Longleaf CCS Hub

Longleaf CCS LLC

Appendix

Quality Assurance and Surveillance Plan

40 CFR 146.90(k)

Appendix to the Testing and Monitoring Plan

Facility Information

Facility Name: Longleaf CCS Hub

Facility Contact: Longleaf CCS, LLC
14302 FNB Parkway
Omaha, NE 68154

Well Locations: Mobile County, Alabama

LL#1: Latitude: 31.071303° N
Longitude: -88.094703° W

LL#2: Latitude: 31.070774° N
Longitude: -88.074523° W

LL#3: Latitude: 31.0447129° N
Longitude: -88.0736318° W

LL#4: Latitude: 31.0569516° N
Longitude: -88.1047433° W

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List of Acronyms/Abbreviations

AoR	Area of Review
CCS	Carbon capture and storage
CO_2	Carbon dioxide
CMG	Computer Modelling Group
DOE	Department of Energy
DAS	Distributed Acoustic Sensing
DTS	Distributed Temperature Sensing
EPA	Environmental Protection Agency
ERRP	Emergency and Remedial Response
ft	Feet
LL	Longleaf
mg/l	Milligrams per liter
MIT	Mechanical Integrity Test
MMcf/d	Million cubic feet/day
mol%	Percentage of total moles in a mixture made up by one constituent
msl	Mean sea level
mt	Metric tons
Mt	Millions of metric tons
mt/d	Metric tons per day
mt/y	Metric tons per day
MT/y	Millions of metric tons per year
PISC	Post-Injection Site Care
PNC	Pulsed Neutron Capture Log
ppmv	Parts per million volume
psi	Pounds per square inch, gauge
psia	Pounds per square inch, absolute
psi/ft	Pounds per square inch per foot
SS	Sub- Sea
TVD	True Vertical Depth
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water

A. Project Management

A.1. Project/Task Organization

A.1.a/b Key Individuals and Responsibilities

The project will be owned and operated by Longleaf CCS, LLC who will serve as the lead on all project tasks while supervising the performance of subcontractors when required for individual tasks. Tasks which are related to testing and monitoring at the Longleaf CCS Hub that will require supervision for purposes of quality control and assurance are broadly divided into:

1. Groundwater Sampling and Analysis
2. Well Logging
3. Mechanical Integrity Testing
4. Injection Monitoring
5. CO_2 Stream Sampling and Analysis
6. Geophysical Monitoring

A.1.c Independence from Project Quality Assurance (QA) Manager and Data Gathering

Most of the physical samples collected and other data gathered as part of the testing and monitoring program will be analyzed, processed, or witnessed by third parties independent and outside of the project management structure. Longleaf CCS, LLC will provide the UIC Program Director with the name and credentials of any vendors, subcontractors, or testing laboratories used for testing and monitoring protocols during each semi-annual reporting period (see Section *K.1* in the *Testing and Monitoring Plan*).

A.1.d QA Project Plan Responsibility

Longleaf CCS, LLC will be responsible for maintaining and distributing the official, approved *Quality Assurance Surveillance Plan (QASP)*. Longleaf CCS, LLC will periodically review this *QASP* and consult the UIC Program Director if/when changes to the plan are warranted.

A.2. Problem Definition/Background

A.2.a Reasoning

The Longleaf CCS Hub *Testing and Monitoring Plan* MVA program has operational monitoring, verification, and environmental monitoring components. Operational monitoring is used to ensure safety and protection of USDWs with all procedures associated with fluid injection, monitoring the response of the injection interval at the wellsite, and the movement of the CO_2 plume and pressure front. Key monitoring parameters include: downhole pressure, wellhead pressure, flow rate, annulus pressure and fluid volume, and above-zone fluid chemistry. Other monitoring parameters include well temperature profile and acoustic sensing. The verification component of the *Testing and Monitoring Plan* will provide data to evaluate if leakage of CO_2 through the caprock or wellbores is occurring. This includes pressure monitoring, PNC loging, temperature monitoring, vertical seismic profile surveys (VSPs), formation fluid monitoring in the above-zone interval, and groundwater monitoring in deep and shallow USDWs. Pressure and geophysical data will be used to validate the geologic and reservoir models.

The objective of the Longleaf CCS Hub *Testing and Monitoring Plan* is to demonstrate that project activities do not endanger the environment or human health. To achieve this goal, this *QASP* was developed to ensure the quality and standards of the testing and monitoring program and to specifically meet the requirements of 40 CFR 146.90(k).

A.2.b Reasons for Initiating the Project

The objective of the Longleaf CCS Hub is to develop a safe and commercially viable CO_2 storage site available to CO_2 emitters in the Mobile, Alabama region.

A.2.c Regulatory Information, Applicable Criteria, Action Limits

Longleaf CCS, LLC is required to perform several types of activities during the lifetime of the CO_2 storage project in order to ensure that the injection wells maintain their mechanical integrity, that fluid migration and operating pressures are within the limits described in the permit application, and that there is negligible threat to USDWs, public health and safety, and the local environment. Monitoring procedures included well MITs, injection pressure and rate monitoring, CO_2 plume and pressure front tracking, and groundwater quality testing (full details of monitoring activities are provided in the *Testing and Monitoring Plan*). This *QASP* discusses data measurement methods as well as the steps Longleaf CCS, LLC will take to ensure that the quality of all gathered samples and data provide confidence in making project decisions and protecting USDWs.

A.3. Project/Task Description.

A.3.a Summary of Work to be Performed

Table 1 describes the testing and monitoring activities, location, and purpose. **Figure 1** displays the surface locations of all injection and monitoring wells, and **Figure 2** displays the stratigraphic locations of all injection and monitoring wells.

Table 1: Summary of Testing and Monitoring

Activity	Location(s)	Method	Analytical Technique	Purpose
CO_2 stream analysis	Master meter at LL#2 well site	Gas chromatograph and physical sampling	Chemical analysis	Analysis of injectate 40 CFR 146.90(a)
Corrosion monitoring	Post-compression and dehydration	Corrosion coupons	Chemical analysis	Corrosion monitoring 40 CFR 146.90(c)
Groundwater quality	AOB#1-2 UOB#1-4 Shallow USDW wells (10)	Kuster Flow Sampler (AOB and UOB wells) and shallow groundwater sampling (ASTM-D4448[1])	Chemical analysis	Groundwater and geochemistry monitoring 40 CFR 146.90(d)
Injection rate and volume	LL#1-4 wellheads	Flow meter	Continuous direct measurement	Continuous monitoring of injection rate and volume 40 CFR 146.90(b)
Injection pressure	LL#1-4 wellheads	Wellhead pressure/ temperature gauge	Continuous direct measurement	Continuous monitoring of injection pressure 40 CFR 146.90(b)
Annular pressure	LL#1-4 wellheads	Annular pressure gauge	Continuous direct measurement	Continuous monitoring of annular pressure 40 CFR 146.90(b)

[1] American Society for Testing and Materials (ASTM) Standard D4448-01(2019). Standard Guide for Sampling Ground-Water Monitoring Wells, ASTM International , West Conshohocken, PA. DOI: 10.1520/D4448-01R19, www.astm.org.

Activity	Location(s)	Method	Analytical Technique	Purpose
Annular Volume	LL#1-4 wellheads	Annular volume gauge	Continuous direct measurement	Continuous monitoring of annulus fluid volume 40 CFR 146.90(b)
Downhole pressure/ temperature	LL#1-4 IOB#1-5 AOB#1-2	Downhole gauges	Direct measurement	Continuous monitoring of injection zone pressure and temperature 40 CFR 146.90(g)(1)
Mechanical integrity	LL#1-4 IOB#1-5 AOB#1-2	Internal – Annular pressure gauge monitoring LL#1-4 only	Direct measurement	Demonstration of internal and external mechanical integrity of the wellbore 40 CFR 146.90(e)
		External – DTS	Distributed indirect measurement	
Pressure falloff testing	LL#1-4	Pressure gauge	Direct measurement	Pressure falloff testing 40 CFR 146.90(f)
CO_2 plume and pressure front monitoring	LL#1-4 IOB#1-5 AOB#1-2	Downhole pressure and temperature gauges, PNC logs, and VSPs.	Direct and indirect measurements	Plume and pressure front tracking 40 CFR 146.90(g)

A.3.b Frequency of Work to be Performed

Table 2 describes the frequency of testing and monitoring activities.

