Attachment 5: Pre-operational Formation Testing Program
40 CFR 146.82(a)(8), 146.87
Vervain Project, McLean County, Illinois
31 January 2023

Project Information

Project Name: Vervain

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List of Acronyms

ACZ	above confining zone
ASTM	American Society for Testing and Materials
bpm	barrels per minute
BGS	below ground surface
BHA	bottomhole assembly
bpm	barrels per minute
CBL	cement bond log
CBL-VDL	cement bond log-variable density log
DST	drill stem test
ECS	Elemental Capture Spectroscopy
EPA	Environmental Protection Agency
FOT	fall-off Test
HGCS	Heartland Greenway Carbon Storage, LLC
IBDP	Illinois Basin–Decatur Project
MIT	mechanical integrity test
NV_ACZ1	Vervain Above Confining Zone Monitor Well #1
NV_ACZ2	Vervain Above Confining Zone Monitor Well #2
NV_INJ1	Vervain Injection Well #1
NV_INJ2	Vervain Injection Well #2
NV_MA1	Mahomet Aquifer Monitoring Well #1
NV_MA2	Mahomet Aquifer Monitoring Well #2
NV_OBS1	Vervain Deep Observation Well
OAL	Oxygen Activation Logging
PVC	polyvinyl chloride
RAT	radioactive tracer logging
SM	standard method
SRT	step-rate testing
TD	total depth
TDS	total dissolved solids
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
ZVSP	zero offset vertical seismic profile

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1. Introduction

This document serves to detail the proposed Pre-Operational Formation Testing Program that will be implemented to characterize the chemical and physical features of the lithology at the Vervain Project Site. The formations of note include, but are not limited to, the following (Figure 1):

- Mt. Simon Arkose and Lower Mt. Simon Sandstone
  (injection zone),
- Middle/Upper Mt. Simon Sandstone and Eau Claire Silt
  (storage zone)
- Eau Claire Formation (confining zone),
- Ironton-Galesville Formations
  (above confining zone (ACZ) monitoring interval)
- Knox Group, and
- St. Peter Formation
  (lowermost underground source of drinking water (USDW)).

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Figure 1: Site-specific Illinois Basin stratigraphic column with age, nomenclature, generalized lithology, and zone of use.

The Pre-Operational Testing Program laid out in this document is designed to meet the testing requirements of Title 40 of the U.S. Code of Federal Regulations Section 146.87 (40 CFR 146.87) and the well construction requirements of 40 CFR 146.86. The well construction plans for NV_INJ1 and NV_INJ2 are presented in the separate Well Construction Plan Sections. (Attachment 4A: NV_INJ1 Well Construction Plan, 2023), (Attachment 4B: NV_INJ2 Well Construction Plan, 2023).

The Pre-Operational Testing Program will determine and verify the depth, thickness, mineralogy, lithology, porosity, permeability, and geomechanical information of the injection zone, confining zone, and other relevant geologic formations. The Program includes a combination of logging, coring, fluid sampling, and formation hydrogeologic testing that will be completed when the following wells are drilled (Figure 2 and Figure 3):

- NV_INJ1: Vervain Injection Well #1,
- NV_INJ2: Vervain Injection Well #2,
- NV_OBS1: Vervain Deep Observation Well,
- NV_ACZ1: Vervain Above Confining Zone Monitoring Well #1, and
- NV_ACZ2: Vervain Above Confining Zone Monitoring Well #2.

The Deep Observation Well (NV_OBS1) is expected to be the first well drilled. A minimal logging suite will be acquired in this well, which will help to establish the depth of formation tops and mitigate any uncertainty around the depth to and thickness of certain formations at the project site (Table 1). This initial logging suite will be used to identify zones for core acquisition, fluid sampling, and well testing in the Above Confining Zone Monitoring Wells (NV_ACZ1 and NV_ACZ2) and the Injection Wells (NV_INJ1 and NV_INJ2).

Based on other projects in Illinois, such as the Illinois Basin– Decatur Project (IBDP), it is expected that the Ironton-Galesville formations will be a suitable ACZ monitoring interval for the project. The NV_OBS1 well will provide information that will allow the project to determine the behavior of various intervals in the Knox Group that have caused lost circulation issues while drilling other wells in Illinois.

