Underground Injection Control – Class VI Permit Application for

High West CCS Project
Spoonbill No. 001 to 005

St. Charles and Jefferson Parishes, Louisiana

SECTION 5 – TESTING AND MONITORING PLAN

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SECTION 5 – TESTING AND MONITORING PLAN

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5.1. Introduction

This Testing and Monitoring Plan describes how High West Sequestration LLC (High West) will monitor the High West CCS Project site pursuant to Statewide Order (SWO) 29-N-6, **§3625**. In addition to demonstrating that the well is operating as planned, this plan is designed to ensure that the CO_2 plume and pressure front are moving as predicted, and there is no endangerment to the underground sources of drinking water (USDW). The monitoring data will be used to validate and adjust the geocellular model to predict the distribution of the CO_2 within the storage interval to support area of review (AOR) re-evaluations and a non-endangerment demonstration.

5.2. Reporting Requirements

High West will report the results of all testing and monitoring activities to the Louisiana Department of Energy and Natural Resources (LDENR) in compliance with the requirements under SWO 29-N-6, **§3629**.

As per the requirement of SWO 29-N-6 **§3629**, High West will provide semi-annual reports to the Commissioner of Conservation (Commissioner) containing the following:

- Any changes to the physical, chemical or other relevant characteristics of the CO_2 stream from what has been described in the proposed operating data
- Monthly average, maximum, and minimum values of injection pressure, flow rate and volume, and annular pressure
- Description of any event that exceeds operating parameters for annulus pressure or injection pressure as specified in the permit
- Description of any event which triggers a shut-off device and the response taken
- 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 project
- Monthly annulus fluid volume added
- Results of any monitoring as described in this section
- The raw operating data from the continuous recording devices prescribed by **§3621.A.6** submitted in digital format

In addition, reports will be submitted within 30 days after the following events:

- Any well workover
- Any test of the injection well conducted if required by the Commissioner

Reports will be submitted to the Commissioner, within 24 hours of the following:

- Any evidence that the injected CO_2 stream or associated pressure front may cause an endangerment to a USDW

- Any noncompliance with a permit condition, or malfunction of the injection system, which may cause fluid migration into or between USDWs
- Any triggering of a shut-off system, either downhole or at the surface
- Any failure to maintain mechanical integrity

Notification must be made to the LDENR, in writing, 30 days in advance of:

- Any planned workover
- Any planned stimulation activities
- Any other planned test of the injection well

All reports, submittals, and notifications will be submitted to LDENR. All records will be retained by High West throughout the project's life and for 10 years following site closure. Data on the nature and composition of all injected fluids collected will also be retained for 10 years after site closure. The records will be delivered to the Commissioner after the retention period if required by the Commissioner. Monitoring data as described in Section 5 will be retained for 10 years after it is collected. Well plugging reports, post-injection site care data and the site closure report itself will be retained for 10 years following site closure.

5.3. Testing Plan Review and Updates

This testing and monitoring plan will be reviewed as required by SWO 29-N-6 **§3625** and updated to incorporate monitoring data as described at least every five years. An amended testing and monitoring plan will also be submitted within one year of an AOR re-evaluation, following any significant changes to the facility such as the addition of monitoring wells or newly permitted injection wells within the area of review, or as required by the Commissioner.

5.4. Testing Strategies

5.4.1. Openhole Logging

High West plans to run an advanced suite of openhole logs, listed in Table 5-1, in the stratigraphic test well to obtain data for parameters used in static and dynamic subsurface modeling. The following log descriptions provide examples of the types of logs to be run. The specific logging vendor will be selected just before drilling the well. Commercial and supply chain issues may affect the final vendor selection.

Table 5-1 – Stratigraphic Test Well Openhole Logging Plan

Run	Hole Section	Log Suite	Depth (ft TVDSS)
1	Surface	Quad combo	0 to 2,900
3	Injection	Quad combo	2,900 to 9,700
4	Injection	NMR	2,900 to 9,700
5	Injection	Borehole Imager	2,900 to 9,700

Spectral Gamma Ray

The spectral gamma ray is a mineralogical characterization tool equipped with a pulsed-neutron spectrometer. This tool resolves uncertainties compared to traditional petrophysical evaluation methods and provides enhanced porosity determination, clay type/volume determination, and lithofacies identification.

Magnetic Resonance

The magnetic resonance tool is a nuclear magnetic resonance-based instrument. By alternating static and pulsed radio frequency magnetic fields, the pore-space fluid hydrogen protons are aligned and spun when interacting with the two magnetic fields. These "spin echoes" can be recorded and analyzed based on amplitude and echo decay rates. This action gives information on the porosity, pore size, and type of fluid present. Reliable data acquisition is available in almost every borehole environment.

Borehole Imaging

A borehole imaging tool will be used to capture high-resolution images of the borehole wall, allowing for the identification of fractures, structural dips, borehole stability, and net pay in thinly bedded sequences. The measurement principle and tool selection will depend on the type of drilling mud utilized. Additionally, this imaging tool will aid in well-to-well correlation of sedimentary and stratigraphic data.

Deep Shear-Wave Sonic/Acoustic

The deep shear-wave sonic and acoustic tool delivers acoustic services using monopole and dipole measurements to provide quality compressional and shear-wave measurements in low-velocity and unconsolidated formations. This tool enhances the value and understanding of petrophysics, reservoir characterization, and rock mechanical properties. The XMAC-F1 service builds on the previous XMAC ELITE, can log at twice the speed, and can measure shear slowness up to 1,200 microseconds per foot (μs/ft).

5.4.2. Coring Plan

During the drilling of the stratigraphic test well, an extensive coring program will be conducted as required by SWO **29-N-6 §3617.2.** Whole core and sidewall core samples will be obtained as outlined in Table 5-2. The data obtained from this program will be used to refine the static and dynamic reservoir models for the intervals detailed in Table 5-2. Additional sidewall cores may be obtained to supplement the whole core intervals.

In compliance with SWO 29-N-6 **§3617.B.2**, a descriptive report prepared by a qualified log analyst, including an interpretation of the results, will be submitted during the drilling and construction of the stratigraphic test well.

Table 5-2 – Planned Core Intervals and Testing Program

Zone	Interval Top (ft TVD)	Interval Base (ft TVD)	Whole Core Interval (TVD ft)	Testing Program
Upper Confining Zone	3,674	4,174	3,775 to 3,835	Routine Core Analysis X-Ray Diffraction Scanning Electron Microscopy Special Core Analysis Mercury Injection Formation Damage Testing
Injection Zone	5,700	9,200	6,435 to 6,495; 8,645 to 8,705	
Lower Confining Zone	9,200	9,700	9,475 to 9,535	

5.4.3. Fracture Pressure Determination

As required in SWO 29-N-6 **§3617.B.4**, the fracture pressure of the confining zones and injection intervals will be determined through mini-frac testing. These measurements will be conducted during the drilling of the stratigraphic well. The target formation will be isolated using packers, and a controlled volume of fluid will be injected at progressively increasing pressures until pressure response data indicates fracture initiation.

5.4.4. Initial Step Rate Injectivity Test

To determine the fracture gradient of the High West CCS Project injection wells in accordance with SWO 29-N-6 **§3617.B.4.a** and **§3617.5**, High West will conduct a step-rate test on each well. This test will involve measuring the fracture gradient using bottomhole and surface readout pressure and temperature gauges, which will be run to the total depth of the wellbore. Initial bottomhole pressure and temperature readings will be recorded prior to injection, with all gauges calibrated before testing begins.

The step-rate test will be conducted using brine. Brine injection rates observed during the test will be converted to equivalent CO_2 injection rates by accounting for the differences in fluid properties. Injection rates can be expressed in terms of mass rate (tons per day, tons/D) and converted to volumetric rates (barrels per day, bbl/D) or gas rates (standard cubic feet per day, scf/D). Using the mass rate is particularly effective for compressible fluids such as CO_2.

The densities of CO_2 under both standard conditions and reservoir conditions will be modeled using the Reference Fluid Thermodynamic and Transport Properties Database (REFPROP, Ver. 10.0) developed by the National Institute of Standards and Technology (NIST). REFPROP uses advanced fluid models to calculate thermodynamic, physical, and transport properties for various fluids and fluid mixtures at variable temperatures and pressures, including liquid, gas, and supercritical states. The software incorporates the most accurate models available for 147 industrially significant fluids, allowing for the creation of detailed tables and plots that display fluid properties under different conditions.

Equations:

(Eq. 1)

$$Qm = (Qv * \rho BH)/\rho SC$$

(Eq. 2)

$$\rho BH = f(TBH, PBH, Fluid\ Composition) \leftarrow\ from\ REFPROP\ software$$

(Eq. 3)

$$\rho SC = f(TBH, PBH, Fluid\ Composition) \leftarrow\ from\ REFPROP\ software$$

Where:

Qv = Volumetric flow rate (bbl/day)

Qm = Mass flow rate (scf/D)

TBH = Temperature at bottomhole (°F)

ρBH = Pressure at bottomhole (°F)

ρBH = CO_2 density at bottomhole conditions, pound per cubic foot (lb/ft^3)

ρSC = CO_2 density at standard conditions (lb/ft^3)

5.4.4.1. Testing Method

This test will be performed on each of the five wells, each targeting a different injection interval. A bottomhole pressure gauge and temperature gauge will be deployed to the bottom of the wellbore in each well, along with a surface gauge providing continuous readout. All gauges will be calibrated before testing, and initial bottomhole pressure and temperature measurements will be recorded prior to injection. A calibrated turbine flowmeter will be utilized to measure expected flow rates.

Brine injection will commence at an initial rate of 1.0 barrel per minute (bpm) and be maintained for at least 30 minutes. Each subsequent injection rate will then be incrementally increased with approximately three readings taken below the estimated formation fracture initiation pressure and three readings above. The injection rate may reach up to 150% above the maximum proposed injection rate. Each stage will be held for a minimum of 30 minutes intervals. The actual step duration will depend on the time required for pressure stabilization during the initial step. After the final step, once pressure stabilizes, the pressures will be recorded at the highest frequency of the gauge for a duration determined from the step-up phase of the test to assess the pressure bleed-off rate. Testing procedures will be repeated for each of the five wells to evaluate fracture gradients across the five distinct zones. Tables 5-3 through Table 5-7 outline the planned test duration and rates for each of the five injection wells.

Table 5-3 – Spoonbill No. 001 Proposed Step-Rate Injection Test

Step	Duration (min)	Rate (bpd)	Rate (bpm)	Volume (bbl)	Cumulative (bbl)
1	30	1,440	1	30	30
2	30	7,200	5	150	180
3	30	12,960	9	270	450
4	30	24,480	17	510	960
5	30	36,000	25	750	1,710
6	30	47,520	33	990	2,700
7	30	59,040	41	1,230	3,930
8	30	70,560	49	1,470	5,400
Total					5,400

Table 5-4 – Spoonbill No. 002 Proposed Step-Rate Injection Test

Step	Duration (min)	Rate (bpd)	Rate (bpm)	Volume (bbl)	Cumulative (bbl)
1	30	1,440	1	30	30
2	30	7,200	5	150	180
3	30	12,960	9	270	450
4	30	21,600	15	450	900
5	30	30,240	21	630	1,530
6	30	38,880	27	810	2,340
7	30	47,520	33	990	3,330
8	30	56,160	39	1,170	4,500
Total					4,500

Table 5-5 – Spoonbill No. 003 Proposed Step-Rate Injection Test

Step	Duration (min)	Rate (bpd)	Rate (bpm)	Volume (bbl)	Cumulative (bbl)
1	30	1,440	1	30	30
2	30	7,200	5	150	180
3	30	12,960	9	270	450
4	30	24,480	17	510	960
5	30	36,000	25	750	1,710
6	30	47,520	33	990	2,700
7	30	59,040	41	1,230	3,930
8	30	70,560	49	1,470	5,400
Total					5,400

Table 5-6 – Spoonbill No. 004 Proposed Step-Rate Injection Test

Step	Duration (min)	Rate (bpd)	Rate (bpm)	Volume (bbl)	Cumulative (bbl)
1	30	1,440	1	30	30
2	30	7,200	5	150	180
3	30	12,960	9	270	450
4	30	24,480	17	510	960
5	30	36,000	25	750	1,710
6	30	47,520	33	990	2,700
7	30	59,040	41	1,230	3,930
8	30	70,560	49	1,470	5,400
Total					5,400

Table 5-7 – Spoonbill No. 005 Proposed Step-Rate Injection Test

Step	Duration (min)	Rate (bpd)	Rate (bpm)	Volume (bbl)	Cumulative (bbl)
1	30	1,440	1	30	30
2	30	7,200	5	150	180
3	30	12,960	9	270	450
4	30	27,360	19	570	1,020
5	30	41,760	29	870	1,890
6	30	56,160	39	1,170	3,060
7	30	70,560	49	1,470	4,530
8	30	84,960	59	1,770	6,300
Total					6,300

5.4.5. Mechanical Integrity Testing – Annulus Pressure Test

High West will perform internal mechanical integrity Tests (MIT) prior to initial injection, annually, and after any subsequent workovers to meet the requirements of SWO 29-N-6 **§3627.A.2.**

High West will perform an annulus pressure test on each injection well to detect any significant leaks when the casing is subjected to a pressure equivalent to that which the casing would be exposed if the tubing or packer failed. To assure the integrity of the injection casing, the tubing/casing annulus will be tested at a pressure equal to the maximum allowed injection pressure or 1,000 psi, whichever is greater. The annular test pressure will be a difference of at least 200 psi either greater or less than the injection tubing pressure.