Table 2: Testing and Monitoring Frequency

Monitoring Activity/Test		Location	Baseline Frequency	Injection Period Frequency	Post-Injection Site Care Frequency
CO_2 Injection Stream Analysis		Master meter at LL#2 well site	Begin before injection	Continuous/ Quarterly	N/A
Corrosion Monitoring		Post-compression and dehydration	Establish coupon baseline	Quarterly	N/A
Fiber Optic / Seismic Monitoring	Distributed Acoustic Sensing (DAS)	LL#1-4, IOB#1-5, AOB#1-2	Beginning before injection	Continuous	Continuous
	Distributed Temperature Sensing (DTS)	LL #1-4, IOB #1-5, AOB #1-2	Beginning before injection	Continuous	Continuous

Monitoring Activity/Test		Location	Baseline Frequency	Injection Period Frequency	Post-Injection Site Care Frequency
Pulsed Neutron Capture Log (PNC)		LL#1-4, IOB#1-5, AOB#1-2	Once before injection	3yrs after injection begins; Every 5yrs after	At end of injection; Every 5yrs after
Mechanical Integrity Tests		LL#1-4, IOB#1-5	Once before injection	Annually	Annually
		AOB#1-2, UOB#1-4	Once before injection	Every 5yrs	Every 5yrs
Pressure Transient Test		LL#1-4	Once before injection	3yrs after injection begins; Every 5yrs after	At end of injection; Every 5yrs after
Bottomhole Pressure Monitoring		LL#1-4, IOB#1-5, AOB#1-2	Beginning before injection	Continuous surface read-out	Continuous surface read-out
Wellhead Pressure Monitoring	Tubing	LL#1-4, IOB#1-5, AOB#1-2	Beginning before injection	Continuous	Continuous
	Annulus	LL#1-4, IOB#1-5, AOB#1-2	Beginning before injection	Continuous	Continuous
Injection Rate and Volume Monitoring		LL#1-4	N/A	Continuous	N/A
Fluid Sampling		LL#1-4, IOB#1-5	Once during well construction	N/A	N/A
		AOB#1-2	At least 3 sampling events prior to injection	Quarterly for first yr; Annually thereafter	Annually
		UOB#1-4, All Shallow Groundwater Wells (10)	At least 3 sampling events prior to injection	Annually	Annually

A.3.c Geographic and Stratigraphic Locations

Figure 1 displays the surface locations of all injection and monitoring wells, including in-zone (5 wells), above-zone (2 wells), deep USDW (4 wells), and shallow USDW (10) monitoring wells. Shallow USDW wells will be located on each existing wellpad in the Longleaf CCS Hub.

Figure 2 displays the stratigraphic locations of all injection and monitoring wells. Injection wells and in-zone monitoring wells will be completed in the Paluxy Formation at an approximate depth of 10,080 ft MSL. Above-zone monitoring wells will be completed in the first porous and permeable interval in the Upper Tuscaloosa Formation that is above the primary confining layer, the Tuscaloosa Marine Shale, at an approximate depth of 7,250 ft MSL. Deep USDW monitoring wells will be completed in the lowest most USDW, the Chicasawhay Formation, at an approximate depth of 1,700 ft MSL. Shallow USDW monitoring wells will be completed within a near-surface freshwater source.

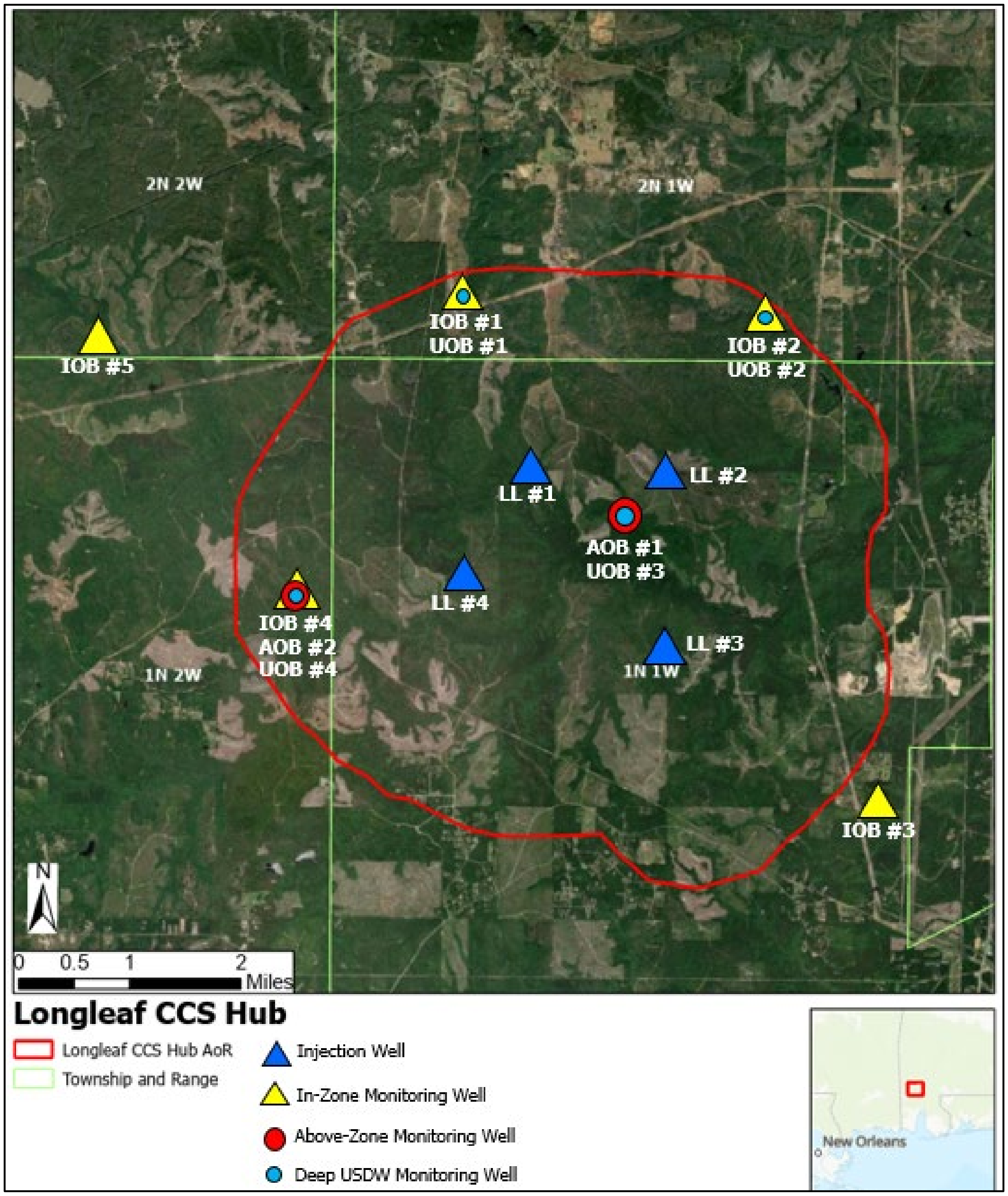

Figure 1: Locations of Proposed Injection and Monitoring Wells at the Longleaf CCS Hub.

Note: Shallow USDW monitoring wells are located on each well pad (10 total).