The lowermost USDW at the site is expected to be in the St. Peter Sandstone as determined from existing data. (Attachment 1:Project Narrative, 2023). The United States Environmental Protection Agency (EPA) defines a USDW as an aquifer with less than 10,000 milligrams per liter (mg/ L) total dissolved solids (TDS). The well logs from NV_OBS1 will be used to identify other possible zones for fluid sampling beyond the St. Peter Sandstone and the Ironton-Galesville formations. The fluid samples will be used to complete the baseline geochemical analysis for the lowermost USDW and the ACZ monitoring interval in which future samples may be compared once injection operations begin.

Baseline groundwater samples will be acquired from existing shallow groundwater wells spatially distributed throughout the AoR as well as two dedicated Mahomet Aquifer Monitoring Wells (NV_MA1 and NV_MA2) that will be co-located with the project injection wells as outlined in the Testing and Monitoring Plan (Attachment 7: Testing And Monitoring Plan, 2023).

A more extensive logging suite will be planned for NV_INJ1 and NV_INJ2 to characterize the main formations of interest (Table 4). The logs from NV_OBS1 will be used to pick coring intervals in NV_INJ1 and NV_INJ2 as well as the intervals for further fluid sampling and step-rate testing within the injection zone.

The current plan is to drill the NV_OBS1 as early as the first quarter of 2024, pending receipt of the appropriate regulatory approvals. After the data acquired in the project wells has been analyzed, a permit modification will be submitted that will provide updated data along with static and computational models that incorporate the data from the testing program.

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Figure 2: Site map of Vervain wells with cross section A-A'. NV_INJ1 and NV_INJ2 are injection wells, NV_OBS1 is a deep observation well, NV_ACZ1 and NV_ACZ2 are above confining zone observation wells, and NV_MA1 and NV_MA2 are Mahomet Aquifer monitoring wells.

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Figure 3: Cross section A-A' (Figure 2) through the Vervain wells.

2. NV_OBS1 Hydrogeologic Characteristics (146.87 (a))

NV_OBS1 will be the first well drilled for the project. A combination of mudlogging and well logging in the well will be used to establish the depths to formation tops, fluid sampling zones, coring intervals, and well testing intervals for the injection wells. Based on similar CCS projects in the Illinois Basin, it is expected that a suitable ACZ monitoring interval will be found in the Ironton-Galesville formations.

Table 1 summarizes the open and cased hole logs that will be run before and after casing is set for the surface, intermediate, and long string casings and the purpose of each well log.

Table 1: NV_OBS1 summary of wireline logs and associated parameters of logging tools to be run for the surface, intermediate, and long string casings.

Log	Log Type	Parameters Obtained	Surface	Intermediate	Long
Open Hole Logging	Gamma Ray	Lithology	X	X	X
	Density	Porosity, density		X	X
	Neutron Porosity	Porosity		X	X
	Spontaneous Potential	Permeability	X	X	X
	Resistivity	Fluid saturation, permeability	X	X	X
	Caliper	Borehole diameter, stress	X	X	X
Special Open Hole Logging	Sonic Log	Porosity, formation velocities		X	X
Casing string will be installed and cemented					
Cased Hole Logging (Required)	CBL – with radial arms	Cement integrity, external mechanical integrity	X	X	X
	Temperature	Temperature, external mechanical integrity	X	X	X
Cased Hole Logging (Optional)	Ultrasonic Cement Evaluation	Cement integrity, external mechanical integrity			X
	Pulsed Neutron	Lithology, baseline fluid saturation, porosity			X

3. ACZ Testing Program (146.87 (a))

NV_ACZ1 and NV_ACZ2 will be drilled after NV_OBS1. Fluid samples will be obtained from the St. Peter Sandstone and the Ironton-Galesville formations. A minimal logging suite will be acquired in NV_ACZ1 and NV_ACZ2 to correlate it to the NV_OBS1, NV_INJ1, and NV_INJ2 wells (Table 2).