Annulus Pressure Test Criteria

1. The duration of the pressure test is 30 minutes.
2. Both the annulus and tubing pressures will be monitored and recorded every 5 minutes.

3. If there is a pressure change of 10% or more from the initial test pressure during the 30-minute duration, the test well has failed to demonstrate mechanical integrity and will be shut in to determine the cause for remediation.
4. If there is no significant pressure change in 30 minutes from the time the pressure source is disconnected from the annulus, the test may be completed as passed.

5.4.6. External Mechanical Integrity Testing

High West will verify the external mechanical integrity of the injection wellbores for Spoonbill No. 001 through No. 005 as required by SWO No. 29-N-6 **§3617.B.1.d** and **§3267.A.3** during the injection phase. The external mechanical integrity of the system will be continuously monitored using a distributed temperature fiber optics array. This technology will enable real-time temperature measurements along the entire length of the wellbore and will be utilized to determine the absence of significant fluid movement while providing early detection of potential leaks.

An annual report will be prepared and submitted to LDENR. The report will be prepared by a knowledgeable analyst and will provide a comprehensive summary and will include an interpretation of the results of the temperature data collected during the monitoring timeframe. This report will provide verification of the absence of significant fluid movement outside of the injection zone into the USDW.

5.4.7. Pressure Falloff Testing

High West will conduct the required initial pressure falloff test under SWO No. 29-N-6 **§3617.B.5.a** and will repeat this test at least every five years in accordance with SWO No. 29-N-6 **§3625.A.6.** These tests are designed to measure near-wellbore formation properties and to monitor for any environmental changes in the near-wellbore area that could affect injectivity and lead to pressure increases. The parameters obtained from these falloff tests will be compared with those derived from computational modeling and previous tests to detect any indications of fluid leakage during the test.

5.4.7.1. Testing Method

For each injection well, the injection rate and pressure will be held as constant as possible before the beginning of the test, with data continuously recorded during the test. After the well is shut in, a downhole pressure array installed during the completion of the well will continuously take the pressure measurements. This system consists of a tubing encapsulated conductor (TEC) cable equipped with bottomhole pressure gauges within each planned injection stage. Once the pressure decay data plotted on a semi-log plot is a straight line, indicating that radial flow conditions are reached, the falloff period will end.

Detailed Pressure Falloff Test Procedure:

1. Prior to testing, keep the injection rate and pressure as constant as practical and continuously recorded.
    a. Maintain the injection at high enough rate and duration to produce a measurable pressure transient that will result in a valid falloff test.
    b. Shut in offset wells prior to and during the test. If shut-in is not feasible, a constant injection rate should be recorded and maintained during the test and then accounted for in the analysis.
    c. Do not shut in two wells simultaneously or change the rate in an offset well during the test.
2. Stop injection and shut in the well completely.
    a. This shut-in should occur over the shortest time possible.
3. During the shut-in period, continue to record temperatures and pressures at the highest obtainable frequency.
    a. The shut-in period should be long enough to observe a straight line of pressure decay on a semi-log plot (i.e., radial flow is achieved). The radial flow portion of the test is the basis for all pressure transient calculations. Therefore, the falloff portion of the test should be designed to reach radial flow, and to sustain a time frame sufficient for analysis of the radial flow period.
    b. A general rule of thumb is to run the test for three to five times the time required to reach radial flow conditions.

5.4.7.2. Analytical Methods

Mechanical integrity and near-wellbore conditions (flow-regimes, well skin, hydraulic property, and boundary conditions) will be determined through standard diagnostic plotting. This determination is accomplished by analyzing observed pressure changes and pressure derivatives on standard diagnostic log-log and semi-log plots using specialized pressure-transient analysis software. The analysis will integrate additional data beyond the injection well's rate and pressure data. The additional data may include operational history, offset well injection and operational history, and information collected from the permanent gauges installed on the TEC cable in the injection well. Depending on the complexity of the pressure response, it may be necessary to incorporate numerical modeling into the interpretation workflow.

Significant changes in the well or reservoir conditions may be identified by comparing the baseline pressure falloff test with subsequent tests. The effects of the fluid flow and the compressibility of the injected fluid will be considered and incorporated into the analysis. The well parameters resulting from falloff testing will be compared against those used in AOR determination and computational site modeling. Notable changes in reservoir properties may dictate that an AOR re-evaluation is necessary.

5.4.7.3. Quality Assurance/Quality Control (QA/QC)

All field equipment will undergo inspection and testing before operation. Manufacturer calibration recommendations will be adhered to for the pressure gauges used in the falloff test.

Documentation certifying proper calibration will also be enclosed with the test results. Further validation of the test results will be determined by an extended collection of pressure data from the exhausted and plugged injection stages. The continuation of pressure monitoring in deeper, inactive stages allows for recording of the naturally occurring pressure decay. Unexpected pressure communication between stages can be detected.

5.4.8. Cement Evaluation and Casing Inspection Logs

In accordance with SWO 29-N-6 **§3617.B.1.b.ii**, **§3617.B.1.c.ii**, and **§3617.B.1.d.iv**, a comprehensive cased hole logging suite will be conducted at the time of the initial well completion on the surface, intermediate and production casing string. This logging suite will include a radial cement evaluation, a multi-arm caliper log, and a digital log to assess the condition of the casing metal. These logs will provide a detailed characterization of the wellbore materials in their original state. After the tubing is installed, an initial through-tubing inspection log will be performed, serving as the baseline for future casing integrity inspections.

Casing inspection logs will be performed every 10 years or at shorter intervals as needed—or as requested by the Commissioner. The tools that will be run at that time include the following:

- Through-tubing casing inspection log
- Multiple-armed calipers to measure the inner diameter of the casing as the tool is raised or lowered into the well

High West will provide a schedule of all logging plans to the Commissioner at least 30 days before conducting the first test. Notice will be provided at least 48 hours in advance of such activity.

5.4.8.1. Casing Log Equipment Overview

Through-tubing logging technology provides the ability to evaluate casing deformation and curve-deviation measurements in conjunction with other well-integrity tools, such as multi-finger calipers and multiple pipe-thickness logging tools. This technology provides quality measurements without requiring the removal of the tubing and packer (Yang et al., 2021).

The following descriptions of the through-tubing logging tools that will be run are provided for information purposes. The final vendor will be selected before operations, based on availability and commercial considerations.

The instruments listed in Table 5-8 use pulsed eddy current (PEC) decay technology to measure the thicknesses of multiple concentric tubulars. Basic PEC decay technology theory is included in the supplemental information at the end of this document. These tools can be run stand-alone or combined with other well integrity and correlation instruments—such as multi-finger imaging caliper, temperature, noise, pressure, fluid density, capacitance, flowmeter, gamma ray, and casing collar locator.

The through-tubing PEC decay measurements are not affected by wellbore fluid types, chemical precipitates, or other foreign material deposits. They are also not affected by the type or distribution of annular materials, such as cement, mud, liquid, or gas.

Table 5-8 – PEC Tool List

Pulsed Eddy Current Decay Thickness Instruments					
Tool	Tool O.D.	Max # concentric pipes	Max O.D.	Max Combined Wall Thicknesses	Ratings (degF/K psi)
MTD-B/C	1-11/16"	2	10-3/4"	1.75"	350/15
MTD-G	1-11/16"	3	16"	2.5"	350/15
ePDT-II	2" / 1-11/16"	3-5	30" / 18-5/8"	3.5"	350/20

*O.D. = outer diameter
degF/K = degrees Fahrenheit per thousand pounds per square inch

Logging speeds depend on the size and number of tubulars to be logged. In general, multiple tubulars and larger sizes will necessitate slower data acquisition speeds, which range from 30 ft per minute to 5 ft per minute, based on the complexity of the wellbore configuration.

The through-tubing PEC decay instruments measure the increase or decrease of metal thickness for each concentric tubular. PEC decay data combined with inspection of the tubular's inner diameter (ID) using an imaging caliper or other methods can reliably predict the inside vs. outside location of corrosion or flaws on the innermost tubular. Internal wear based on drilling or other known causes of internal damage is readily assessed, assuming that the measured metal loss in such cases is "internal."

The degree of penetration is reported in percent wall loss from the nominal and absolutes value of metal thickness, expressed in inches or millimeters. Because of well-understood and long-established PEC decay physics principles, reported metal gain or loss is assumed to be distributed evenly around the pipe's circumference.

The through-tubing PEC decay instruments measure the increase or decrease of metal thickness, which includes both internal and external corrosion effects. This overall metal thickness/degree of penetration is valid in identifying areas of concern with well integrity. Additionally, integrity assessment of the injection tubulars (i.e., tubing[s] and first casing) is only part of whether a wellbore and its associated tubulars are in such a condition as to be protective of public health, safety, and the environment. The newer-generation through-tubing PEC decay instruments provide an opportunity to assess the state of the protection tubulars (i.e., second casing, surface casing, etc.).

5.4.9. Logging and Testing Reporting

In accordance with SWO 29-N-6 **§3617.B.1**, a descriptive report prepared by a qualified log analyst, including an interpretation of the results, will be submitted subsequent to the drilling and construction of Spoonbill No. 001 through No. 005.

5.5. Monitoring Plan

High West will incorporate a robust monitoring program as required by SWO 29-N-6 to ensure the safe and effective operation of Class VI well. As summarized in Table 5-9, the monitoring system encompasses multiple types, each designed to track key operational and environmental parameters. These monitoring types include pressure and temperature monitoring within the injection zone, geophysical and seismic monitoring to detect any subsurface migration, and groundwater monitoring to assess potential impacts on underground sources of drinking water. The table details the specific monitoring systems employed, their respective locations, and the sampling frequency, ensuring a comprehensive and systematic approach to data collection. By integrating these monitoring components, the system enhances regulatory compliance, supports data-driven decision-making, and safeguards both environmental and public health. Additional details on the individual monitoring methods and their implementation are provided in the subsequent sections.

Table 5-9 – Testing and Monitoring Plan

Monitoring Type	Monitoring Program	Location	Frequency
CO_2 Injection Stream Composition	• CO_2 sampling station	CO_2 meter run	Continuous
Corrosion Monitoring	• Corrosion coupon system	Facility flowline	Quarterly
Continuous Recording of Injection Pressure, Rate, and Volume	• Surface pressure and temperature gauges • Coriolis mass flowmeter	Wellhead	Continuous
Well Annulus Pressure Between Tubing and Casing	• Annular pressure gauge	Wellhead	Continuous
Groundwater Monitoring	• USDW monitoring well	USDW No. 001 USDW No. 002	Annually
Above Confining Zone (ACZ) Monitoring	• Fluid samples • Pressures	Above Zone Monitoring (AZM) well	Continuously Annually
Direct Reservoir Monitoring	• Spoonbill Nos. 001 and 002: cemented gauges along the production casing. • All injection wells: pressure and temperature	Spoonbill No. 001 Spoonbill No. 002 Spoonbill No. 003 Spoonbill No. 004 Spoonbill No. 005	Continuously

Monitoring Type	Monitoring Program	Location	Frequency
	gauges ported inside the production casing above the perforations. • Gauges will be connected to surface readout through TEC lines.		
Indirect Reservoir Monitoring	• VSP surveys	Facility	Every 5 years
Internal and External Mechanical Integrity	• Annulus pressure test • DTS Monitoring • Casing pressure test • Pressure falloff test • Casing Inspection Logs	Spoonbill No.001 Spoonbill No. 002 Spoonbill No. 003 Spoonbill No. 004 Spoonbill No. 005	• Annually • Continuously • 5 years • 5 years • 10 years

5.5.1. Continuous Injection Stream Physical Monitoring

High West will ensure continuous monitoring of the injection pressure, rate and volume, and annulus pressure are in compliance with SWO 29-N-6 **§3625.A.2** requirements. A Supervisory Control and Data Acquisition system (SCADA) will be installed at the injection well site to facilitate the operational data collection, monitoring, and reporting.