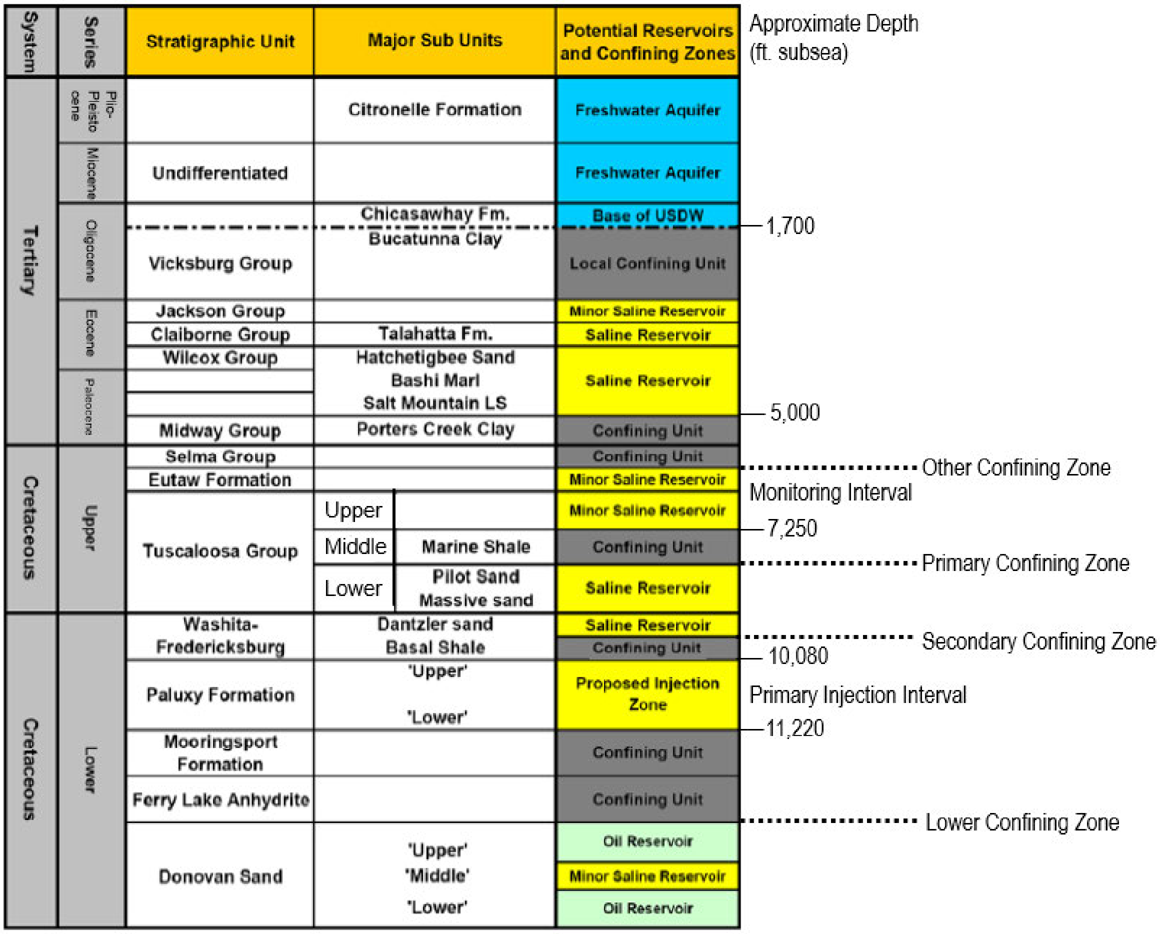

Figure 2: Geologic Stratigraphic Column at the Longleaf CCS Hub (modified from Pashin et al., 2008).[2]

A.4. Quality Objectives and Criteria

<u>A.4.a Performance/Measurement Criteria</u>

The overall objective for this *QASP* is to develop and implement procedures for subsurface monitoring, field sampling, laboratory analysis, and reporting which will provide results to meet the characterization and non-endangerment goals of the Longleaf CCS Hub. Please refer to **Table 3** through **Table 8** for specifications and action limits of technologies used for Longleaf CCS Hub testing and monitoring.

[2] Pashin, J. C, McIntyre, M. R., Grace, R. L. B., Hills, D. J., "Southeastern Regional Carbon Sequestration Partnership (SECARB) Phase III, Final Report", Report to Advanced Resources International by Geological Survey of Alabama, Tuscaloosa, September 12, 2008

Table 3: Summary of Analytical and Field Parameters for Shallow USDW, Deep USDW, and Above-Zone Fluid Sampling

Parameters	Analytical Methods[3]	Detection Limit/Range	Typical Precisions	QC Requirements
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb, Se, and Tl	ICP-MS EPA Method 6020B[4] or EPA Method 200.8[5]	0.001 to 0.1 mg/L (analyte, dilution and matrix dependent)	±15%	Daily Calibration; blanks, duplicates and matrix spikes at 10% or greater frequency
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES EPA Method 6010D[6] or EPA Method 200.7[7]	0.005 to 0.5 mg/L (analyte, dilution and matrix dependent)	±15%	Daily Calibration; blanks, duplicates and matrix spikes at 10% or greater frequency
Anions: Br, Cl, NO_3, and SO_4	Ion Chromatography EPA Method 300.0[8]	0.02 to 0.13 mg/L (analyte, dilution and matrix dependent)	±15%	Daily Calibration: blanks and duplicates at 10% or greater frequency
Dissolved CO_2	Coulometric Titration ASTM 513-16[9]	25 mg/L	±15%	Duplicate measurement; standards at 10% or greater frequency
Total Dissolved Solids	Gravimetry APHA 2540C[10]	12 mg/L	±15%	Balance calibration, duplicate analysis
Alkalinity	APHA 2320B[11]	4 mg/L	±3 mg/L	Duplicate Analysis
pH (field)	EPA 150.1[12]	2 to 12 pH units	±0.2 pH unit	User Calibration per manufacturer recommendation

[3] An equivalent method may be employed with the prior approval of the UIC Program Director
[4] U.S. EPA. 2014. "Method 6020B (SW-846): Inductively Coupled Plasma-Mass Spectrometry." Revision 2. Washington, DC.
[5] U.S. EPA. 1994. "Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma – Mass Spectrometry." Revision 5.4. Environmental Monitoring Systems Laboratory Office of Research and Development U.S. Environmental Protection Agency, Cincinnati, Ohio.
[6] U.S. EPA. 2014. "Method 6010D (SW-846): Inductively Coupled Plasma-Optical Emission Spectrometry." Revision 4. Washington, DC.
[7] U.S. EPA. 1994. "Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma – Atomic Emission Spectrometry." Revision 4.4. Environmental Monitoring Systems Laboratory Office of Research and Development U.S. Environmental Protection Agency, Cincinnati, Ohio.
[8] U.S. EPA. 1993. "Method 300.0: "Methods for the Determination of Inorganic Substances in Environmental Samples." Revision 2.1. Washington, DC.
[9] ASTM Standard D513-16. 1988 (2016). "Standard Test Methods for Total and Dissolved Carbon Dioxide in Water," ASTM International, West Conshohocken, PA. DOI: 10.1520/D0513-16, www.astm.org
[10] American Public Health Association (APHA), SM 2540 C, "Standard Methods for the Examination of Water and Wastewater", APHA-AWWA-WPCF, 20th Edition (SDWA) and 21st Edition (CWA).
[11] Method 2320 B, Standard Methods for the Examination of Water and Wastewater, APHA-AWWA-WPCF, 21st Edition, 1997.
[12] U.S. EPA. 1971 (1982). "Method 150.1: pH in Water by Electromagnetic Method", Cincinnati, OH.

Parameters	Analytical Methods[3]	Detection Limit/Range	Typical Precisions	QC Requirements
Specific Conductance (field)	APHA 2510[13]	0 to 200 mS/cm	±1% of reading	User calibration per manufacturer recommendation
Temperature (field)	Thermocouple	-5 to 50ºC	±0.2ºC	Factory Calibration
Isotopes: $\delta^{13}C$ of DIC	Isotope Ratio Mass Spectrometry	12.2mg/L HCO_3^- for $\delta^{13}C$	±0.15% for $\delta^{13}C$	10% duplicates; 4 standards/batch

Abbreviations: ICP=inductively coupled plasma; MS= mass spectrometry; OES= Optical emission spectrometry; GC-P=Gas chromatography-Pyrolysis

Table 4: Summary of Analytical Parameters for CO_2 Stream

Parameters	Method	Detection Limit/Range	Typical Precisions	QC Requirements
CO_2 Purity	ISBT 2.0 Caustic absorption Zahm-Nagel or online gas quality equipment	99.00% to 99.99%	± 10 % of reading	User calibration per manufacturer
Water Content	Online gas quality equipment	To be updated with manufacturer specifications	To be updated with manufacturer specifications	To be updated with manufacturer specifications
Total Hydrocarbons	ISBT 10.0 THA (FID) or online gas quality equipment	1 uL/L to 10,000 uL/L (ppm by volume)	5 - 10 % of reading relative across the range	daily blank, daily standard within 10 % of calibration, secondary standard after calibration
Inert Gases (N_2, Ar, O_2)	ISBT 4.0 (GC/DID) GC/TCD or online gas quality equipment	1 uL/L to 5,000 uL/L (ppm by volume)	± 10 % of reading	daily standard within 10 % of calibration, secondary standard after calibration
Alcohols, aldehydes, esters	ISBT 11.0 (GC/FID) or online gas quality equipment	0.1 uL/L to 100 uL/L (ppm by volume)- dilution dependent	5 - 10 % of reading relative across the range	daily blank, daily standard within 10 % of calibration, secondary standard after calibration
Hydrogen Sulfide	ISBT 14.0 (GC/SCD) or online gas quality equipment	0.1 uL/L to 100 uL/L (ppm by volume)- dilution dependent	5 - 10 % of reading relative across the range	daily blank, daily standard within 10 % of calibration, secondary standard after calibration
Total Sulfur	ISBT 14.0 (GC/SCD) or online gas quality equipment	0.01 uL/L to 50 uL/L (ppm by volume)- dilution dependent	5 - 10 % of reading relative across the range	daily blank, daily standard within 10 % of calibration, secondary standard after calibration

[13] American Public Health Association (APHA), SM2510, 1992. Standard Methods for the Examination of Water and Wastewater", APHA-AWWA-WPCF, 18th Edition, 1992.