This well and the associated data will be used to complete the following objectives:

- Confirm that the St. Peter Sandstone is the lowermost USDW, and
- Establish baseline aqueous geochemistry of the St. Peter Sandstone and Ironton-Galesville formations for comparison to future monitoring data.

Table 2: NV_ACZ1 and NV_ACZ2 summary of wireline logs and associated parameters of logging tools to be run for the surface and long string casings.

Log	Log Type	Parameters Obtained	Surface	Long
Open Hole Logging	Gamma Ray	Lithology	X	X
	Density	Porosity, density		X
	Neutron Porosity	Porosity		X
	Spontaneous Potential	Permeability	X	X
	Resistivity	Fluid saturation, permeability	X	X
	Caliper	Borehole diameter, stress	X	X
Cased Hole Logging (Required)	CBL – with radial arms	Cement integrity, external mechanical integrity	X	X
	Temperature	Temperature, external mechanical integrity	X	X
Cased Hole Logging (Optional)	Pulsed Neutron	Lithology, baseline fluid saturation, porosity		X

4. NV_INJ1 and NV_INJ2 Pre-Operational Formation Testing Program (146.87 (a))

NV_INJ1 and NV_INJ2 are the CO_2 injection wells, and the primary wells used for pre-operational data collection that will include but not be limited to:

- Wireline logs, core, fluid samples, and well test data,
- Well integrity data that will ensure that the well will not serve as an upward conduit for CO_2 or injection zone fluid migration to the overlying USDWs.

4.1 Deviation Surveys (146.87 (a)(1))

Deviation surveys will be obtained as the injection wells are drilled to determine the wellbore path from the surface to the total depth of the wells. It is currently planned that a wireline survey tool will be used to measure the inclination. The tool has an electronic timer that is set at the surface to allow enough time to run the tool in the drill pipe to the desired depth. Following the set time, the tool is removed from the well. The result of the survey will then be reviewed prior to continuation of drilling.

An alternative way to measure these deviation surveys is done by placing a measurement while drilling (MWD) tool, used to take well path surveys, on the bottomhole assembly (BHA) just above the drill bit. This tool records the inclination (deviation) and azimuth (direction), and then transmits this information to surface in real-time.

Hole deviation will be maintained at less than five degrees, as the planned maximum allowable deviation in the well is 5 degrees. If necessary, the wellbore will be steered back to acceptable deviation with directional tools, with a downhole motor or rotary steerable system added to the BHA. Under this situation surveys will be taken at the frequency shown in Table 3. In general, a survey will be performed every 300 feet during the drilling of the borehole unless deviation of the borehole becomes apparent.

Should the deviation increase, more frequent surveys will be performed, and remedial actions will occur as necessary to bring the well within specification. More frequent surveys will also be performed while drilling through zones that are likely to cause the bit to “walk” creating a greater risk for deviation.

Table 3: NV_INJ1 and NV_INJ2 deviation survey frequencies to be taken when MWD tool is used.

Range of Deviation	Frequency of Survey
<1 degree	1 survey per every 300 feet of hole
>1 degree, but < 2 degrees	1 survey per every 240 feet of hole
>2 degrees, but < 3 degrees	1 survey per every 120 feet of hole
>3 degrees, but < 4 degrees	1 survey per every 90 feet of hole
>4 degrees, but <5 degrees	1 survey per every 30 feet of hole

4.2 Well Logging Before and After Surface Casing (146.87 (a)(2)

Table 4 summarizes the open and cased hole well logs that will be acquired before casing is set for the surface casing section of the well. Sensitive, Confidential, or Privileged Information [redacted]

4.3 Well Logging Deep Section (146.87 (a)(2)&(3))

Table 4, Figure 4, and Figure 5 summarize the open and cased hole logs that will be run before and after casing is set for the surface, intermediate, and long string casings, and the purpose of each well log. The cased hole well logs will be acquired after the well is cemented and completed (Table 4).