Continuous monitoring of the injected carbon dioxide stream pressure and temperature will be performed using digital pressure gauges installed in the CO_2 pipeline near the pipeline-wellhead interface. An on-site SCADA system will be connected to the pipeline, and a Coriolis mass flow transmitter used to measure the injected CO_2 mass flow rate will be installed on the injection well. It will be connected to the SCADA system at the carbon dioxide storage site to ensure continuous monitoring and control of the CO_2 injection rate. Downhole measurement will be accomplished using a TEC cable to power and communicate with the pressure and temperature gauges

5.5.1.1. Analytical Methods

High West will review and interpret continuously monitored parameters to validate that the operating conditions stay within the permitted limits. The data review will also analyze trends to help determine any need for equipment maintenance or calibration. These data reports will be submitted semi-annually as required by SWO 29-N-6 **§3629.A.1.a.**

5.5.1.2. Continuous Monitoring of Annulus Pressure

In accordance with SWO 29-N-6 **§3625.A.2**, continuous recording devices will be installed and utilized to track both the tubing-casing annulus pressure and the volume of annulus fluid added.

The annular monitoring system consists of a continuous annular pressure gauge, an annulus fluid tank, a fluid pump, an annulus fluid rate meter, pressure regulators, and a continuously monitored tank fluid level. The annulus system will maintain annulus pressure with a fluid pump and fluid bleed system connected to the annulus fluid tank.

Data deviation from baseline, predicted, or average values will be monitored continuously by the measurement devices as described and compared to real-time average, historical average, and predicted values. A 10% change in casing-tubing pressure or annular fluid volumes may indicate a loss of mechanical integrity. Deviation from expected values will initiate an alarm on the process control system, resulting in an immediate shut-in or data review.

5.5.1.3. Analytical Parameters
High West will review and interpret continuously monitored parameters to validate that they are within permitted limits. The data review will also include an examination for trends to help determine any need for equipment maintenance or calibration. The data collected will be utilized to submit as part of the required semi-annual reports per SWO 29-N-6 **§3629.A.1.a.**

5.5.2. CO_2 Mass Rate to Volumetric Injection Rate Calculation Methodology

If a mass meter is used, the flow rates measured during CO_2 injection can be converted to a volumetric flow rate by considering the density of the fluid. The pressure, temperature, and fluid composition are required to calculate density at specific conditions. To determine the density, REFPROP or a similar fluid-property calculation software may be used.

Output Variables:

Q_{vbh} = *Volumetric flow rate at bottomhole standard cubic feet per day (scf/D)*

Input Variables:

Q_m = *Mass flow rate (scf/D)*

ρ_{sc} = *CO_2 density at standard conditions (lb/ft^3) (calculated from REFPROP)*

T_{bh} = *Temperature at standard conditions ($°\mathrm{F}$)*

P_{bh} = *Pressure at standard conditions (psi)*

ρ_{bh} = *CO_2 density at bottomhole conditions (lb/ft^3) (calculated from REFPROP)*

T_{bh} = *Temperature at bottomhole ($°\mathrm{F}$)*

P_{bh} = *Pressure at bottomhole ($°\mathrm{F}$)*

Equation:

(Eq. 4)

$$Q_{vbh} = \frac{Q_m * \rho_{sc}}{\rho_{bh}}$$

5.5.2.1. Chemical Composition Monitoring

In accordance with SWO 29-N-**6 §3625.A.1** requirements, High West plans to sample the CO_2 injection stream and use the results of those samples to evaluate any potential interactions of CO_2 and other injectate components. CO_2 injection stream samples will be taken quarterly for chemical analysis of the parameters listed in Table 5-10, plus continuous pressure and temperature analysis.

5.5.2.2. Sampling Methods

CO2 samples will be analyzed at LELAP-certified and approved laboratories. The collection and reporting of the samples will be documented in accordance with the chain of custody procedures. CO_2 stream samples will be collected from the CO_2 pipeline, in a location representative of injection conditions. A sampling station will be connected to the pipeline inlet meter at a sampling manifold. Sampling cylinders will be purged with the injectate gas to expel laboratory-added gas or vacuum cylinders used to obtain the samples.

Modifications to sampling frequency will be implemented for events such as a change in CO_2 content. High West will monitor parameters to ensure that operating conditions remain within permitted limits. Any deviations from the average baseline parameters or samples will be reported on the semi-annual reports as required by SWO 29-N-6 **§3629.A.1.a**.

5.5.2.3. Parameters to be Measured

Table 5-10 provides a list of the CO_2 parameters that will be measured during composition monitoring.

Table 5-10 – Summary of Parameters to be Measured

Parameter
Oxygen
Nitrogen
Carbon monoxide
Nitrogen oxides
Total hydrocarbons
Methane
Sulfur dioxide
Total sulfur
Hydrogen sulfide
Ethanol
CO_2 purity
Water

5.5.3. Corrosion Coupon Monitoring

Monitoring corrosion of the well tubing and casing materials will be conducted in adherence with SWO 29-N-6 **§3625.A.3** requirements. A quarterly evaluation of a corrosion coupon monitoring system will be performed in addition to the examination of casing inspection logs conducted every 10 years with permit renewal.

High West will monitor corrosion using the corrosion coupon method and collect samples according to the description in Section 5.5.2.1.

5.5.3.1. Sampling Methods

Samples of materials used in the construction of the compression equipment, pipeline, and injection well that encounter the CO_2 stream will be included in the corrosion monitoring program either by using actual material and/or conventional corrosion coupons. The samples consist of those items listed in Table 5-11. Each coupon will be weighed, measured, and photographed prior to initial exposure.

Table 5-11 – Corrosion Coupon Material

Equipment Coupon	Material of Construction
Long string surface casing (surface to 2,000 ft)	Carbon steel
Long string intermediate casing (surface to 3,800 ft)	Carbon steel
Long string injection casing (surface to 3,800 ft)	Carbon steel
Long string injection casing (3,800 to 11,100 ft)	Chrome alloy
Long string injection casing (11,100 to 11,500 ft)	Carbon Steel
Long string tubing	Chrome alloy
Wellhead	Chrome alloy
Packers	Chrome alloy

5.5.3.2. Deviation Response

In any event where the sampling or analysis indicates that there is a variance from the normal baseline, an investigation will take place and the appropriate response, including any corrective action, will be determined. If the investigation indicates a potential endangerment to the USDW, injection operations will be ceased, and a report will be submitted to the LDENR within 24 hours.

5.5.4. Groundwater Quality Monitoring

High West will ensure compliance with the requirements of SWO 29-N-6 **§3625.A.4** by monitoring groundwater quality and geochemical changes through a multi-well monitoring strategy. This approach targets distinct subsurface intervals, including shallow groundwater, sands included in the USDW, and above confining zone permeable sands. Water samples will be collected from two USDW wells, and one above-zone monitoring well. Table 5-12 outlines the locations of these wells, their radial distances from the injection well, and the depths of the formations from which samples will be collected.

Water samples will be collected throughout all phases of the sequestration project lifecycle—pre-operation, injection, and post-injection. During the pre-operation phase, baseline water quality parameters will be established through sampling conducted prior to the start of CO_2 injection. During the injection phase, water samples will be collected annually, with sampling performed within 45 days prior to the anniversary of the injection authorization each year. After the cessation of injection, sampling will continue every five years to ensure ongoing compliance and monitoring of groundwater quality.

Table 5-12 – Groundwater Monitor Well Locations

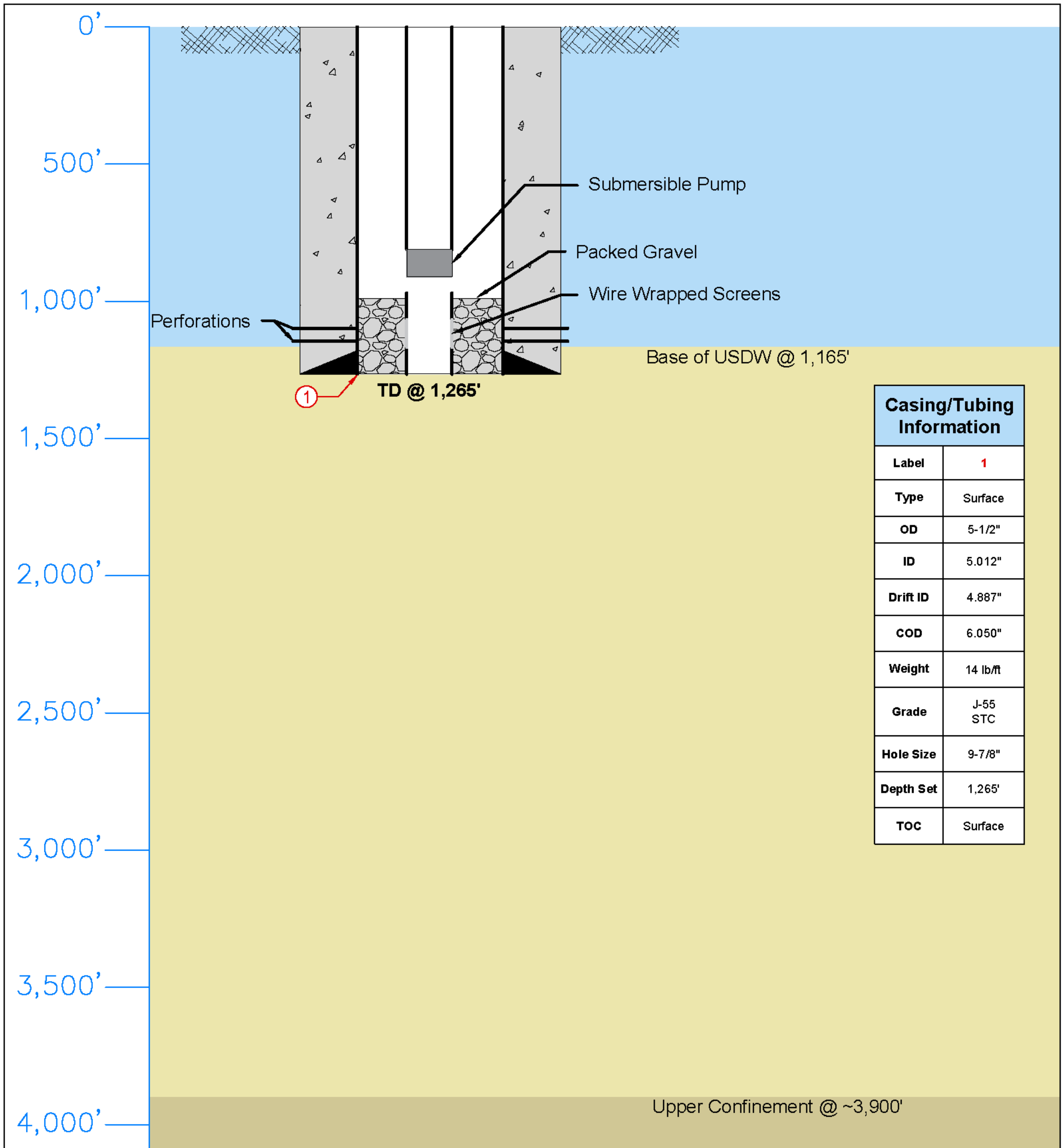
Well Name	X NAD 1927 South Zone (bhl)	Y NAD 1927 South Zone (bhl)	Distance From Site (ft)	Monitoring Interval Depth (ft)
USDW No. 001	[redacted]		5,075	1,165
USDW No. 002			19,670	1,165
AZM No. 001			5,160	~3,600

High West will install two USDW monitoring wells. USDW No. 001 will be constructed near the location of the AZM well. USDW No. 002 will be constructed by converting the High West stratigraphic test well to USDW Monitor Well No. 002.

The wells will be arranged in a configuration around the injection well to ensure that water samples are collected from areas where the injected CO_2 is anticipated to migrate. This design provides comprehensive coverage for effective sampling. A map showing the proposed locations of the USDW monitoring wells is presented in Figure 5-1. The proposed well design for the USDW monitoring wells is shown in Figure 5-2 and 5-3. The AZM well design is shown in Figure 5-4.