Parameters	Method	Detection Limit/Range	Typical Precisions	QC Requirements
Oxygen	ISBT 4.0 (GC/DID) GC/TCD or online gas quality equipment	1 uL/L to 5,000 uL/L (ppm by volume)	± 10 % of reading	daily standard within 10 % of calibration, secondary standard after calibration
Carbon Monoxide	ISBT 5.0 Colorimetric ISBT 4.0 (GC/DID) or online gas quality equipment	5 uL/L to 100 uL/L (ppm by volume)	± 20 % of reading	duplicate analysis

Note: Analytical parameters presented are for physical bottle sampling and laboratory analysis. A gas chromatograph will be installed to continuously detect CO_2 purity, total hydrocarbons, inert gases, hydrogen, alcohols, oxygen, carbon monoxide, and glycol. Quarterly bottle analysis will be performed to analyze the CO_2 stream for hydrogen sulfide and total sulfur. The detection range, accuracy, precision, and calibration requirements of the gas chromatograph will be shared with the UIC Program Director as requested.

Table 5: Specifications for MIT Testing and and Geophysical Monitoring Technology

Logging Tool	Analytical Methods	Detection Limit/Range	Typical Precisions	QC Requirements	Calibration Frequency
Ultrasonic Cement Bong Log (SLB USI Tool)	Vendor best practice	0-10 MRayl	±0.5 MRayl	Vendor Calibration (3rd party)	Per Vendor Discretion
PNC Logging (SLB Pulsar and RST Tool)	Vendor best practice	Porosity: 0 to 60 pu	TBD	Vendor Calibration (3rd party)	Per Vendor Discretion
Distributed Temperature Sensing	Vendor best practice	-40ºF to 149ºF	0.01ºC	Vendor Calibration (3rd party)	Per Vendor Discretion

Table 6: Summary of Analytical Parameters for Coupon Corrosion Monitoring

Parameters	Analytical Methods	Detection Limit/Range	Typical Precisions	QC Requirements
Mass	NACE RP0775-2018[14]	.005 mg	±2%	Annual Calibration of Scale (3rd Party)
Thickness	NACE RP0775-2018	.001 mm	±.005 mm	Factory calibration

[14] The National Association of Corrosion Engineers (NACE) Standard RP0775, (2018). *Preparation, Installation, Analysis, And Interpretation of Corrosion Coupons In Oilfield Operations*, Houston, TX. ISBN 1-57590-086-6.

Table 7: Summary of Measurement Parameters for CO_2 Injection Process Monitoring

Parameters	Methods	Detection Limit/Range	Vendor Specified Accuracy	QC Requirements	Calibration Frequency
Operational Annular Pressure Monitoring	ISO/IEC 17025 (2017)	0-3,000 psi	± .5% FS	Annual Calibration of Scale (3rd party)	As suggested by control system/gauge manufacturer
Wellhead Injection pressure (*e.g. PPS PPS31 Wellhead Pressure Logger or similar product*)	ISO/IEC 17025 (2017)	0-5,000 psi	±0.03% FS	Annual Calibration of Scale (3rd party)	As suggested by gauge manufacturer
Injection mass flow rate (*e.g. Emerson Coriolis mass flow meter or similar product*)	AGA Report 3 API Chapter 14 Part 3[15]	547.95-3,561.64 mt/day	±0.1% of rate for liquid ±0.35% of rate for gas	Annual Calibration of Scale (3rd party)	As suggested by gauge manufacturer
Downhole Temperature (*e.g. Baker Hughes SureSENS QPT ELITE pressure/temperature gauge or similar product*)	Unknown	77 ºF to 302 ºF	0.27 ºF	Initial Manufacturer Calibration	Not required on downhole gauges
Downhole Pressure (*e.g. Baker Hughes SureSENS QPT ELITE pressure/temperature gauge of similar product*)	Unknown	200 psi to 10,000 psi	± 0.015% FS	Initial Manufacturer Calibration	Not required on downhole gauges

[15] API MPMS Ch. 14 / AGA Report No. 3: Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids – Concentric, Square-edged Orifice Meters, 2016.

Table 8: Actionable Testing and Monitoring Outputs

Activity or Parameter	Project Action Limit	Detection Limit	Anticipated Reading
DTS	Action to be taken when a temperature anomaly is observed	Refer to Table 5	Difference between profiles observed during baseline & injection stream temperature
PNC logging	Action to be taken when a CO_2 saturation anomaly is observed	Refer to Table 5	Brine saturated ~ 60 cu CO_2 saturated ~ 8 cu
DAS	Action to be taken when an acoustic anomaly is observed	Refer to Table 5	Baseline and injection noise
Injection rate	Injection rate is reduced if max instantaneous rate of 4,110 mt/d is reached	Refer to Table 7	Averaging 3,425 mt/d
Surface/downhole pressure	Injection stops if MASP is reached or 90% fracture pressure downhole is reached	Refer to Table 7	< 2,000 psi at surface < 6,400 psi downhole (see *Injection Well Operations Plan)*
Annular pressure	<3% pressure loss over 1 hour	Refer to Table 5	>3% pressure loss over 1 hour
Annular volume	10% loss of annular volume or continuous fluid make up exceeding 24 hours	Tank fluid level indicator	Annular fluid make up is expected when temperature of the fluid changes
Annular pressure/volume	Action to be taken when annulus pressure is below 250 psi, above 500 psi, or less than injection pressure downhole in injection wells	Refer to Table 7	250-500 psi at surface Volume TBD during baseline
Above-zone water quality (fluid sampling)	Action to be taken when chemical profile anomaly is observed	Refer to Table 3	Profiles TBD during baseline
Above-confining-zone pressure	Action will be taken when a pressure/temperature anomaly occurs	Refer to Table 3	Profiles TBD during baseline
CO_2 plume monitoring	Action to be taken if CO_2 plume is observed outside of expected/modelled spatial limits/geologic intervals	Dependent on geologic conditions	Profiles TBD during baseline

A.4.b Precision

For groundwater sampling, data accuracy will be assessed by the collection and analysis of field blanks to test sampling procedures and matrix spikes to test lab procedures. Field blanks will be taken no less than one per sampling event to spot check for sample bottle contamination. Assessment of analytical precision will be the responsibility of the individual laboratories. Third party laboratories used will be EPA approved and certified laboratories.

A.4.c Bias

Assessment of analytical bias is to be the responsibility of the individual laboratories per their standard operating procedures and analytical methodologies.

A.4.d Representativeness

Data representativeness is the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition. The Longleaf CCS Hub sampling network has been designed to provide data representative of site-specific conditions. For analytical results of individual groundwater samples, representativeness will be estimated by ion and mass balances. Ion balances within ±10% error or less will be considered valid. Mass balance assessment will be used in cases where the ion balance is greater than ±10% to help identify the source of error. For a sample and its duplicate, if the relative percent difference is greater than 10%, the sample may be considered non-representative.

A.4.e Completeness

Data completeness is a measure of the quantity of valid data obtained from a measurement system compared to the quantity that was expected to be obtained under normal conditions. It is anticipated that data completeness of 90% for groundwater sampling will be acceptable to meet monitoring goals. In cases of direct pressure and temperature measurements, it is expected that data will be recorded no less than 90% of the time.

A.4.f Comparability

Data comparability is the confidence with which one data set can be compared to another. The data sets generated by the Longleaf CCS Hub will be done so in accordance with a consistent methodology so that each data set is directly comparable to another. This allows for appropriate data comparison and identification of anomalies, if present.

To ensure appropriate QA/QC standards, direct pressure, temperature, and logging measurements obtained through the proposed operations will be directly comparable to data previously obtained.

A.4.g Method Sensitivity

Table 9 summarizes the representative logging tool specifications. **Table 10** through **Table 13** provide additional details on gauge specifications and sensitivities.

Table 9: Representative Logging Tool Specifications

Parameter	Ultrasonic Imager Log	PNC/Reservoir Saturation Tool	DAS	DTS	Pulsar
Logging speed	1,800 ft/hr	150 ft/hr	NA	NA	1,000 ft/hr
Vertical resolution	6 inches	24 inches	*25cm	*25-50 cm	15 inches
Investigation	Casing-to-cement interface	4-6 inches	*0-24.8 miles	At fiber location	10-16 inches
Temperature rating	350°F (175°C)	300°F (150°C)	500°F	149ºF	350°F (175°C)
Pressure rating	20,000 psi	15,000 psi	20,000 psi	20 psi	15,000 psi

Table 10: Pressure and Temperature—Downhole Gauge Vendor Specifications

Parameter	Value
Calibrated working pressure range	200 psi to 10,000 psi
Initial pressure accuracy	+-0.015% (1.5 psi at full scale)
Pressure resolution	0.0001 psi
Pressure drift stability	2.0 psi per year at full scale
Calibrated working temperature range	77°F to 302°F (25°C to 150°C)
Initial temperature accuracy	0.27°F (0.15°C)
Temperature resolution	0.0001°F
Temperature drift stability	0.018°F (<0.01°C)
Max temperature	302°F

Note: Specifications from the *Baker Hughes SureSENS QPT ELITE Pressure/Temperature Gauge* are provided as an example of typical specifications from a vendor. A similar product may be used.