In addition to the well logs listed in Table 4, the project may run other specialty well logs over the injection zone and confining interval to further characterize these formations. Specialty logs may include, but are not limited to, elemental capture spectroscopy (ECS), dipole sonic in multiple modes, or zero offset vertical seismic profiles (ZVSP).

Table 4: NV_INJ1 and NV_INJ2 summary of wireline logs and associated parameters of logging tools to be run for the surface, intermediate, and long string casings.

Log	Log Type	Parameters Obtained	Surface	Intermediate	Long
Open Hole Logging	Gamma Ray	Lithology	X	X	X
	Density	Porosity, density		X	X
	Neutron Porosity	Porosity		X	X
	Spontaneous Potential	Permeability	X	X	X
	Resistivity	Fluid saturation, permeability	X	X	X
	Caliper	Borehole diameter, stress	X	X	X
	Image Log	Lithology, porosity, borehole diameter, fracture characterization, stress			X
Special Open Hole Logging	Sonic Log	Porosity, formation velocities		X	X
Casing string will be installed and cemented					
Cased Hole Logging (Required)	CBL – with radial arms	Cement integrity, external mechanical integrity	X	X	X
	Temperature	Temperature, external mechanical integrity	X	X	X
Cased Hole Logging (Optional)	Ultrasonic Cement Evaluation	Cement integrity, external mechanical integrity		X	X
	Pulsed Neutron	Lithology, baseline fluid saturation, porosity		X	X

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Figure 4: NV_INJ1 Summary of wireline logs and associated parameters of logging tools to be used (surface to TD)

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Figure 5: NV_INJ2 Summary of wireline logs and associated parameters of logging tools before and after surface casing (surface to TD)

4.4 Well Core Program (146.87 (b)&(d))

Once NV_OBS1 has been drilled, the well logs will be analyzed and used to pick the optimal intervals to obtain cores from the confining zone and the injection zone in NV_INJ1. Up to 60 feet of core will be acquired in both the Eau Claire Formation and the Mt. Simon Sandstone. Table 5 summarizes the plans for whole core acquisition and testing from NV_INJ1.

Table 5: Whole core collection plan.

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Sidewall core intervals will be selected as contingency should the project be unable to obtain the desired whole core intervals. Using well logs, a neural network will be run to determine the heterogeneous rock types. This will be used to determine the sidewall core locations and to fill any gaps in the whole core program. Sidewall cores collected will provide a comprehensive set of routine rock property data for calibrating geophysical wireline logs and to supplement formation property data where whole core data are not available. As a contingency, whole cores or sidewall cores may be collected from NV_INJ2 as well.

Additional core will be collected if:

- Interpretation of the characterization well data indicates that additional data are needed to meet Class VI permit requirements.
- As required by the Director.

Once the whole core is collected, preserved, and transported to a core lab, the following will be completed:

1. The core will be slabbed.
2. High resolution core photography will be completed.
3. Core viewing and core descriptions will be completed by a project geologist.
4. Using well logs, a neural network will be run to determine the heterogeneous rock types.
5. To best capture the heterogeneity present in the core, the core viewing and heterogeneous rock type analysis will be used to select whole core plug locations.
6. Whole core plugs will be taken from the whole core at regular intervals.
7. Core analysis will be completed. Core testing will provide information on rock properties (e.g., porosity, permeability, petrology, and mineralogy) that are representative of the injection and confining zones near the injection well. Table 6 contains details of the planned laboratory testing for the whole core sections.
8. The details in Table 6 are a preliminary plan only and are expected to change once site-specific data is acquired. Core plugs, sidewall plugs, and core analysis will be adjusted based on the drilling and log data acquired.

If sidewall core is collected, preserved, and transported to a core lab, the following will be completed.

1. High resolution core photography,
2. Core viewing and core descriptions will be completed by a project geologist, and
3. Core analysis and testing will provide information on rock properties (e.g., porosity, permeability, petrology, and mineralogy) that are representative of the injection and confining zones near the injection well.

Core samples will provide information on geologic properties in the immediate area. The laboratory-derived core measurements will be integrated with wireline logs and used for petrophysical calibration. The integrated dataset will then be correlated with wireline logs from offset wells to support the correlation and confirmation of stratigraphy, rock properties, and site characterization.