[redacted]

Figure 5-1 – Monitoring Well Locations

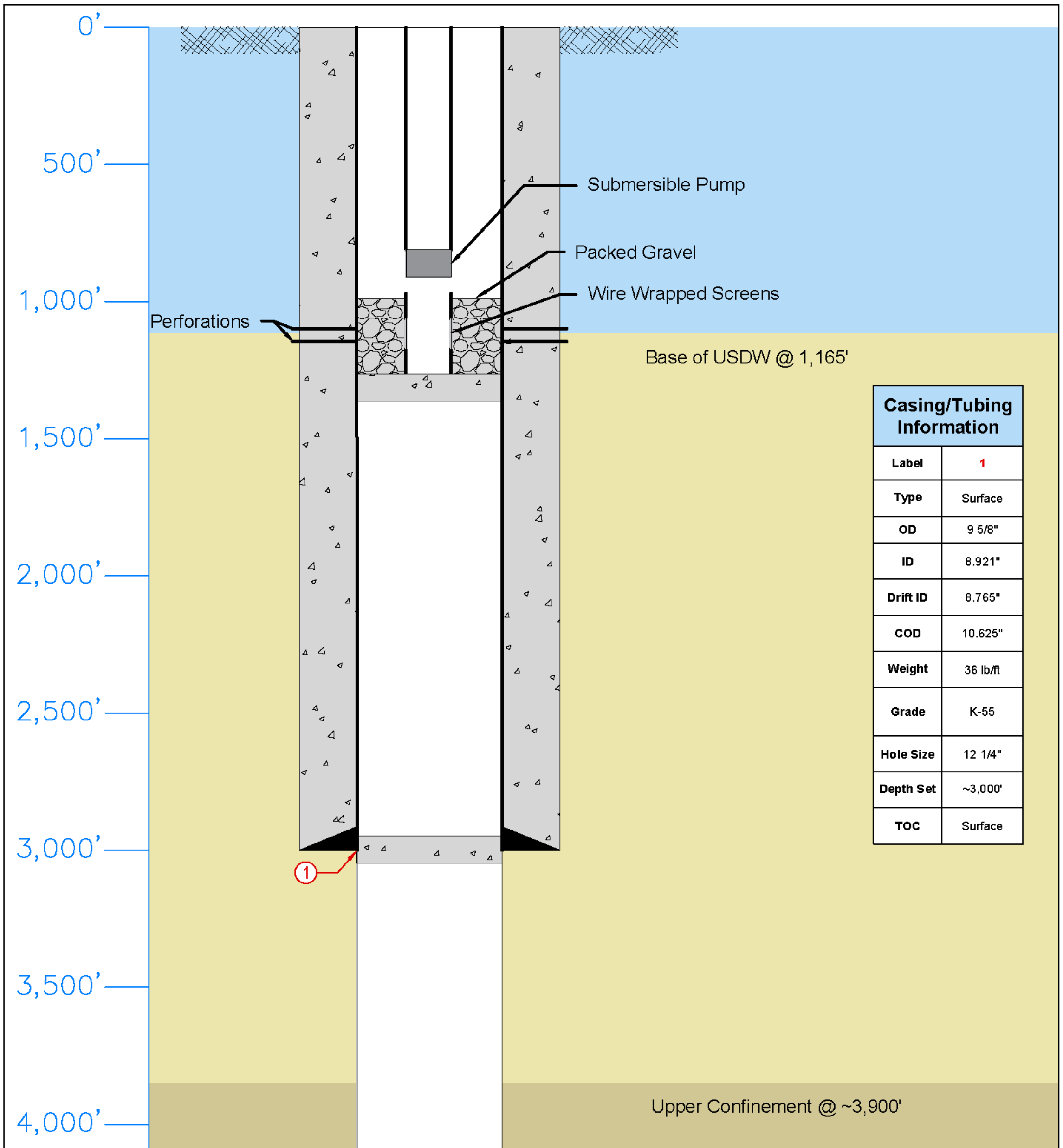


Casing/Tubing Information

Label	1
Type	Surface
OD	5-1/2"
ID	5.012"
Drift ID	4.887"
COD	6.050"
Weight	14 lb/ft
Grade	J-55 STC
Hole Size	9-7/8"
Depth Set	1,265'
TOC	Surface

LONQUIST		USDW Monitor Well No. 001	
	Country: USA	**State/Province:** Louisiana	**County/Parish:** St. Charles
	API No: TBD	**Field:**	**Well Type/Status:** Class VI
Louisiana License EF-7423	**RRC District No:**	**Project No:** LS232	**Date:** 02/20/2025
12912 Hill Country Blvd. Ste F-200 Austin, Texas 78738 Tel: 512.732.9812 Fax: 512.732.9816	**Drawn:** Lauren Mayo	**Reviewed:** Andy Ellis	**Approved:** William H. George, P.E.
	Rev No: 1	**Notes:**	

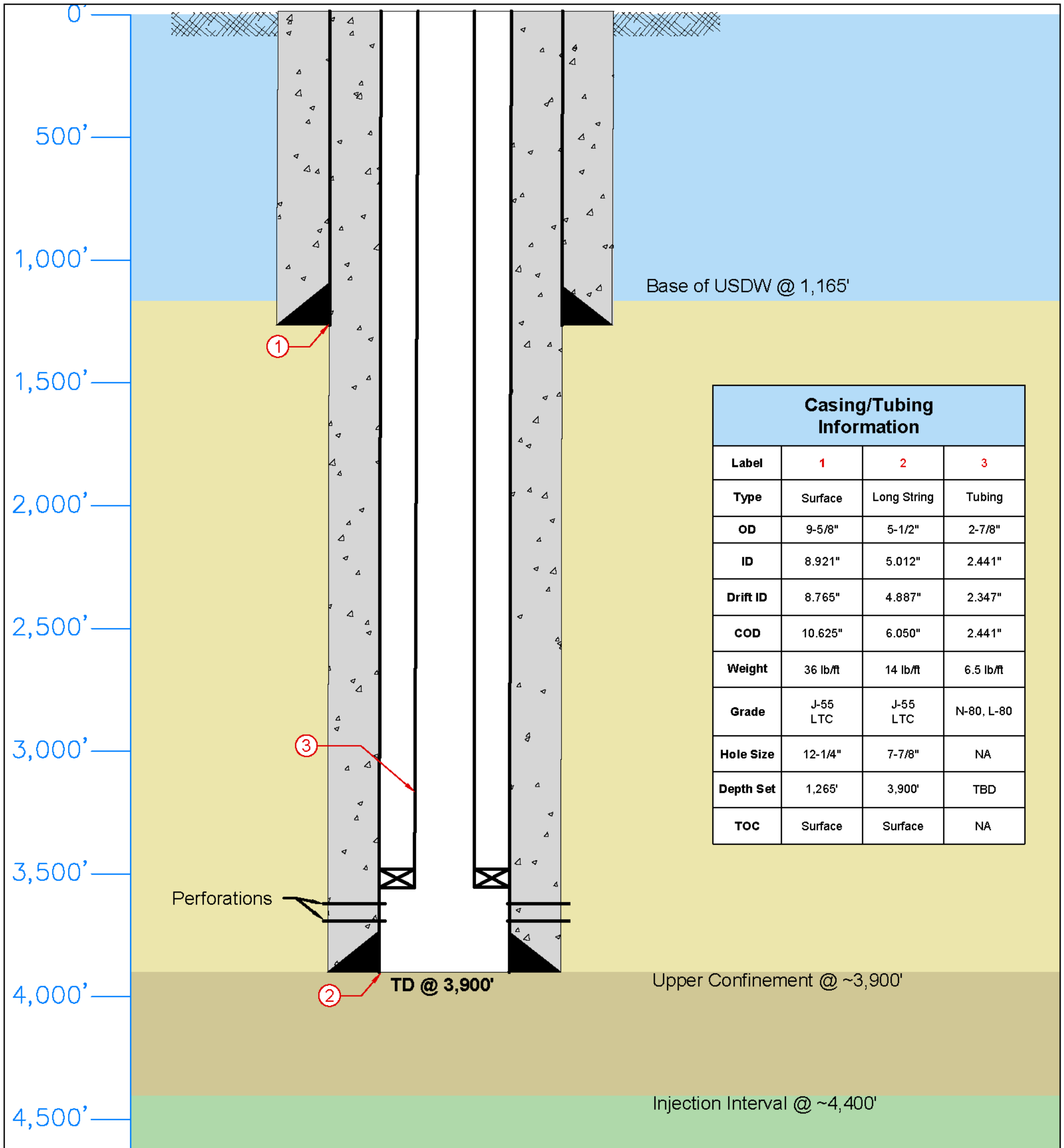
Figure 5-2 – USDW Monitoring Well Design



Casing/Tubing Information	
Label	1
Type	Surface
OD	9 5/8"
ID	8.921"
Drift ID	8.765"
COD	10.625"
Weight	36 lb/ft
Grade	K-55
Hole Size	12 1/4"
Depth Set	~3,000'
TOC	Surface

LONQUIST		USDW Monitor Well No. 002	
	Country: USA	**State/Province:** Louisiana	**County/Parish:** St. Charles
	API No: TBD	**Field:**	**Well Type/Status:** Class VI
Louisiana License EF-7423	**RRC District No:**	**Project No:** LS232	**Date:** 02/20/2025
12912 Hill Country Blvd. Ste F-200 Austin, Texas 78738 Tel: 512.732.9812 Fax: 512.732.9816	**Drawn:** Lauren Mayo	**Reviewed:** Andy Ellis	**Approved:** William H. George, P.E.
	Rev No: 1	**Notes:**	

Figure 5-3 – USDW Monitoring Well Design



Casing/Tubing Information

Label	1	2	3
Type	Surface	Long String	Tubing
OD	9-5/8"	5-1/2"	2-7/8"
ID	8.921"	5.012"	2.441"
Drift ID	8.765"	4.887"	2.347"
COD	10.625"	6.050"	2.441"
Weight	36 lb/ft	14 lb/ft	6.5 lb/ft
Grade	J-55 LTC	J-55 LTC	N-80, L-80
Hole Size	12-1/4"	7-7/8"	NA
Depth Set	1,265'	3,900'	TBD
TOC	Surface	Surface	NA

LONQUIST		AZM Well No. 001	
	Country: USA	**State/Province:** Louisiana	**County/Parish:** St. Charles
	API No: TBD	**Field:**	**Well Type/Status:** Class VI
Louisiana License EF-7423	**RRC District No:**	**Project No:** LS232	**Date:** 01/03/2025
12912 Hill Country Blvd. Ste F-200 Austin, Texas 78738 Tel: 512.732.9812 Fax: 512.732.9816	**Drawn:** Lauren Mayo	**Reviewed:** Andy Ellis	**Approved:** William H. George, P.E.
	Rev No: 1	**Notes:**	

Figure 5-4 – Above Zone Monitoring Well Design

5.5.4.1. Parameters to be Measured

Fluid samples will be collected from the USDW monitoring wells using an electric submersible pump. The pump will evacuate a minimum of two wellbore volumes of liquid before collecting a representative sample at the surface. Samples will be taken quarterly with the parameters to be measured listed in Table 5-13.

Table 5-13 – Groundwater Quality Parameters Measured

Parameters	Analytical Methods
Mississippi River Alluvial Aquifer and Miocene zones	
Cations:	**ICP-MS**
Al, Ca, Mn, As, Cd, Cr, Cu, Pb, Sb, Se, and Tl	EPA Method 6020. EPA Method 200.7/200.8 or similar by inductively coupled plasma optical emission spectroscopy (ICP-OES) or mass spectroscopy (ICP-MS) or EPA Method 6010B
Cations:	**ICP-OES,**
Ca, Fe, K, Mg, Na, and Si	EPA Method 6010B. EPA Method 200.7/200.8 or similar by inductively coupled plasma optical emission spectroscopy (ICP-OES) or mass spectroscopy (ICP-MS) or EPA Method 6020
Anions:	**Ion Chromatography,**
Br, Cl, F, NO3, and SO4	EPA Method 300.0/300.1 or similar by ion chromatography; SM 4500 for sulfide by colorimetry
Dissolved CO_2	Coulometric titration, ASTM D513-11 or RSK-175M by gas chromatography/flame ionization detector (GC/FID)
Total Dissolved Solids	Gravimetry; APHA 2540 C or EPA Method 160.1/SM 2540 C by gravimetry
Alkalinity	APHA 2320B or SM 2320 B/EPA Method 310.1 by titration
pH (field)	EPA Method 150.1/SM4500-H+B electrometrically
Specific conductance (field)	APHA 2510 or EPA Method 120.1 by conductivity meter
Temperature (field)	Thermocouple

5.5.4.2. Sampling Methods

Water samples will be sent to a laboratory accredited by LELAP. Standard chain-of-custody procedures will be followed, and records maintained to allow a full reconstruction of how the samples were collected, stored and transported, including any problems encountered.

5.5.4.3. Analytical

High West will test water samples and maintain results for the parameters listed in Table 5-13. If the CO_2 injectate contains unique impurities, groundwater samples will also be tested to flag any concentrations exceeding the baseline.

Potential signs that fluid may be leaking from the injection interval(s) may be detected upon observation of the following trends:

- Change in TDS
- Changing signature of major cations and anions
- Decreasing pH
- Increasing concentration of injectate impurities
- Increased concentration of leached constituents
- Increased reservoir pressure and/or static water levels

If a significant change is observed, further investigation may be warranted. These next steps could include, but are not limited to, using a pressure jar to collect a sample of the fluid and dissolved CO_2 to confirm the results.

5.5.4.4. Baseline Samples

Baseline groundwater samples will be taken at least 3 months prior to the start of injection at USDW No. 001 and USDW No. 002.

AZM No. 001 has been designed with the ability to collect a fluid sample if required.