Table 11: Wellhead Pressure/Temperature Gauge Vendor Specifications

Parameter	Value
Calibrated working pressure range	0-5,000 psi
Initial pressure accuracy	±0.03% FS
Pressure resolution	0.0003% FS
Pressure drift stability	< 3.0 psi
Calibrated working temperature range	-4ºF to 158ºF
Initial temperature accuracy	±0.09 ºF (0.5ºC)
Temperature resolution	0.02 ºF (0.01 ºC)
Max temperature	158ºF

Note: Specifications from a *PPS PPS31 Wellhead Pressure Logger* are provided as an example of typical specifications from a vendor. A similar product may be used.

Table 12: Leak Detection – Handheld Leak Detection Device

Parameter	Value
Calibrated working detection range	0 – 10,000 ppm CO_2
Accuracy	±5% of reading or ±2% of full scale
Measurement resolution	20 ppm

Table 13: Mass Flow Rate Field Gauge – CO_2 Mass Flow Rate Vendor Specifications

Parameter	Value
Calibrated working flow rate range	547.95-3,561.64 mt/d
Mass flow rate accuracy	±0.10% of rate (liquid), ±0.35% of rate (gas)
Mass flow rate repeatability	±0.10% of rate (liquid), ±0.20% of rate (gas)
Mass flow rate drift stability	To be determined

Note: Specifications from an *Emerson Coriolis Mass Flow Meter* are provided as an example of typical specifications from a vendor. A similar product may be used.

A.5. Special Training/Certifications

A.5.a Specialized Training and Certifications

All sampling equipment and wireline logging tools will be operated by trained, qualified, and, where required, certified personnel according to the service company which provides the equipment. Subsequent data will be processed and analyzed by technically skilled personnel according to industry standards. Groundwater sampling and laboratory chemical analysis will be evaluated by EPA certified laboratories that employ qualified and experienced personnel who understand and regularly follow environmental sampling/chemical analysis standard operating procedures and quality control protocols. Longleaf CCS, LLC will provide relevant certifications for all vendor/subcontractor staff upon request.

A.5.b/c Training Provider and Responsibility

Longleaf CCS, LLC or the designated subcontractor for the data collection activities will provide necessary training for personnel.

A.6. Documentation and Records

The Longleaf CCS Hub monitoring program is broken down into several focus areas:

- *Operational Monitoring:* CO_2 stream analysis, CO_2 injection rate and pressure, annular pressure/volume, corrosion monitoring, wellhead/valve leak detection.
- *Hydrogeologic Testing:* Pressure falloff tests.
- *Mechanical Integrity Testing:* DTS and PNC logging.
- *Direct Plume Monitoring:* Downhole and surface pressure/temperature gauges
- *Indirect Plume Subsurface Monitoring:* PNC logging, DAS, VSPs, DTS.
- *Above-Zone Monitoring:* DTS, downhole pressure/temperature gauges, formation fluid sampling.
- *Deep and Shallow USDW Monitoring:* Fluid sampling.

Each monitoring focus area produces different types of data and has distinct data-management needs (input, storage, processing, manipulation, querying, access/output). In order to efficiently store and utilize this array of data, several databases under individual tasks (i.e., pressure monitoring) will be generated and maintained, depending on their compatibility with an overarching distributed data-management system. To the best degree possible, these individual databases will be linked to a centralized database and file archive system. Monitoring data will be collected under the appropriate quality assurance protocols (e.g., compliance related data will have higher QA protocols than non-compliance related data). These various data sets will be acquired and manipulated into many different file-formats and data forms (hard copy, electronic image files, physical samples, etc.). Each data type will require different data-management protocols and storage/management tools which may vary from simple file management to relational databases to geographic information systems.

Technical experts will screen, validate, and/or pre-process raw data to produce “interpretation-ready” or interpreted data sets. Data with different levels of quality assurance differentiations (e.g., legacy data vs compliance-driven data) and at different levels of processing/verification will be managed separately.

A.6.a Report Format and Package Information

Longleaf CCS, LLC will provide the UIC Program Director with semi-annual reports containing all relevant project data and testing and monitoring information for the reporting period in compliance with 40 CFR 146.91(a). Refer to Section K of the *Testing and Monitoring Plan* for further detail on the timing and content of reporting for specific events and operations.

A.6.b Other Project Documents, Records, and Electronic Files

Other documents, records, and electronic files such as well logs, test results, plugging reports, or other data will be stored and maintained for 10 years post site closure and provided at the request of the UIC Program Director.

A.6.c/d Data Storage and Duration

Pursuant to 40 CFR 146.91(f)(3), any monitoring data collected through implementation of the *Testing and Monitoring Plan* will be retained for at least 10 years after it is collected. All site characterization data will be retained throughout the life of the geologic sequestration project and for at least 10 years following site closure. See Section K.4 of the *Testing and Monitoring Plan* for further information on data and document retention.

A.6.e *QASP* Distribution Responsibility

A representative from Longleaf CCS, LLC will be designated as the responsible party for ensuring that all those on the distribution list will receive the most current copy of the approved *QASP*.

B. Data Generation and Acquisition

B.1. Sampling Process Design

This section describes the monitoring network that will be used to support collection of the various characterization and monitoring measurements needed to ensure safe and nominal CO_2 injection operations, track the development of the CO_2 plume and elevated pressure front, and identify/quantify any potential leakage of CO_2. Based on the current conceptual understanding of the Longleaf CCS Hub geology, this strategy was developed to ensure safe, long-term containment of CO_2 within the injection interval and non-endangerment of USDWs.

B.1.a Design Strategy

CO_2 Stream Monitoring Strategy

The objective of repeatedly analyzing the CO_2 stream is to evaluate the potential interactions of CO_2 and/or other constituents of the injectate with formation solids and fluids. This analysis can also identify (or rule out) potential interactions with well materials. Establishing the chemical composition of the injectate also supports regulatory determinations under the Resource Conservation and Recovery Act (RCRA)[16] and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)[17]. Additionally, monitoring the chemical and physical characteristics of the CO_2 may help distinguish the injectate from the native fluids and gases if unintended leakage from the storage reservoir occurred.

[16] Resource Conservation and Recovery Act (RCRA), 42 U.S.C. 6901 et seq. (1976)
[17] Comprehensive Environmental Response, Compensation, and Liability Act, (CERCLA) 42 U.S.C. 9601 et seq. (1980).

Longleaf CCS, LLC expects multiple sources of CO_2 from the Mobile, Alabama region, with additional sources to be added throughout the life of the project. Each source will have a different gas stream composition, and the composition of the final injected gas stream will change slightly depending on which sources are operational. In order to detect any significant changes in the physical or chemical properties of the CO_2 stream that may result in a deviation from the permitted specifications, Longleaf CCS, LLC will analyze the CO_2 stream continuously with a gas chromatograph at the master meter located at the Injection Well LL#2 wellpad. Additionally, physical samples will be taken quarterly to be tested for hydrogen sulfide and total sulfur content (See Section B of the *Testing and Monitoring Plan* for more details).

Corrosion Monitoring Strategy

Corrosion coupon analyses will be conducted quarterly to aid in ensuring the mechanical integrity of the equipment in contact with the CO_2. Coupons shall be sent out quarterly for analysis, which will be conducted in accordance with the NACE RP0775-2018[18] standard to determine and document corrosion wear rates based on mass loss.

Shallow Groundwater Monitoring Strategy

Ten monitoring wells will be constructed for shallow groundwater monitoring at the Longleaf CCS Hub. These wells will be installed and screened in a near-surface freshwater source to monitor the geochemistry of groundwater commonly accessed by private water wells in the area. The wells were selected to give a representative spatial distribution around the planned CO_2 injection wells and modeled plume development.

Above-Zone and Deep Groundwater Monitoring Strategy

Two above-zone monitoring wells will be completed in the Upper Tuscaloosa Formation and four deep USDW monitoring wells will be completed in the Chickasawhay Formation (lowest most USDW). The above-zone monitoring wells will serve to detect any early leakage above the confining zone, and the deep USDW monitoring wells will monitor the formation fluid geochemistry of the lowest most USDW. In addition to baseline

[18] The National Association of Corrosion Engineers (NACE) Standard RP0775, (2018). *Preparation, Installation, Analysis, And Interpretation of Corrosion Coupons In Oilfield Operations*, Houston, TX. ISBN 1-57590-086-6.

sample collection and analysis prior to the start of injection, pressurized fluid samples will be collected from these six monitoring wells during the injection phase. Mechanical Integrity Testing and downhole temperature monitoring at the injection wells will also provide data to ensure the mechanical integrity of the well is maintained. With the planned sampling and monitoring frequencies, baseline conditions will be documented, natural variability in conditions will be characterized, unintended brine or CO_2 leakage will be detected, and sufficient data will be collected to demonstrate that the effects of CO_2 injection are limited to the intended Paluxy Formation storage reservoir.