Formal core plans and numbers of cores to be used for each analysis listed in Table 6 will be provided once they are finalized with a coring contractor prior to well installation.

Table 6: Summary of potential core analyses and associated parameters

Core Analysis Type	Parameters Obtained	Formations
Routine Core Analysis	Porosity, Permeability, Grain Density	Mt. Simon Sandstone Eau Claire Formation Intervals TBD
Tight Rock Analysis	Porosity, Permeability, Grain Density	Eau Claire Formation Intervals TBD
Thin-Section Petrography	Mineralogy, Lithology, Porosity, Grain size, Textural maturity, Oil Staining	Mt. Simon Sandstone Eau Claire Formation Intervals TBD
X-Ray Diffraction	Mineralogy, clay identification	Mt. Simon Sandstone Eau Claire Formation Intervals TBD
Core Gamma Ray Log	Lithology, Porosity, Grain Size, Geologic Contacts	Both Whole Core Intervals
Relative Permeability	Relative permeability, Wettability	Mt. Simon Sandstone Intervals TBD
Mercury Injection Capillary Pressure	Capillary Pressure	Mt. Simon Sandstone Eau Claire Formation Intervals TBD
Triaxial Tests	Rock Strength, Ductility, Poisson's Ratio, Young's Modulus	Mt. Simon Sandstone Eau Claire Formation Intervals TBD
Rock Compressibility	Rock Compressibility	Mt. Simon Sandstone Eau Claire Formation Intervals TBD

4.5 Fluid Sampling and Analysis (146.87 (b – d))

Characterization of formation fluids will be based on analysis of fluid samples acquired from NV_ACZ1, NV_ACZ2, NV_INJ1, and NV_INJ2. These samples will be collected through swabbing, drill stem tests (DSTs), or using downhole pumps and will provide information on the baseline geochemistry of the subsurface fluids. The sampled formations will include, but are not limited to, the injection formation, the ACZ monitoring interval, and the lowermost USDW. All fluid samples will be analyzed for TDS and other major analytes. This list of analytes as well as their detection limits is provided in Table 7. The static fluid level of the injection zone will also be established in NV_INJ1.

Table 7: Summary of analytical and field parameters for groundwater samples

Parameters	Analytical Methods *
Cations: Ca, Fe, K, Mg, Na, Si	EPA 6010B
Cations: Al, Sb, As, Ba, Cd, Cr, Cu, Pb, Mn, Hg, Se, Tl	EPA 200.8, EPA 245.1
Anions: Br, Cl, F, NO_3, and SO_4	EPA 300.0
Alkalinity	SM 2320B
Total Dissolved Solids (TDS)	SM 2540C
Total Organic Carbon (TOC)	SM 5310C
Dissolved Inorganic Carbon (DIC)	SM 5310C
Total and Dissolved CO_2	ASTM D513-06B
Stable Isotopes of δ13C	Isotope Ratio Mass Spectrometry **
pH	Field with multi-probe system
Conductivity/Resistivity	Field with multi-probe system
Temperature	Field with multi-probe system

* An equivalent method may be employed with the prior approval of the UIC Program Director.
**: Gas evolution technique by Atekwana and Krishnamurthy (1998)

4.6 Geomechanical Testing (146.87 (d)&(e))

The geomechanical characterization of the injection and confining zones for the project will be assessed by analyzing one or more of the following data sets: core analyses, log data, and in-situ field tests. These analyses may include, but are not limited to, triaxial compressive strength tests of core samples, dipole sonic and image logs, and step rate testing (SRT). The results of these analyses will provide information on the direction and magnitude of the three principal components of the stress field as well as the fracture gradient.

4.6.1 Step-Rate Testing

An SRT will be performed on the Mt. Simon Sandstone interval by analyzing the pressure response to increasing rates. This is done to determine:

- Fracture opening pressure (to determine the fracture gradient),
- Fracture propagation pressure, and
- Fracture closure pressure.

Injection at each of the rates will be performed on NV_INJ1 and NV_INJ2 for the same period as detailed in the high-level procedure below.