5.5.4.5. Deviation Response

In the case of any occurrence wherein the sampling or analysis reveals a deviation from the average of the baseline samples, the proper regulatory authorities will be informed. Subsequently, an inquiry will be conducted, and a suitable course of action—including potential corrective measures—will be identified. If a sample is determined to be an outlier, caused by data error and anomalies, that sample may be deleted from the average. Screening of outliers may include methods such as boxplots, normal probability plots, the Grubbs test, and the Dixon test (Rangeti et al., 2015). If the investigation indicates a potential endangerment to the USDW, injection operations will be ceased, and a report will be submitted to the LDENR within 24 hours.

5.5.4.6. Laboratory to be Used/Chain of Custody Procedures
Water samples will be sent to a laboratory accredited by LELAP. Standard chain-of-custody procedures will be followed, and records maintained to allow a full reconstruction of how the samples were collected, stored and transported, including any problems encountered.

5.5.4.7. Plan for Guaranteeing Access to all Monitoring Locations
As part of surface-use lease agreements with landowners across the plume area, groundwater monitoring wells will be installed to ensure access for sampling and maintenance. To prevent unauthorized access, each well will be securely capped and locked.

5.5.4.8. Additional Freshwater Baseline Sampling
A groundwater well search was conducted, and no water wells were found within the AOR.

5.5.5. Upper Confining Interval/Above Zone Monitoring

High West will continuously monitor pressure changes above the confining zone throughout the operational period to ensure compliance with SWO 29-N-6 **§3625.A.4**. AZM No. 001 will be drilled at the location shown previously in Figure 5-1 and will reach a depth of 4,000 ft.

This AZM well will be equipped with wireline-retrievable downhole pressure and temperature gauges, which will be connected to a surface data logger for real-time data collection. The recorded data will be analyzed to detect any deviations from baseline values, providing an early warning system for potential fluid migration from the confining zone into the USDW, ensuring well integrity and regulatory compliance.

Additionally, the AZM Well No. 001 will be equipped with Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS) fiber optic technology along tubing. These additional sensors will serve as a redundant data collection system, ensuring continued monitoring in the event of sensor failure at the primary data collection points.

AZM Well No. 001 has been designed with the ability to collect a fluid sample if required.

5.5.5.1. Pressure Monitoring
Pressure in the first mappable sand identified above the upper confining zone (UCZ), will be continuously monitored using wireline-retrievable downhole pressure gauges, which will be connected to a surface data logger for real-time data collection. Any deviations from the baseline measurements will initiate an investigation. If necessary, fluid samples can be collected from this well.

5.5.5.2. Fluid Sampling Methods
Fluid samples will be collected from the AZM wells using an electric submersible pump. The pump will evacuate a minimum of two wellbore volumes of liquid before collecting a

representative sample at the surface. Samples will be taken quarterly with the parameters to be measured listed in Table 5-13.

5.5.6. Plume and Critical Pressure Front Monitoring

High West will use both direct and indirect methods to track the CO_2 plume and the critical pressure front, in accordance with SWO 26-N-6 **§3625.A.7.a**nd **§3625.A.7.b.** The critical pressure front will be directly monitored by continuously recording pressures and temperatures to calculate the extent of this pressure increase. The CO_2 plume will be indirectly monitored using seismic survey technology, such as a Vertical Seismic Profile (VSP).

High West will use these methods to verify reservoir conditions during injection, track plume and critical pressure front migration, and validate the reservoir model. Continuous pressure and temperature monitoring of the injection reservoir in all the injection wells will allow for monitoring of reservoir conditions and inform calculations, while VSP surveys will determine the actual CO_2 plume migration. The VSP surveys will be run before injection initiation to establish a baseline, periodically as needed, and every 5 years at a minimum.

5.5.6.1. Direct Monitoring

The five injection wells will be equipped with downhole pressure and temperature gauges to enable continuous monitoring of injection conditions. The gauges will be cemented in the annulus of the long string casing and ported inside the casing above the top injection perforation. The gauges will be connected to a surface data logger utilizing tubing encapsulated cable (TEC). This configuration will allow for precise measurement of pressure and temperature parameters above the injection perforations. This configuration ensures accurate data collection for plume growth management. Additional details are provided in Section 5.5.3.8.9.

Spoonbill No. 001 will deploy formation pressure and temperature gauges designed to monitor and collect data from the same injection intervals as Spoonbill No. 002, Spoonbill No. 003, Spoonbill No. 004, and Spoonbill No. 005. Similarly, Spoonbill No. 002 will be outfitted with formation pressure and temperature gauges to capture data from the same injection intervals influenced by Spoonbill No. 003, Spoonbill No. 004, and Spoonbill No. 005.

Additionally, fiber optic sensing technology will be deployed across all five injection wells to enable continuous, real-time monitoring of wellbore conditions and CO_2 plume. Each well will be equipped with fiber optic cables for Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS), which will be cemented in the annulus behind the long string casing. DTS will provide temperature distribution data, supporting injection performance evaluation and leak detection. The DAS system will enable borehole seismic acquisition, including time-lapse VSP, to track the extent and movement of the CO_2 plume. DAS data from Spoonbill No. 001 and Spoonbill No. 002 will be utilized to develop high-resolution VSP imaging, enhancing reservoir characterization and long-term monitoring.

The inclusion of fiber optic sensing across all wells provides a redundant data collection system in the event of sensor failure.

5.5.6.2. Direct Monitoring: Rate Transient Analysis

Rate transient analysis, in conjunction with reservoir simulations using known reservoir characteristics, will allow for calculating more complex parameters within the injection intervals. Direct monitoring will be based on continuous pressure, temperature, and injection rate data to calculate the properties of the reservoir and verify the plume model results. Pressure and temperature gauges will be run on TEC cable on the injection well.

The reservoir model built during the site evaluation phase will be used to predictively monitor the reservoir conditions during injection operations. Through flow simulation and transient flow analyses, the reservoir model will be regularly updated with injection activity, to evaluate the effect of the injection stream on reservoir conditions. This analysis can be performed to monitor the magnitude and extent of temperature and pressure changes within the injection zone. Continual monitoring of bottomhole pressures and temperatures combined with known reservoir parameters will be used to calculate reservoir conditions throughout the injection intervals.

Any shut-in period can be observed and treated as a pressure falloff test. To do this during a shut-in period, the shut-in wellhead pressure, bottomhole pressure, and temperature readings will be recorded and used for pressure transient analysis of the reservoir. The analysis results will include the radius and magnitude of pressure buildup and reservoir performance characteristics, such as permeability and transmissibility. Analysis results will then confirm, and adjust as necessary, the previous model realizations.

Through predictive modeling and analysis of recorded pressure and temperature data, High West can closely monitor the effect of the injection well on the subsurface, to help ensure regulatory compliance and safety while contributing to informed decision-making.

5.5.6.3. Indirect Monitoring: Time-Lapse Seismic Surveying

High West will utilize time-lapse VSP as the primary method to indirectly monitor the extent and development of the CO_2 plume in compliance with SWO 29-N-6 **§3325.A.7.b** requirements. High-resolution borehole seismic data will be acquired using fiber optic cable with Distributed Acoustic Sensing (DAS). The fiber optic cable will be installed and cemented in the annulus behind the long-string casing of Spoonbill No. 001 and Spoonbill No. 002.

The DAS fiber optic cable, designed with sensors spaced one meter apart, will enable the generation of VSP data at the highest possible resolution. Three-dimensional models of the CO_2 plume will be developed using a walk-away seismic source, with data collected at the Spoonbill No. 001 and Spoonbill No. 002 injection wells. An impulsive seismic source, such as dynamite, will serve as the acoustic source, with its location determined based on well positioning and site conditions.

High West has begun preliminary design of the VSP survey, which will be used to monitor plume activity at the proposed project site. Figure 5-5 shows the acquisition layout centered around Spoonbill No. 001 with its permanent DAS installation. The source configuration will consist of four source lines, phased at 45 degrees, and a total of 583 individual source points.

[redacted]

Figure 5-5 – High West CCS Project Preliminary VSP Acquisition Patterns

Reservoir monitoring using time-lapse seismic surveys has an extensive history of use in tertiary oil and gas recovery. The methodology has undergone thorough testing in saline aquifers with the presence of CO_2. The time-lapse effect is primarily driven by the change in acoustic impedance, resulting from compressional changes in velocity between high CO_2 concentrations and formation gases and fluids. As CO_2 displaces formation fluids, the difference in acoustic impedance with time is an effective proxy for plume shape and can be visualized.

The work steps involved in a time-lapse VSP survey primarily include the following:

1. Rock Physics Model
2. Petro-Elastic Model
3. Feasibility
4. Baseline Survey (Data Acquisition)
5. Repeat/Time-Lapse Survey (Data Acquisition)
6. Interpretation

The following subsections discuss key portions of these work steps.

5.5.6.3.1. Rock Physics Model

A rock physics model is critical to time-lapse interpretation. This model establishes a relationship between fluid substitution and the change in acoustic impedance. It can be produced with high confidence, provided the reservoir characterization data is accurate. Changes in seismic response can be projected with a synthetic survey design and reservoir model, relying on the rock physics model to calculate formation fluid impact on acoustic impedances. This model determines if the monitoring program can facilitate the detection of expected formation-fluid substitutions.

Deterministic petrophysical analysis estimations can be used to forecast the dry mineral rock components before any saturation modeling. The model accounts for the following rock properties:

- Total porosity
- Effective porosity
- Water saturation
- Clay (type)
- Quartz
- Mineral content
- Oil/gas residual (if any)

As an example of this workflow application, High West has carried out a comparative study based on a nearby CO_2 sequestration project situated approximately 50 miles from the proposed site, near Donaldsonville, Louisiana. The locations of the wells used in the study are shown in Figure 5-6. Of the three wells evaluated, two (highlighted in green in Table 5-14) were selected for calibration. The table also summarizes all available data from the subject wells.

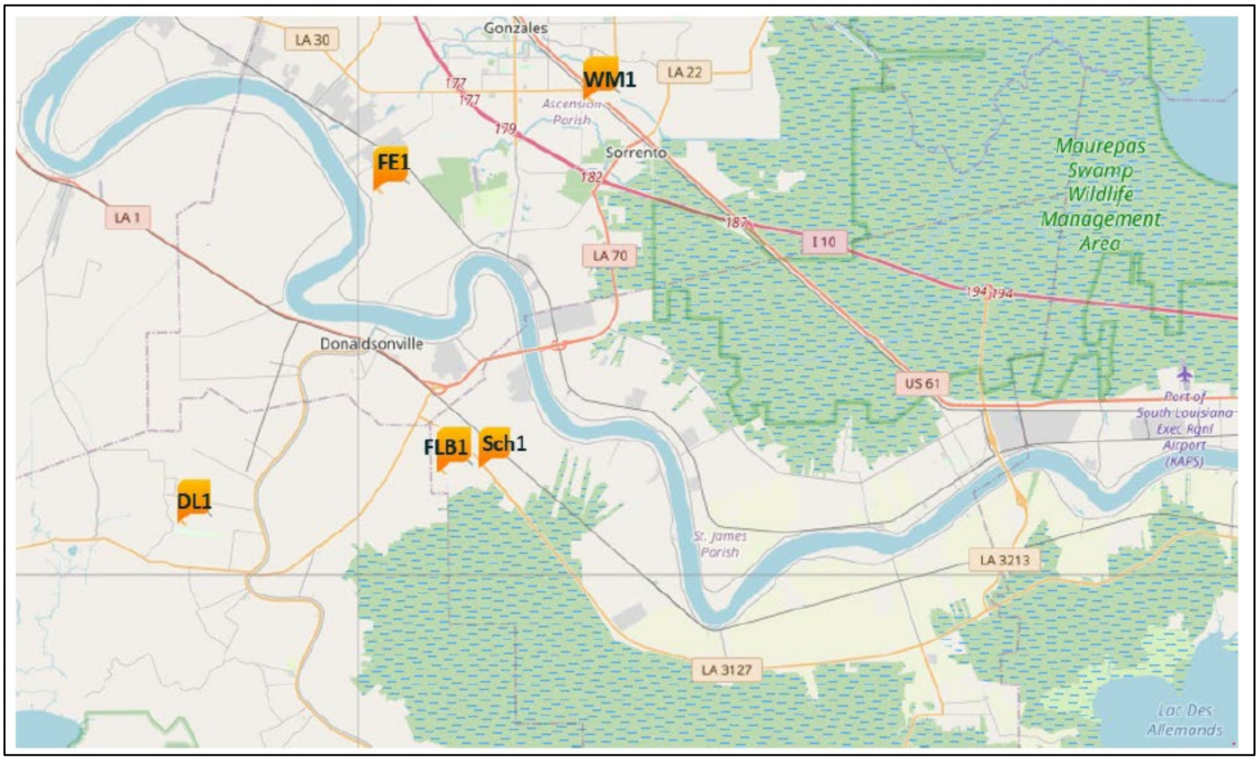


Figure 5-6 – Map with Locations of Study and Calibration Wells

Table 5-14 – Provided Measured and Petrophysical Logs

Well	UWI	KB above MSL, ft	YEAR LOGGED	MUD TYPE	SP	GR	CALI	DENSITY	DRHO	NEU	RESIST	SONIC	SHEAR	Petrophysics
Falcon Estate 1	170052013200	16.5	1979	WBM	Yes	no	no	no	no	no	Yes	Yes	no	Schl: Dry volumes of Illite and Quartz; Vcl; PHIT; PHIE
William J Melancon 1	170052022000	23.9	1988	WBM	Yes	Yes	Yes	no	no	no	Yes	Yes	no	Schl: Dry volumes of Illite and Quartz; Vcl; PHIT; PHIE
Schexnayder 1	170932031600	37.5	2012	WBM	Yes	Yes	Yes	DPSS below target sands	no	NPSS	Yes	Yes	no	Schl: Dry volumes of Illite and Quartz; Vcl; PHIT; PHIE
DORIS_LANDRY_SAGERS ETAL_1	170072051500	27	2010	WBM	Yes	Yes	Yes	DPSS	Yes	NPSS	Yes	Yes	Yes	Schl: Dry volumes of Illite and Quartz; Vcl; PHIT; PHIE
FEDERAL_LAND_BANK_23	170932011600	22.4	1976	WBM	Yes	Yes	Yes	DPHI and RHOB	Yes	NPHI	Yes	Yes	no	Schl: Dry volumes of Illite and Quartz; Vcl; PHIT; PHIE