Parameters will include selected constituents that: (1) have primary and secondary EPA drinking water maximum contaminant levels, (2) are the most responsive to interaction with CO_2 or brine, (3) are needed for quality control, and (4) may be needed for geochemical modeling. After a sufficient baseline is established, monitoring scope may shift to a subset of indicator parameters that are (1) the most responsive to interaction with CO_2 or brine and (2) are needed for quality control to accurately test for and monitor the presence (or lack thereof) of CO_2 migration. Implementation of a reduced set of parameters would be done in consultation with the UIC Program Director. During any period where a reduced set of analytes is used, if statistically significant trends are observed that are the result of unintended CO_2 or brine migration, the analytical list would be expanded to the full set of monitoring parameters. All groundwater and formation fluid samples will be analyzed using a laboratory meeting the requirements under the EPA Environmental Laboratory Accreditation Program. The full list of analytical parameters and selected methods is provided in **Table 3.**

Direct CO_2 Plume and Pressure Front Monitoring Strategy

Downhole pressure/temperature gauges will be used in all deep monitoring and injection wells to directly monitor the formation pressure and temperature of the injection reservoir (Paluxy Formation) and above-zone interval (Upper Tuscaloosa Formation). Downhole pressure/temperature gauges will continuously monitor for any changes in injection pressure/temperature or in-zone and above-zone pressure/temperature.

Indirect CO_2 Plume and Pressure Front Monitoring Strategy

Several technologies will be deployed within the injection and deep monitoring wells to indirectly monitor the presence/absence of the CO_2 plume and elevated pressure front. A fiberoptic line with DTS and DAS capabilities will be run along the outside of the long-string casing through the Tuscaloosa Marine Shale to continuously record temperature and acoustic variations. External mechanical integrity at all deep wells (injection, in-zone, and above-zone monitoring wells) will be monitored continuously using DTS. PNC logging techniques will be utilized to verify external MIT for each injection and deep monitoring well by detecting the presence or absence of CO_2 in critical formations. PNC logging will also serve to track the CO_2 plume progression in in-zone monitoring wells.

B.1.b Sampling Site Contingency

All testing and monitoring techniques will take place on private property of the project stakeholders, and Longleaf CCS, LLC will have leased all well pad locations. No problems of site inaccessibility are anticipated. If inclement weather makes site access difficult, sampling schedules will be revised and alternative dates may be selected that would still meet permit-related conditions.

B.1.c Critical/Informational Data

Detailed field and laboratory documentation will be recorded on field and laboratory forms and notebooks during groundwater sampling and analytical efforts. Critical information to be documented includes time and date of activity, person(s) performing activity, location of activity, instrument calibration data, and field parameter values. For laboratory analyses, many critical data are generated during the analysis process and provided to end users in digital and printed formats. Noncritical data may include appearance and odor of the sample, issues with well or sampling equipment, and weather conditions.

B.1.d Sources of Variability

Potential sources of variability relating to testing and monitoring activities include:

- Natural variation in formation pressure/temperature, fluid quality, and seismic activity.
- Variation in formation pressure/temperature, fluid quality, and seismic activity associated with nominal project operations.
- Changes in recharge due to precipitation (seasons).
- Changes in instrument calibration during sampling or analytical activity.
- Different personnel collecting or analyzing samples.
- Variation in environmental conditions during field sampling.
- Changes in analytical data quality during life of the project.
- Data entry errors.

Variability related to testing and monitoring activities may be eliminated or mitigated through the following methods:

- Gathering sufficient baseline data to observe natural variation in monitoring parameters.
- Evaluating data in a timely manner after collection to observe anomalies that can be addressed by resampling or reanalyzing.
- Conducting statistical analysis of data to determine whether variability is natural/expected variation or unexpected variation.
- Maintaining weather-related data from onsite sources or from nearby locations (such as a local airport).
- Verifying instrument calibration before, during, and after sampling and analysis.
- Ensuring that staff are fully trained and certified if appropriate.
- Performing laboratory quality assurance checks using third party reference materials, and/or blind/replicate sample checks.
- Utilizing a systematic review process of data that may include sample-specific data quality checks.

B.2. Sampling Methods

B.2.a/b Sampling Standard Operating Procedures

The primary groundwater sampling method will be a low-flow sampling method consistent with ASTM D6452-99[19] or Puls and Barcelona[20]. If a flow-through cell is not used, field parameters will be measured in grab samples. Prior to sampling, wells will be purged to ensure samples are representative of formation fluids. Before any purging or sampling activities begin, static water levels will be measured using an electronic water level indicator. Each groundwater monitoring well will contain a dedicated pump (e.g., bladder pumps) to minimize potential cross contamination between wells. Given sufficient flow rates and volumes, field parameters such as groundwater pH, temperature, specific conductance, and dissolved oxygen will be monitored in the field using portable probes and a flow-through cell consistent with standard methods[21]. Field chemistry probes will be calibrated at the beginning of each sampling day according to equipment manufacturer procedures using standard reference solutions. When a flow-through cell is used, field parameters will be continuously monitored and will be considered stable when three successive measurements made three minutes apart meet the criteria listed in **Table 14.**

Table 14: Stabilization Criteria of Water Quality Parameters During Shallow Well Purging

Field Parameter	Stabilization Criteria
pH, temperature, specific conductance, dissolved oxygen, turbidity	*parameter measurement until ±10% value stabilization

*Exact parameter stabilization threshold will depend on which purge method is selected from ASTM DX

Groundwater samples will be collected after field parameters have stabilized. Flow-through filter cartridges (0.45 µm) will be utilized as required and consistent with ASTM D6564-00[22]. Prior to sample collection, filters will be purged with a minimum of 100 mL of

[19] ASTM, 2005, Method D6452-99 (reapproved 2005), *Standard Guide for Purging Methods for Wells Used for Ground-Water Quality Investigations*, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA

[20] Puls, R W, and Barcelona, M J. *Ground water issue: Low-flow (minimal drawdown) ground-water sampling procedures*. United States: N. p., 1996. Web.

[21] APHA, 2005, Standard methods for the examination of water and wastewater (21st edition), American Public Health Association, Washington, DC.

[22] ASTM, 2017, Method D6564-00, *Standard Guide for Field Filtration of Ground-Water Samples*, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA.

well water (or more if required by the filter manufacturer). For alkalinity and total CO_2 samples, efforts will be made to minimize exposure to the atmosphere during filtration, collection in sample containers, and analysis.

B.2.c Continuous Monitoring

Injection Process Monitoring

Data related to the operational process (injection rate and volume and annular pressure and volume) will be continuously monitored with pressure/temperature gauges, flow meters, and the annulus monitoring system, all of which will be linked to the surface control system controlled by Longleaf CCS, LLC. This operational data will ensure that injection is operating safely, efficiently, as expected, and not posing a risk to any USDWs. Additionally, continuously monitored operational parameters will feed into reservoir and computational models to validate that the CO_2 plume and pressure front are behaving as expected.

DTS

DTS technology will continuously collect temperature data along a fiberoptic line installed along the outside of the long-string casing. The DTS line will collect temperature data along the long-string casing every 10 minutes to verify mechanical integrity and monitor the presence or absence of the CO_2 plume.

DAS

DAS technology will continuously collect acoustic data along a fiberoptic line installed along the outside of the long-string casing. Additionally, DAS will be utilized during VSPs to measure the arrival times of seismic waves in the subsurface to monitor the footprint of the CO_2 plume.

Pressure/Temperature Gauges

Downhole pressure/temperature gauges will be deployed within all deep wells to continuously measure pressure/temperature variations within the Paluxy Formation injection interval and Upper Tuscaloosa Formation above-zone monitoring interval.

Downhole pressure/temperature gauges will directly monitor the presence or absence of the CO_2 plume and elevated pressure front.

B.2.d Sample Homogenization, Composition, Filtration

Described in Section B.2.b.

B.2.e Sample Containers and Volumes

All samples will be collected in new containers using industry accepted standards and practices. Container type and size for each sample type are listed in **Table 15** and **Table 16**.