A formal procedure will be provided to the EPA prior to the running of the SRT.

1. Record static pressure and temperature for a minimum of one hour.
2. Rig-up pump truck, ensure sufficient volume of fluid is present at location to begin testing.
3. Pressure test lines above maximum anticipated operating pressure, but below equipment rating.
4. Begin SRT.
    a. Pump first step of test at first desired rate (ex: 0.5 barrels per minute (bpm)) for a defined time (ex: 0.5 hours)
    b. After the first step is completed, increase rate to next step (ex: 1.0 bpm) for the same defined step time (0.5 hours).
    c. Repeat until the end of the test.
5. Shut-in well at the wing valves(s). Record the time of shut-in, the rate prior to shut-in and the shut-in pressure.
6. Rig-down pump truck.
7. Monitor pressure fall-off for minimum of 24-hours.

The data from this test will be analyzed using appropriate analysis software, and the results will be included in the post installation reporting. Gauge calibration records will be provided at this time as well.

4.6.2 Pressure Fall-off Test

A pressure fall-off test (FOT) will be run on NV_INJ1 and NV_INJ2. The purpose of this test is to further characterize the injection zone. During this test, fluid will be injected at a constant rate for a predetermined length of time, after which the well is shut in, and the FOT monitored for an equal amount of time as the injection lasted.

The data from this test will be evaluated using rate superposition analysis to determine formation properties information such as: permeability, skin factor (damage), and flow regimes present. This test analysis will act as a "baseline" measurement to determine the change in overall effectiveness and injectivity of the injection zone over time, among other things. A high-level procedure is provided below. (Note that a formal procedure will be provided to the EPA prior to the running of the FOT.)

1. Record static pressure and temperature for a minimum of one hour.
2. Rig-up pump truck, ensure sufficient volume of fluid is present at location to begin testing.
3. Begin injection. Inject at constant rate for predetermined duration.
4. At the end of the injection period, shut the well in at the wing-valve(s). Record the time of shut-in, rate prior to shut-in, and the shut-in pressure.
5. Secure the well.
6. Rig-down pump truck
7. After the pressure has been allowed to decline for approximately the same duration as the injection the test can conclude.

The data from this test will be analyzed using pressure transient analysis software, and the results will be included in the post installation reporting. Gauge calibration records will be provided at the same time.

4.7 Mechanical Integrity Testing (146.87 (a)(4))

4.7.1 Internal Mechanical Integrity Testing (146.87 (a)(4)(i))

Internal mechanical integrity refers to the integrity of the seal between the long string casing, injection tubing, wellhead, and packer as well as the integrity of the individual components. In this subsection, annulus refers to the casing-tubing annulus. The effectiveness of this seal can be confirmed with a mechanical integrity test (MIT) and annular pressure monitoring.

Internal mechanical integrity will be demonstrated by way of an annulus pressure test as is standard for underground injection control (UIC) wells. The annulus pressure test will be performed after the tubing, packer, downhole equipment, and the wellhead have been installed. Prior to the installation of the wellhead, the annulus will be filled with fluid as outlined in the Well Construction components of this application (Attachment 4A: NV_INJ1 Well Construction Plan, 2023), (Attachment 4B: NV_INJ2 Well Construction Plan, 2023).

The annulus pressure test will then be performed by pressuring up the annulus after the well has reached thermal equilibrium. Once this has occurred, the annulus will be pressured up to 100 psi as outlined later in the application (Attachment 6A: NV_INJ1 Well Operations Plan, 2023), (Attachment 6B: NV_INJ2 Well Operations Plan, 2023). A calibrated digital gauge will be installed on the annulus, and the pressure will be monitored for a period no less than 60-minutes.

During this period, the casing and tubing pressure will be monitored at 5-minute intervals. Following the conclusion of the test, the gauge will be removed, and the casing pressure will be lowered to the normal operational pressure. The test will be considered successful if the pressure has deviated by less than 5% of the initial value.