Data from the wells were loaded and carefully reviewed to identify any unrealistic values or anomalies. Elastic logs from both the calibration and main study wells—including Vp, Vs, and density (RhoB)—were examined to flag intervals with poor or unreliable data quality. Issues such as sonic cycle skipping, borehole washouts, and inconsistencies in Vp and Vs velocity picks were identified as sources of erroneous responses. To validate the integrity of the elastic data, quality control cross-plots (e.g., Vp-Vs, Rho-Vp, and Vp/Vs vs. depth) were generated to ensure the measured values fell within a physically reasonable elastic domain. The complete measured dataset and petrophysical results for the calibration wells are presented in Figure 5-7, while those for the main study wells are shown in Figure 5-8.

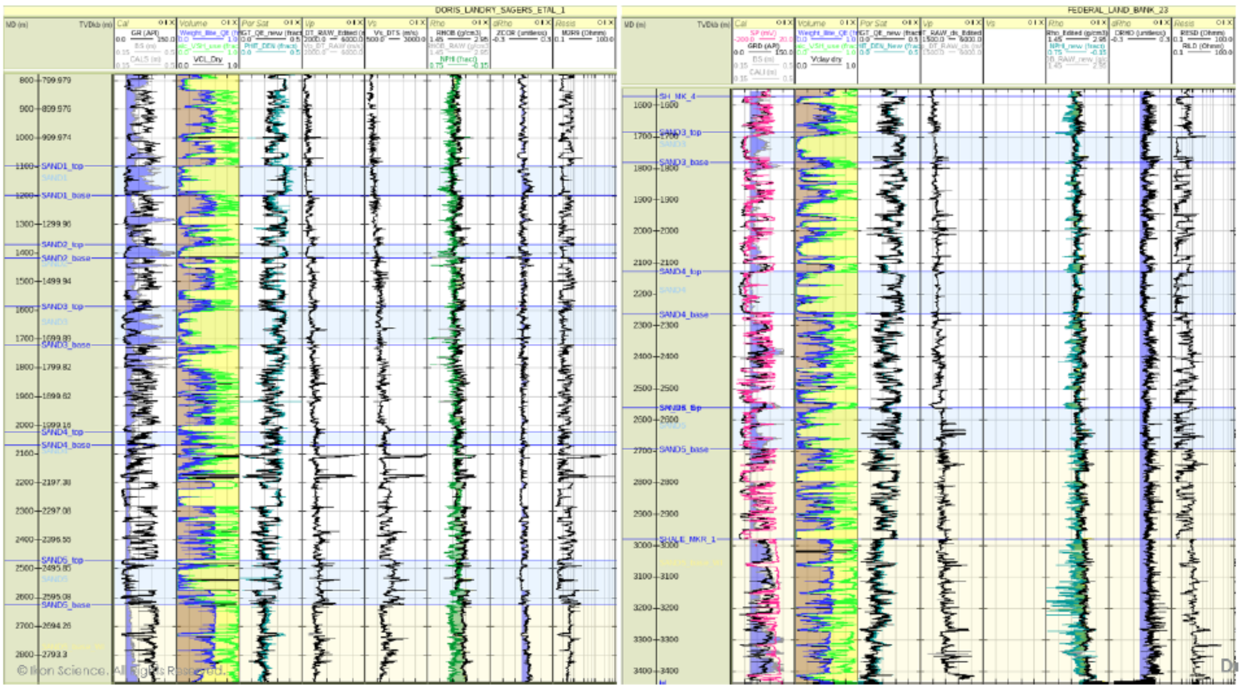


Figure 5-7 – Calibration Well

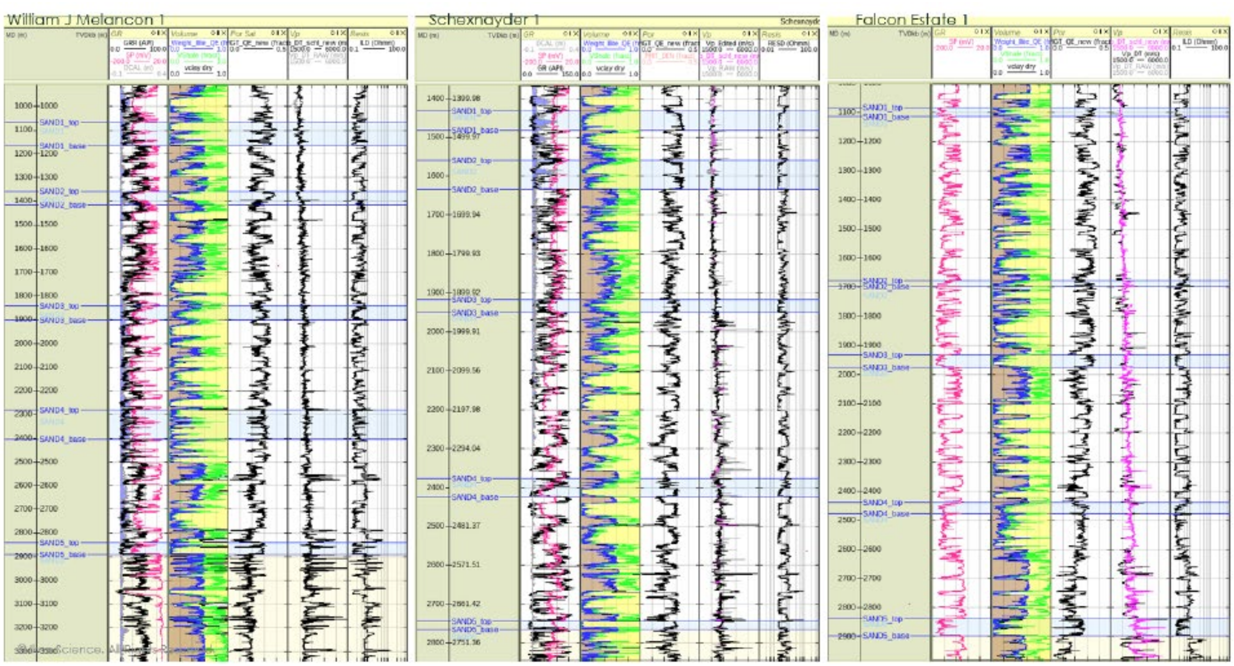


Figure 5-8 – Main Study Wells

Following data collection, the dataset was conditioned to ensure quality and consistency in preparation for generating the rock physics model. Figure 5-9 illustrates an example of conditioned well data used in the rock physics modeling process.

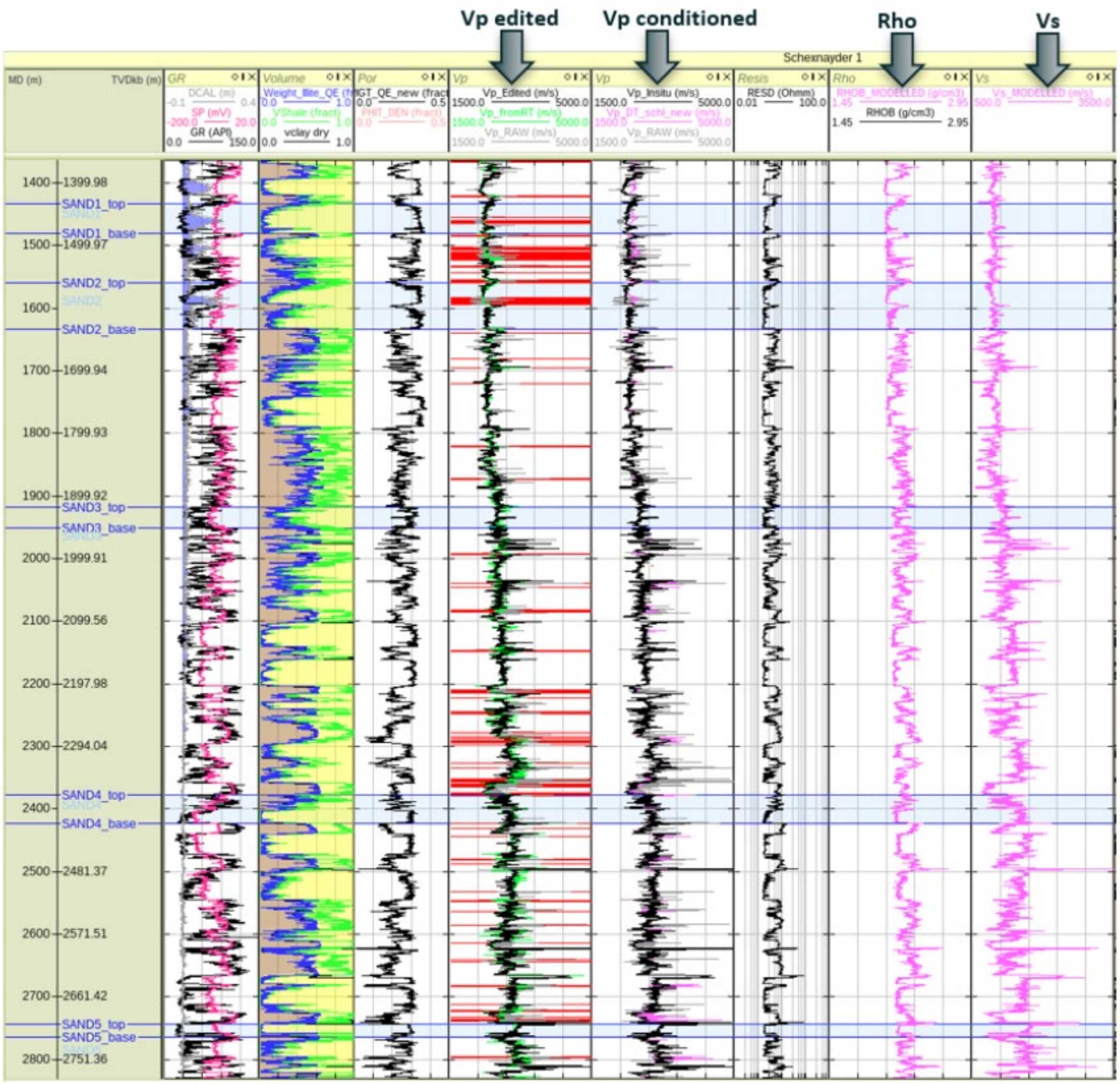


Figure 5-9 – Conditioned Well Data

5.5.6.3.2. Petro-Elastic Model

The rock physics model will generate a zero-order dry rock model, which is then used to establish a petro-elastic model by perturbing the elastic parameters for varying degrees of saturation.

Continuing with the example from the nearby study, to estimate changes in elastic parameters with varying fluid saturation, a three-step approach was used: first, the dry-rock response was calculated; next, a dry-rock model was applied; and finally, the desired fluid fill was introduced into the dry-rock framework. Figure 5-10 provides the data for the dry rock response model generated for the William J Melacon No. 001.