Table 15: Summary of Sample Containers, Preservation Treatments, and Holding Times for CO_2 Gas Stream Analysis

Sample	Volume/Container Material	Preservation Technique	Sample Holding time (max)
CO_2 gas stream	(2) 2L MLB Polybags (1) 75 cc Mini Cylinder	Sample Storage Cabinets	5 Business Days

Table 16: Summary of Anticipated Sample Containers, Preservation Treatments, and Holding Times for Groundwater Samples

Target Parameters	Volume/Container Material	Preservation Technique	Sample Holding Time
Cations: Ca, Fe, K, Mg, Na, Si, Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, Tl	250 ml/HDPE	Filtered, nitric acid, cool 4°C	60 days
Dissolved CO_2	2 × 60 ml/HDPE	Filtered, cool 4°C	14 days
Isotopes: 3H, δD, δ18O, δ34S, and δ13C	2 × 60 ml/HDPE	Filtered, cool 4°C	4 weeks
Isotopes: δ34S	250 ml/HDPE	Filtered, cool 4°C	4 weeks
Isotopes: δD, δ18O, δ13C	60 ml/HDPE	Filtered, cool 4°C	4 weeks
Alkalinity, anions (Br, Cl, F, NO_3, SO_4)	500 ml/HDPE	Filtered, cool 4°C	45 days
Field Confirmation: Temperature, dissolved oxygen, specific conductance, pH	200 ml/glass jar	None	< 1 hour
Field Confirmation: Density	60 ml/HDPE	Filtered	< 1 hour

B.2.f Sample Preservation

Sample preservation methods are outlined in **Table 15** and **Table 16**.

B.2.g Cleaning/Decontamination of Sampling Equipment

Pumps will be installed in each groundwater monitoring well in order to mitigate potential cross contamination among wells. Each installed pump will remain in the well for the duration of the project except for maintenance or replacement. The pumps will be cleaned on the outside before installation with a non-phosphate detergent. The pump will then be rinsed appropriately with deionized water. At least 1.0 L of deionized water will be cycled through the pump and tubing. Individual prepared pumps and tubing will be placed in clean containers for transport to the field for installation. All sampling glassware (such as pipettes, beakers, filter holders, etc.) will be cleaned using tap water and then washed in a dilute nitric acid solution before being thoroughly rinsed with deionized water prior to use.

B.2.h Support Facilities and Tools

The following tools may be needed to sample groundwater: generator, vacuum pump, compressor, multi-electrode water quality sonde, and various meters to take analytical measurements such as pH and electrical conductance. Analytical field activities may take place in field vehicles and/or portable onsite trailers. Well gauges used for verification will be handled using industry standard best practices and procedures recommended from the vendor.

Coupons consisting of material that will directly contact the CO_2 stream will be placed within a flowline. Each sample will be attached to an individual holder and inserted in a flowthrough pipe arrangement, exposing the samples to the CO_2 stream and allowing access for removal and testing. The flowthrough pipe arrangement will be located at the well location downstream of all process compression, dehydration, and pumping equipment. A parallel stream of high-pressure CO_2 will be routed from the flowline through the corrosion monitoring system. This loop will operate while injection is occurring, providing representative exposure of the samples to the CO_2 composition, temperature, and pressures that will be seen at the wellhead and injection tubing. Injection will be able to continue while samples are removed for testing.

B.2.i Corrective Action, Personnel, and Documentation

Properly testing equipment and implementing corrective actions on broken or malfunctioning field equipment will be the responsibility of field personnel. If corrective action is not possible in the field, then equipment will be sent back to the manufacturer or qualified technician to be repaired, serviced, or replaced. Substantial corrective actions that may impact analytical results will be documented in field notes. In the event that defective equipment will cause disruptions to the sampling schedule, Longleaf CCS, LLC will contact the UIC Program Director.

B.3. Sample Handling and Custody

Sample handling and hold times will be congruent with US EPA (1974)[23], APHA (2005)[24], Wood (1976)[25], and ASTM Method D6517-00 (2005)[26]. Samples will be kept at their preservation temperature and sent to the selected laboratory within 24 hours of collection. Analysis of the samples will be completed within the holding time specified in **Table 16**. If alternative sampling methods become necessary, these methods will be discussed with the UIC Program Director prior to sampling.

B.3.a Maximum Hold Time/Time Before Retrieval

See **Table 15** and **Table 16**.

B.3.b Sample Transportation

Samples will be transported in coolers with ice maintained to approximately 4 degrees Celsius and sent to approved laboratory within 24 hours of sampling.

[23] U.S. Environmental Protection Agency (US EPA), 1974, Methods for chemical analysis of water and wastes, US EPA Cincinnati, OH, EPa-625-/6-74-003a.
[24] APHA, 2005, Standard methods for the examination of water and wastewater (21st edition), American Public Health Association, Washington, DC.
[25] Wood, W.W., 1976, Guidelines for collection and field analysis of groundwater samples for selected unstable constituents, In U.S. Geological Survey, Techniques for Water Resources Investigations, Chapter D-2, 24 p.
[26] ASTM, 2005, Method D6517-00 (reapproved 2005), Standard guide for field preservation of ground-water samples, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA.

B.3.c Sampling Documentation

Sampling personnel will compile field documentation for all groundwater samples collected. Field notes will be archived.

B.3.d Sample Identification

Each groundwater sample container will have a label with the following information: project name/number, sample date and location, sample ID number, fresh or brine water, volume taken, analyte, filtration used (if applicable), and preservative used (if any).

B.3.e. Sample Chain-of-Custody.

A standardized form will be used to document groundwater sample chain-of-custody. Copies of this form will be provided to laboratory personnel upon delivery of groundwater samples for analysis. These forms will be archived for future reference.

B.4. Analytical Methods

B.4.a Analytical Standard Operating Procedures

Analytical standard operating procedures are referenced in **Table 3** through **Table 7**. Other laboratory specific standard operating procedures utilized by the laboratory will be determined after a contract laboratory has been selected. Upon request, Longleaf CCS, LLC will provide the UIC Program Director with all laboratory standard operating procedures developed for the specific parameter using the appropriate standard method. Each laboratory technician conducting the analysis on the samples will be trained on the standard operating procedure developed for each standard method.

B.4.b Equipment/Instrumentation Needed

Equipment and instrumentation are specified in the individual analytical methods referenced in **Table 3** through **Table 7.**

B.4.c Method Performance Criteria

Nonstandard method performance criteria are not anticipated for this project.

B.4.d Analytical Failure

Each laboratory conducting the analyses in **Table 3** through **Table 7** will be responsible for appropriately addressing analytical failure according to their individual standard operating procedures.

B.4.e Sample Disposal

Each laboratory conducting the analyses in **Table 3** through **Table 7** will be responsible for appropriate sample disposal according to their individual standard operating procedures.

B.4.f Laboratory Turnaround

Laboratory turnaround will vary by laboratory, but generally turnaround of verified analytical results within two months will be suitable for project needs.

B.4.g Method Validation for Nonstandard Methods

Nonstandard methods are not anticipated for this project. If nonstandard methods are needed or proposed in the future, the UIC Program Director will be consulted on appropriate actions to be taken.

B.5. Quality Control

B.5.a QC activities

Blanks

Field blanks will be utilized for both the shallow and deep groundwater sampling to identify potential contamination due to the collection and transportation processes. Field blanks will be collected and analyzed for the inorganic analytes listed in **Table 3** at a frequency of 10% or more. The field and transportation conditions for field blanks will be the same as those of the groundwater samples.

Duplicates

During each round of shallow groundwater sampling, a second groundwater sample is collected from one well, selected based on a rotating schedule. These duplicate samples are collected from the same source and at the same time as the original sample in a different, yet identical, sample container. Duplicate samples are processed with all other samples and are used to determine sample heterogeneity and analytical precision.

B.5.b Exceeding Control Limits

If the sample analytical results exceed control limits (i.e., ion balances > ±10%), further examination of the analytical results will be done by evaluating the ratio of the measured total dissolved solids (TDS) to the calculated TDS (i.e., mass balance) per APHA method. The method indicates which ion analyses should be considered suspect based on the mass balance ratio. Suspect ion analyses are then reviewed in the context of historical data and interlaboratory results, if available. Suspect ion analyses are then brought to the attention of the analytical laboratory for confirmation and/or reanalysis. The ion balance is recalculated, and if the error is still not resolved, suspect data are identified and may be given less importance in data interpretations.

B.5.c Calculating Applicable QC Statistics

Charge Balance

The groundwater sample analytical results are evaluated to determine correctness of analyses based on anion-cation charge balance calculation. All potable waters are electrically neutral; thus, the chemical analyses should produce equally negative and positive ionic activity. The anion-cation charge balance will be calculated using the formula:

$$\%\, difference = 100 * \frac{\sum cations - \sum anions}{\sum cations + \sum anions}$$

where the sums of the ions are represented in milliequivalents (meq) per liter, and the criteria for acceptable charge balance is ±10%.

Mass Balance

The ratio of the measured TDS to the calculated TDS will be calculated in instances where the charge balance acceptance criteria are exceeded using the formula:

$$1.0 <* \frac{measured\ TDS}{calculated\ TDS} < 1.2$$

with anticipated values between 1.0 and 1.2.

Outliers

A determination of one or more statistical outliers is essential prior to the statistical evaluation of groundwater. This project will use the EPA's Unified Guidance (March 2009)[27] as a basis for selection of recommended statistical methods to identify outliers in groundwater chemistry data sets as appropriate. These techniques include Probability Plots, Box Plots, Dixon's test, and Rosner's test. The EPA-1989[28] outlier test may also be used as another screening tool to identify potential outliers.