In addition to this standard internal integrity monitoring, inspection of the tubing will be performed to monitor the tubing for corrosion (Attachment 7: Testing And Monitoring Plan, 2023)

Once injection commences, injection pressure, annular pressure, and annular fluid volumes will be monitored continuously to ensure internal well integrity and proper annular pressure is maintained (Attachment 7: Testing And Monitoring Plan, 2023).

4.7.2 External Mechanical Integrity (146.87 (a)(4)(ii – iv))

External mechanical integrity refers to the absence of fluid movement/leaks through channels in the cement between the long string casing and the borehole. The upward migration of injected fluids through this zone could result in contamination of USDWs. The external integrity of NV_INJ1 and NV_INJ2 will be confirmed throughout the project. The frequency of the testing to determine external mechanical integrity will be performed on the schedule defined in the testing and monitoring plan (Attachment 7: Testing And Monitoring Plan, 2023).

Generally accepted methods for evaluating external mechanical integrity include:

- Temperature or noise log,
- Oxygen-activation logging (OAL) or radioactive tracer (RAT) logging (during operation)

After completion, a baseline temperature log will be run from surface to the bottom of the long string casing in each injection well to provide initial temperature conditions over the well.

Temperature logging performed after injection has started will be performed at regular intervals based on the schedule provided in the testing and monitoring plan (Attachment 7: Testing And Monitoring Plan, 2023). The results of these logs will be compared to the baseline log to determine if anomalies that suggest CO_2 is migrating up the well bore are present.

If the temperature logging data suggests an issue with external well integrity exists, a radioactive tracer (RAT) log will be performed to evaluate external well integrity with greater sensitivity. In addition to the baseline temperature log, a Cement Bond Log (CBL), and advanced ultrasonic cement evaluation log will be run across the entire long casing string after completion of the injection well to confirm that the casing string was properly cemented. Cement Bond Logs-Variable Density Logs (CBL-VDLs) are recorded with sonic tools that detect the bond of the casing and formation to the cement between the casing and wellbore to identify damage. Ultrasonic tools provide higher accuracies and resolutions for cement evaluation.

4.8 Injection Well Schedule (146.87 (f))

Heartland Greenway Carbon Storage, LLC (HGCS) will provide Region 5 with the opportunity to witness all logging and testing detailed in this section. HGCS will submit a schedule of such activities to the Director 30 days prior to conducting the first test and submit any changes to the schedule 30 days prior to the next scheduled test, as much as reasonably possible.

Table 8 shows the tentative days required to collect the data for the Pre- Formation Testing Program for the primary project wells. An abbreviated drilling program for NV_INJ1 and NV_INJ2 is shown below and consists of the following steps that are subject to change as circumstances dictate.

1. Drill the surface hole to the surface casing depth.
    a. Sensitive, Confidential, or Privileged Information [redacted]
2. Log the surface hole with open hole logs.
    a. Note: *a list of these logs is provided in Table 4 above.*
3. Install the surface casing and cement in place per the methodology described in the Well Construction Program (Attachment 4A: NV_INJ1 Well Construction Plan, 2023), (Attachment 4B: NV_INJ2 Well Construction Plan, 2023).
4. To ensure the isolation of any shallow USDW and to confirm the integrity of cement-casing and cement-formation bond, a cement bond log will be run. Following this, and prior to drilling out the surface casing shoe, a casing pressure test will be completed.
    a. Note: *details on the casing pressure test are provided in* (Attachment 4A: NV_INJ1 Well Construction Plan, 2023), (Attachment 4B: NV_INJ2 Well Construction Plan, 2023).
5. Once the surface casing is cemented, tested and a good bond log has been run, the rig will drill through the surface casing shoe, then drill the well to the intermediate casing depth.
    a. Sensitive, Confidential, or Privileged Information [redacted]
6. Log the intermediate hole with open hole logs.
    a. Note: *a list of these logs is provided in Table 4 above.*

