring

[redacted]

Any periods of shut-in for an injection well may be observed and treated as a falloff test by recording the shut-in wellhead pressure, bottomhole pressure, and temperature readings. This information, together with the continuous measurements obtained during regular operating conditions, will aid in updating the CO_2 plume reservoir models and plume growth forecasts.

5.5.5.2 Indirect Monitoring: Time-Lapse Seismic Surveying

[redacted]

[redacted]

[redacted]

The timing of [redacted] will occur when the following criteria have been met and the analysis of operational and testing data demonstrates compliance with the Class VI permits—in the [redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

Should at any time the acquisition of indirect monitoring data suggest deviation from expected behavior for compliance with the permits, ExxonMobil will discuss the need with the Commissioner and take appropriate action.

[redacted]

[redacted] A significant amount of direct and indirect monitoring data will be available by this time and conclusions made regarding the predictive capabilities of the CO_2 plume and pressure front subsurface dynamic model for the [redacted] intervals. ExxonMobil expects that the model will be a reliable predictor of the growth rate and extent of CO_2 saturation and pressure plumes. With the Commissioner's concurrence, [redacted]

If additional surface seismic surveys are necessary during the PISC period to improve the model's predictive capability or show CO_2 plume stability, ExxonMobil will communicate with the Commissioner on the nature and timing of such contingent surveys.

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted]

[redacted]

5.5.5.3 <u>Seismicity Monitoring (Induced Seismicity)</u>

[redacted]

[redacted]

References:

Holmes, G., Bongiovanni, N., Wulf, T. et al. (April 2023). Time Lapse Seismic in a CO2 EOR Flood and Implications for CCCS Reservoir Monitoring, GeoGulf 23 Conference, Abstract, Houston, TX.

Appendix E – Testing and Monitoring