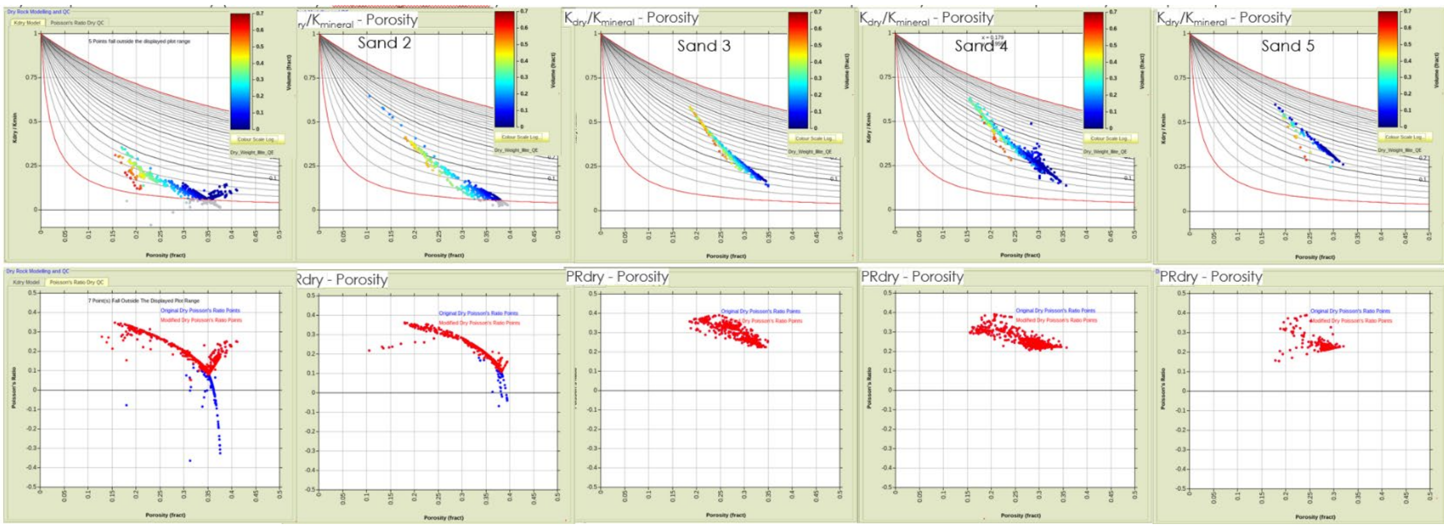


Figure 5-10 – Dry Rock Response, William J. Melacon No. 001

A dry rock model was generated using Ikon Science's proprietary modelling approach. Variations in CO_2 saturation (ranging from brine to low and high CO_2 conditions) resulting from injection were modeled using Gassmann fluid substitution. In the study well, William J Melacon 1, fluid substitution was performed from 100% brine to CO_2 saturations ranging from 10% to 95%, in 10% increments. The resulting elastic property changes are illustrated in Figure 5-11 for William J Melancon 1, showing 10% CO_2 saturation in light green and 95% CO_2 saturation in red.

The referenced study has been provided in *Appendix F* of this submission.

The process of simulating various CO_2 saturation scenarios can aid in determining the expected seismic response measured during VSP surveys.

After collecting openhole logs and core from the stratigraphic test well, High West will determine whether the VSP feasibility study results conducted on well data near Donaldsonville are representative of results expected for VSP surveys conducted for the High West CCS Project. The study will be updated with locally derived data if they are found to be materially different.

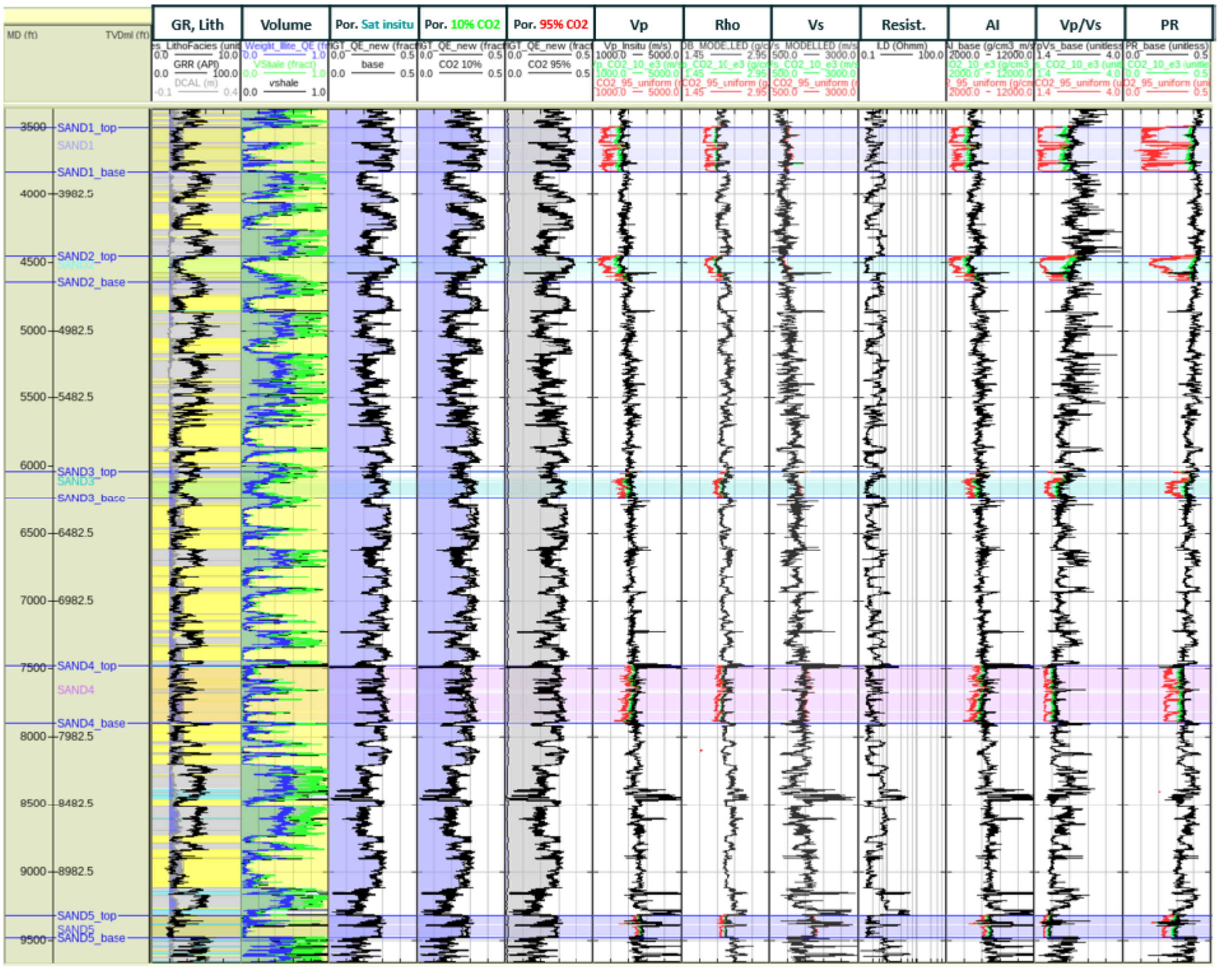


Figure 5-11 – Fluid Substitution

5.5.6.3.3. 1D and 2D Models

Changes in the magnitude of the CO_2 plume are measured for different scenarios using 1D and 2D models. This section will detail the methodology used to generate these models.

Seismic waves that travel through the Earth are created with seismic surveys, and geophones listen for the waves that are subsequently reflected. The seismic waves can be made with a “shot,” referring to explosives or other mechanical sources—most commonly a vibrator, which generates seismic waves by pounding a steel plate against the Earth. Geophones are recorders that detect sound waves reflected to the surface, and the data sent by geophones is then stored using seismographs. The geophones enable geophysicists to calculate the time it takes for seismic waves to reflect off transition zones between formations. Geoscientists can use the variation in sonar velocities to understand subsurface lithology.

Figure 5-12 depicts a standard VSP survey with a geophone configuration.

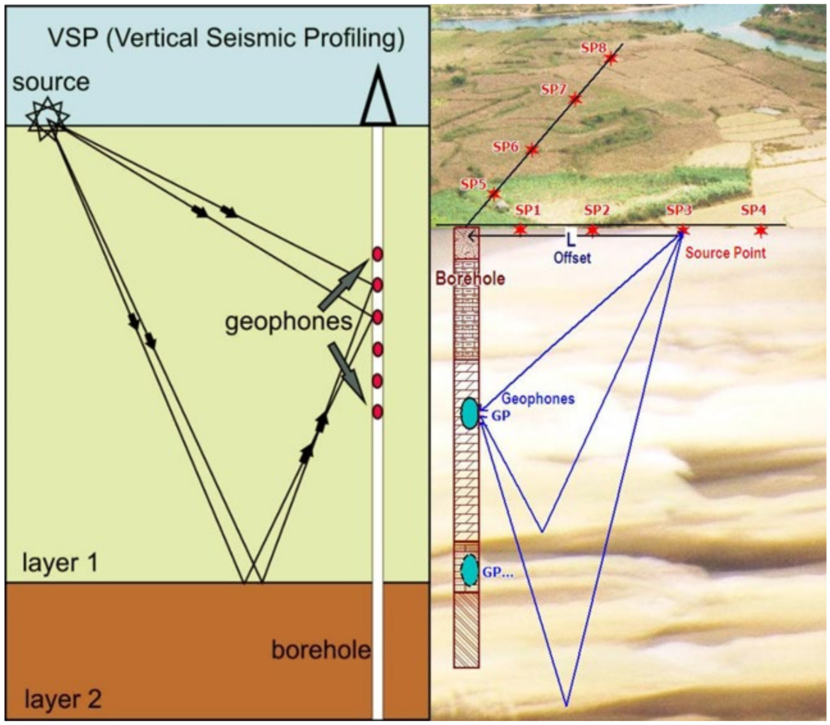


Figure 5-12 – Illustration of a Vertical Seismic Profile Survey

5.5.6.3.4. 1D Model

The previously discussed principles apply to 1D seismic surveys. A standard method of obtaining 1D seismic data is with a checkshot survey, as illustrated in Figure 5-13. Geophones are situated vertically along the wellbore while all shots are fired from the surface. This placement allows the geophones to record seismic waves at different depths and provide measurements—at the highest levels of accuracy—of sonic velocities of the geologic layers affected by wellbore construction. These systems are commonly used to generate more accurate 2D, 3D, VSP, and 4D surveys.

The 1D survey methodology assumes that each formation is homogeneous in the horizontal direction; therefore, the surveys can only provide average sonic velocities. The 1D survey data can also be used to correct the sonic logs and create synthetic seismograms, which are used to forecast seismic responses of the subsurface. One variation of 1D seismic surveys is an acoustic log, which generates acoustic data along the wellbore using wireline sonic tools. Although the purposes of these logs differ from those of seismic surveys, they can provide a way to a 1D understanding of variation in velocities.

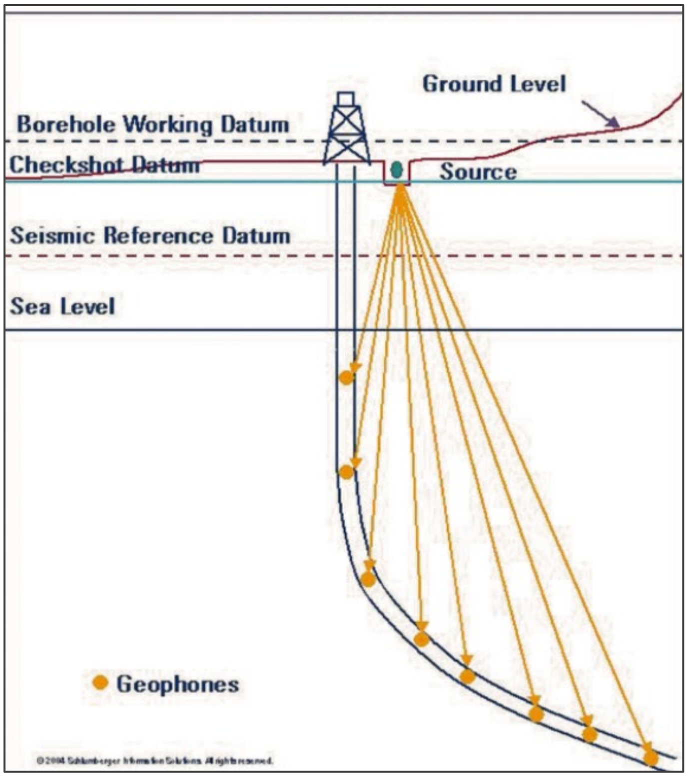


Figure 5-13 – Illustration of a Checkshot Survey

A 1D offset model will be constructed for each case, and differences in reflection amplitudes will be measured.

5.5.6.3.5. 2D Model

A geologic model can be built once the results of a 1D model have been interpreted. The model reflects two saturation scenarios: one with connate formation fluid, and the other with CO_2-replaced fluid.

Applying the same principles discussed in the previous section, 2D seismic surveys can provide a snapshot of a thin layer of the crust of the Earth. The geophones for this survey are placed in a line along the surface and record reflected seismic waves from each formation. For best results, 2D surveys require setting multiple lines, ideally parallel to the structure dip and orthogonal to the geologic strike. The surveys provide subsurface information on various formations, faults, and other characteristics. Geologists can interpret contour lines and produce geologic maps using the intersection of numerous 2D surveys, which cost less and have less environmental impact than 3D surveys. They are commonly used to explore new areas and allow geologists to visualize the formations lying beneath the surface.