7. Install the intermediate casing and cement in place per the methodology described in the Well Construction Program (Attachment 4A: NV_INJ1 Well Construction Plan, 2023), (Attachment 4B: NV_INJ2 Well Construction Plan, 2023).
8. To ensure the isolation of the lowermost USDW and to confirm the integrity of cement-casing and cement-formation bond, a cement bond log will be run. Following this, and prior to drilling out the intermediate casing shoe, a casing pressure test will be completed.
    a. Note: *details on the casing pressure test are provided in* (Attachment 4A: NV_INJ1 Well Construction Plan, 2023), (Attachment 4B: NV_INJ2 Well Construction Plan, 2023).
9. Once the intermediate casing is cemented, tested and a good bond log has been run, the rig will drill through the intermediate casing shoe, then drill the well to TD.
    a. Sensitive, Confidential, or Privileged Information
10. The well will be logged with open hole logs.
    a. Note: *a list of these logs is provided in Table 5.*
11. Whole core depths will be determined from NV_OBS1 to guide coring depths in NV_INJ1 to collect cores from the reservoir and confining zone intervals. Sidewall core will be collected as required to fill in data gaps.
12. The long string casing will be installed and cemented in place per the methodology described in the Well Construction Program (Attachment 4A: NV_INJ1 Well Construction Plan, 2023), (Attachment 4B: NV_INJ2 Well Construction Plan, 2023).
13. Select intervals of the Mt. Simon Sandstone will be perforated and cleaned with acid per the methodology described in the Well Construction Program.
14. The injection string, packer and wellhead will be installed per the methodology described in the Well Construction Program.
15. Internal and External mechanical integrity will be displayed.
16. Fluid samples will be taken from the Mt. Simon Sandstone and will be analyzed for TDS, other major analytes, and stable isotopes.
    a. Note: *further detail on the fluid sampling is provided in Section 4.5 of this document.*
17. Geomechanical testing will be performed on the Mt. Simon Sandstone by means of an SRT to determine the in-situ fracture pressure of the formation.
18. Geomechanical testing will be performed on the core taken from the Eau Claire Formation as detailed in Section 4.4 of this document.
19. A pressure fall-off test (FOT) will be performed on the well to determine reservoir parameters.

Table 8: Tentative days required to conduct Pre-Operational Testing Program

Well	Depth in feet	Days	Data Sets
NV_OBS1	6,262	30	1. Open hole logs 2. Cased hole logs
NV_ACZ1	4,103	20	1. Fluid sampling (Deepest USWD, Ironton-Galesville) 2. Open hole logs 3. Cased hole logs
NV_ACZ2	4,103	20	1. Fluid sampling (Deepest USWD, Ironton-Galesville) 2. Open hole logs 3. Cased hole logs
NV_INJ1	6,238	45	1. Whole core acquisition 2. Open hole logs 3. Special open hole logs 4. Cased hole logs 5. Mt. Simon Sandstone fluid sample(s) 6. Geomechanical and reservoir testing
NV_INJ2 (Contingency)	6,259	45*	1. Whole core acquisition* 2. Open hole logs 3. Special open hole logs 4. Cased hole logs 5. Mt. Simon Sandstone fluid sample(s) 6. Geomechanical and reservoir testing
*NV_INJ2 will only be used to collect core as a contingency.			

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5. References

(2023). *Attachment 1:Project Narrative.* Class VI Permit Application Narrative; Vervain.

(2023). *Attachment 4A: NV_INJ1 Well Construction Plan.* Class VI Permit Application Injection Well #1 Construction Plan; Vervain.

(2023). *Attachment 4B: NV_INJ2 Well Construction Plan.* Class VI Permit Application Injection Well #2 Construction Plan; Vervain.

(2023). *Attachment 6A: NV_INJ1 Well Operations Plan.* Class VI Permit Application Injection Well #1 Operations Plan; Vervain.

(2023). *Attachment 6B: NV_INJ2 Well Operations Plan.* Class VI Permit Application Injection Well #2 Operations Plan; Vervain.

(2023). *Attachment 9: Testing And Monitoring Plan.* Class VI Permit Application Testing And Monitoring Plan; Vervain.

Atekwana EA, Krishnamurthy RV, 1998, *Seasonal variations of dissolved inorganic carbon and* $\delta^{13}C$ *of surface waters: Application of a modified gas evolution technique*. J Hydrol 205:265–278