Processing Workflow and Time-Lapse/4D Seismic Volume Determinations

To produce the final interpretation, CO_2 volume buildups from consecutive surveys will be observed over time. A time lapse or 4D model is created when VSP, 1D, 2D, or 3D dedicated seismic surveys are combined with a time element (i.e., surveys recorded at various time intervals—Year 1, Year 5, Year 10, etc.). The wheel spoke pattern of 2D survey lines, with the injector and VSP receiving fiber optic at its center, can be interpreted as similar to a 3D survey. Changing volumes of gas buildup, represented by either log shifts on the VSP, 1D, or 2D responses, or heat blooms (i.e., change in fluid density) on the 3D model, are identified in the time-lapse/4D interpretation of a seismic survey.

Figure 5-14 illustrates a basic workflow example:

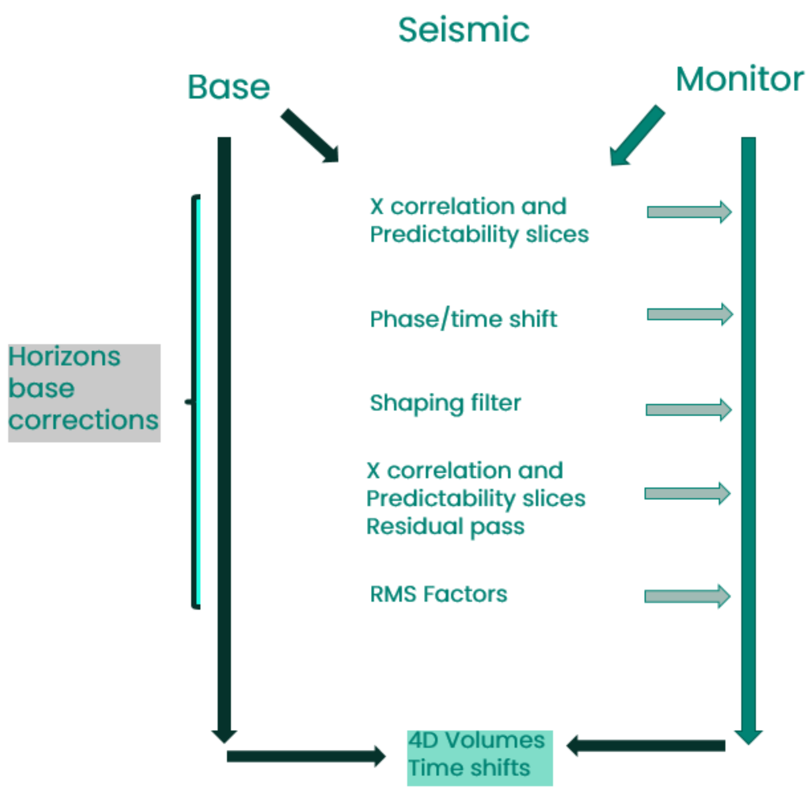


Figure 5-14 – Time-Lapse/4D Processing Workflow Diagram

The 3D horizon model is established from the base survey, and each successive survey creates a reflection differential mapped on the 3D model. The map is used to determine plume geometry, and the process is repeated in time increments to illustrate the time-lapsed development of the injectate plume.

To ensure consistency, all seismic volumes will be processed using the same software and for each workflow step outlined. Figure 5-15 presents a time-lapse/4D model visualization in 3D with analysis software. Color coding is used to display amplitude over time for each horizon. A similar output will be generated from VSP surveys at the High West CSS Project.

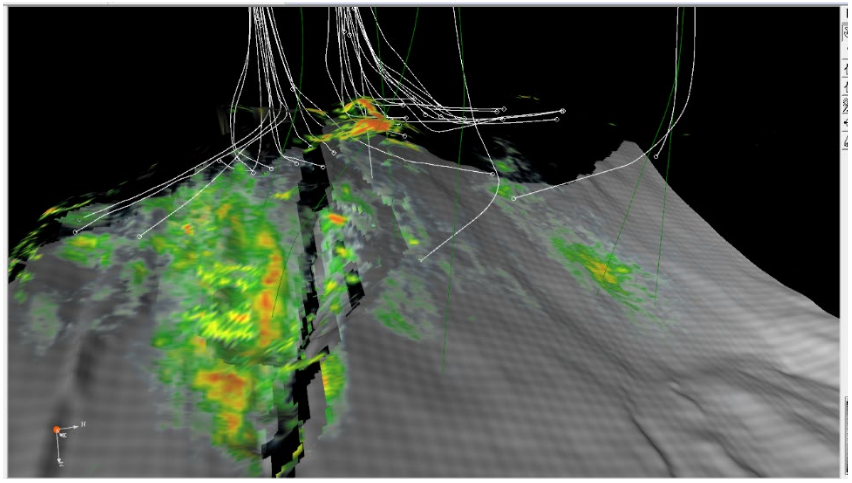


Figure 5-15 – Example of Time-Lapse/4D Model (showing time-lapsed gas replacement of connate fluids)

5.5.6.3.6. Inversion Workflow

Log data, post-stack seismic volumes, and a structural model will be used to invert baseline surveys, as Figure 5-16 shows. Later, monitor surveys will employ the same low component and residual corrections for consistency and the detection of changes over time—changes assumed to result from the injection operations.

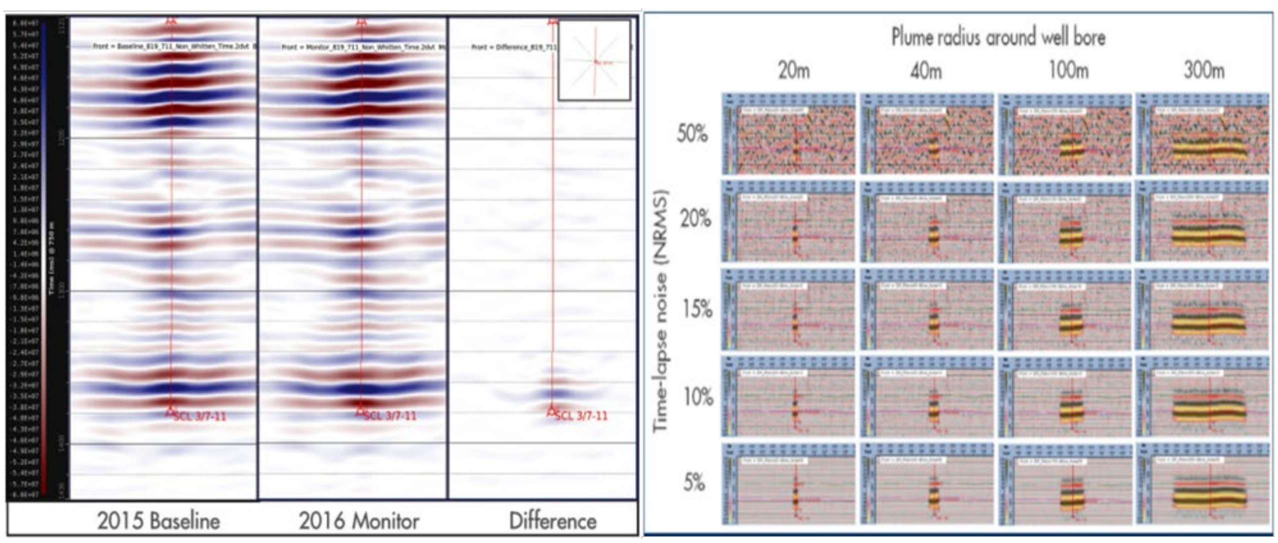


Figure 5-16 – Baseline and subsequent VSP used to determine difference in amplitude attributed to CO_2 injection measured from the injector well itself. At the right, estimation of the plume growth over time.

5.5.6.3.7. Baseline Survey

Conducting a quality VSP baseline survey is critical, because it is the only opportunity to capture an image of the reservoir before injection operations or offset activity—either natural or man-made—impact it. Without this survey, the future interpretation of formation changes cannot be assessed. Also, the size of the baseline survey constrains the extent of plume measurement ability. It is essential to acquire a baseline survey with sufficient coverage if the initial reservoir models are not accurately forecasting plume migration.

5.5.6.3.8. Equipment Design and Setup

The proposed equipment for periodic survey operations to determine the CO_2 plume growth over time includes the time-lapse VSP, which uses a DAS fiber optic cable—to be installed in the Spoonbill No. 001 and Spoonbill No. 002 injection wells and connected to an interrogator box at the surface. The DAS system is synchronized to the seismic acquisition system controlling both the receiver (the DAS fiber optic array cemented in the injection well) and the source (seismic vibrator trucks).

Monitoring Schedule

The plume extent for High West CCS Project will be monitored using the DAS-VSP on the following schedule:

- The initial DAS-VSP survey will be conducted prior to the injection phase to capture the starting conditions for the formation brine.
- The first monitoring survey will be performed approximately 1 year after injection begins. The timing for this first survey is based on simulations that predict that the plume extent remains within the DAS-VSP imaging cone. This first survey allows early insights into the actual plume migration relative to the predicted model.
- Subsequent monitoring surveys will be conducted at least every 5 years.
- During the post-injection site care phase of the project, surveys will occur immediately after injection ceases into the last injection sand and 5 years after injection ceases. If the plume can be shown to have stabilized, additional DAS-VSP surveys will not be required. Pressures and temperatures will continue to be measured from the offset monitoring wells.

5.5.6.3.9. Equipment Overview

This section discusses the typical hardware setup and use of in situ monitoring equipment for temperature, pressure, and seismic that will employ fiber optic cable to communicate with a surface-located interrogator box, to record real-time or periodic data. The equipment described is representative of the technology that will be employed. Specific vendor-proprietary equipment details will be provided when the vendor is selected nearer to the time the well is drilled.

5.5.6.3.10. Fiber Optical Cable Discussion

Fiber optic sensing technology will be installed in the wells to provide real-time, continuous monitoring of subsurface conditions. This technology will measure temperature and acoustic parameters along the entire wellbore. The fiber optic cable will be connected to a surface interrogator unit, which will analyze changes in scattered light to extract meaningful data.

5.5.6.3.11. Distributed Acoustic Sensing Fiber Optic

The combination of Distributed Acoustic Sensing fiber optic and the DAS interrogator unit will allow for detection of sound waves, vibrations and mechanical disturbances along the entire length of the wellbore.

5.5.6.3.12. Tubing Encapsulated Conductor

Tubing Encapsulated Cable (TEC) is a protective conduit designed to house electrical, hydraulic, and fiber optic lines, ensuring reliable signal transmission. It safeguards these components from harsh downhole conditions, enabling long-term, uninterrupted data transfer from the measurement sensor to the surface data logger.

5.5.6.3.13. Pressure Temperature Gauge

The downhole pressure and temperature gauge will enable real-time monitoring of the injection zone, ensuring continuous data acquisition throughout the project's lifespan. The sensors will be enclosed in durable, seal-tight housing, designed to withstand harsh downhole conditions and support long-term data collection for reliable reservoir surveillance.

5.5.6.3.14. VSP Monitoring Conclusion

The VSP method for quantifying carbon dioxide plume development over time has been demonstrated in several worldwide cases. Using offset petrophysical data, modeling results will generate a modeled differential in compressional velocity and density that will produce detectable changes in the reservoir where the connate fluid has been replaced by carbon dioxide. This information provides confidence that deploying the method in a time-lapse format will generate a time-lapse/4D image of the plume's extent and future development.

The fiber optic configuration installed in the Spoonbill No. 001 and Spoonbill No. 002 wells, coupled with pressure and temperature monitoring, will be used directly in pressure front calculations, plume calculations, and VSP.

Most importantly, the need to drill additional artificial penetrations for monitoring purposes is reduced, because the VSP system plus direct plume calculations will allow for accurate monitoring of plume and pressure front migration. This monitoring reduces the risk of inadvertently forming a conduit from the confinement zones in the monitoring wells.

5.5.7. Monitoring Conclusion

The testing and monitoring plans developed for the High West CCS Project are designed to collect critical data to support static and dynamic reservoir modeling, track the growth of the of CO_2 plume, and provide early detection to ensure that CO_2 does not reach the USDW or pose risks to health, safety, or the environment. This plan includes a comprehensive monitoring strategy, incorporating continuous monitoring of the injection stream composition, injection conditions, and reservoir behavior through permanent install gauges.

The interval above the upper confining zone will be monitored using pressure gauges regular fluid sampling to assess containment integrity. USDW protection will be ensured through dedicated monitoring wells where regular sampling will be conducted. The CO_2 plume extent will be evaluated using both direct and indirect methods. Reservoir pressure data will support rate transient analysis (RTA) calculations to estimate plume migration, while VSP technologies will be used to track the plume extent indirectly, providing high-resolution subsurface imaging for long-term monitoring.

Supporting documents for this Testing and Monitoring Plan are available in Appendix F.

Appendices:

Appendix F-1	VSP Feasibility Study