B.6. Instrument/Equipment Testing, Inspection, and Maintenance

Logging tool equipment will be maintained as per wireline industry best practices. Pressure/temperature gauges will be maintained to manufacturer standards. For groundwater sampling, field equipment will be maintained, factory serviced, and factory calibrated per manufacturer's recommendations. Spare parts that may be needed during sampling will be included in supplies on-hand during field sampling. For laboratory equipment, all testing, inspection, and maintenance will be the responsibility of the analytical laboratory per standard practice or method-specific protocol.

B.7. Instrument/Equipment Calibration and Frequency

B.7.a Calibration and Frequency of Calibration

Pressure/temperature gauge calibration information is located in **Table 10** and **Table 11.** All field and downhole gauges will be calibrated prior to use by the equipment supplier. Gauges will be recalibrated as needed based on results of inspection, or after any repairs or maintenance. Logging tool calibration will be at the discretion of the service company providing the equipment, following standard industry practices. Calibration frequency will be determined by standard industry practices. CO_2 flow meters will be

[27] U.S. Environmental Protection Agency (US EPA), 2009, Statistical analysis of groundwater monitoring data at RCRA facilities—Unified Guidance, US EPA, Office of Solid Waste, Washington, DC.
[28] U.S. Environmental Protection Agency (US EPA) 2009, Data Quality Assessment: Statistical Methods for Practitioners, US EPA Cincinnati, OH, EPA-QA/G-9S

calibrated using industry standards and at a frequency recommended by the manufacturer.

For groundwater sampling, portable field meters or multiprobe sondes used to determine field parameters (e.g., pH, temperature, specific conductance, dissolved oxygen) will be calibrated according to manufacturer recommendations and equipment manuals (Hach, 2006)[29] before sample collection begins. Recalibration is performed if any components yield atypical values or fail to stabilize during sampling.

For CO_2 stream sampling, the gas chromatograph will be calibrated based on the manufacturer's guidance.

B.7.b Calibration Methodology

Calibration of the orifice flow meters will be carried out using the carrier gas to validate the characteristics of the approved CO_2 composition using methods described in **Table 7**. Logging tool and all field and downhole gauge calibration methodology will follow standard industry practices recommended by the respective manufacturers.

For groundwater sampling, standards used for calibration typically require a pH of 7 and 10, a potassium chloride solution with 1,413 microseimens per centimeter (µS/cm) at 25°C for specific conductance, and a 100% dissolved oxygen solution. Calibration of pH meters will be performed per manufacturer's specifications using a 2-point calibration bounding the range of the sample. For coulometry, sodium carbonate standards (typically with a concentration of 4,000 mg CO_2/L) are routinely analyzed to evaluate instrument.

B.7.c Calibration Resolution and Documentation

Logging tool calibration resolution and documentation will follow standard industry practices. Groundwater sampling equipment calibration occurs regularly, and values are recorded in sampling records, with any errors in calibration noted. For parameters where calibration is not acceptable, redundant equipment may be used so loss of data is minimized.

[29] Hach Company, February 2006, Hydrolab DS5X, DS5, and MS5 Water Quality Multiprobes User Manual, Hach Co., 73 p.

B.8. Inspection/Acceptance for Supplies and Consumables

B.8.a/b Supplies, Consumables, and Responsibilities

Individual vendors and subcontractors selected and approved by Longleaf CCS, LLC will be responsible for ensuring that all supplies and consumables for field and laboratory operations are inspected and acceptable for data collection activities. Procurement of supplies and consumables related to groundwater analyses will be the responsibility of the laboratory conducting water analyses in accordance with the established standard methodologies and operating procedures.

B.9. Nondirect Measurements

B.9.a Data Sources

Plume development will also be monitored via DTS, DAS 3D-VSP, and PNC logs. PNC logs detect CO_2 concentration surrounding the wellbore, and repeat logging runs will be compared to the baseline conducted before injection operations begin. DTS monitors variations in temperature along the wellbore at a high resolution, measured approximately every 10 minutes. DAS measures strain caused by acoustic waves passing through/near the fiberoptic cable installed on the outside of the long string casing and can act as a downhole VSP geophone.

B.9.b Relevance to Project

Time-lapse VSPs and scheduled PNC logging will be used to track CO_2 plume movement. After initial baseline testing is conducted prior to injection, processing and comparison of subsequent surveys will allow Longleaf CCS, LLC to monitor the extent of the plume, ensuring that the plume is contained and behaving as expected. Numerical modeling will be updated with new seismic, pressure, and saturation data throughout the project to best characterize the CO_2 plume growth and movement over time.

B.9.c Acceptance Criteria

The collection of seismic data will follow standard industry practices to ensure accuracy in the resulting data. Similar ground conditions, seismic shot points located within acceptable limits, carefully inspected and operational geophones, and uniform seismic input signal will be used for each survey to ensure repeatability.

Gauges and other logging equipment used to collect non-direct measurements will be checked periodically and maintained according to manufacturer recommendations for equipment care and operation, to ensure the accuracy of readings as they are incorporated into the model.

B.9.d Resources/Facilities Needed

Longleaf CCS, LLC will subcontract all necessary resources and facilities for the seismic monitoring, logging, in-zone pressure monitoring, and groundwater sampling.

B.9.e Validity Limits and Operating Conditions

Intraorganizational verification by trained and experienced personnel will ensure that all seismic surveys and numerical modeling are conducted according to industry standards.

B.10. Data Management

B.10.a Data Management Scheme

Longleaf CCS, LLC or a designated contractor will maintain the required project data as described in Section K.4 of the *Testing and Monitoring Plan*. Data will be backed up on secure servers.

B.10.b Recordkeeping and Tracking Practices

All records of gathered data will be securely held and properly labeled for auditing purposes.

B.10.c Data Handling Equipment/Procedures

All equipment used to store data will be properly maintained and operated according to proper industry techniques. Longleaf CCS, LLC will ensure that all necessary supervisory control and data acquisition (SCADA) systems and vendor data acquisition systems will interface with one another and that all subsequent data will be held on a secure server.

Meter data will be captured via the flow computer.

B.10.d Responsibility

The primary Longleaf CCS, LLC project manager will be responsible for ensuring proper data management is maintained during pre-operational testing and the Operations Manager for the injection and post-injection periods.

B.10.e Data Archival and Retrieval

All data will be held and maintained by Longleaf CCS, LLC as described in Section K.4 of the *Testing and Monitoring Plan*. Data will be backed up on secure servers to be accessed by project personnel as required.

B.10.f Hardware and Software Configurations

All Longleaf CCS, LLC and vendor hardware and software configurations will interface appropriately.

B.10.g Checklists and Forms

Checklists and forms will be generated and completed as necessary.

C. Assessment and Oversight

C.1. Assessments and Response Actions

C.1.a Activities to be Conducted

Refer to **Table 1** and **Table 2** for a summary of work to be performed and proposed work schedule. After completion of groundwater sample analysis, the results will be reviewed for quality control criteria as noted in Section B.5 of this *QASP*. If the data fail to meet the established quality criteria, samples will be reanalyzed if still within holding time criteria. If outside of holding time criteria, additional samples may be collected or sample results may be excluded from data evaluations and interpretations. Evaluation for data consistency will be performed according to procedures described in the EPA 2009 Unified Guidance[30].

C.1.b Responsibility for Conducting Assessments

Each organization gathering data will be responsible for conducting their own internal assessments. All stop work orders will be handled internally within each individual organization.

C.1.c Assessment Reporting

All assessment information will be reported to the Longleaf CCS, LLC project manager.

C.1.d Corrective Action

All corrections which may affect a single organization's data collection responsibility shall be addressed, verified, and documented by the individual project managers, and communicated to others as necessary. Corrective actions affecting multiple organizations should be addressed by all members of the project leadership and communicated to other members on the *QASP* distribution list. Integration of information from multiple monitoring sources (operational, in-zone monitoring, above-zone monitoring) may be required to determine whether data and/or measurement method corrections are required, as well as the most effective and cost-efficient action to implement. Longleaf CCS, LLC will coordinate multiorganization assessments and correction efforts as needed.

C.2. Reports to Management

C.2.a/b QA Status Reports

QA status reports are not required unless there are significant adjustments to the methods and procedures listed above. If any testing or monitoring techniques are

[30] U.S. Environmental Protection Agency (US EPA), 2009, Statistical analysis of groundwater monitoring data at RCRA facilities—Unified Guidance, US EPA, Office of Solid Waste, Washington, DC.

changed, this *QASP* will be reviewed and updated appropriately after consultation with the UIC Program Director. The revised *QASP* will be distributed by Longleaf CCS, LLC to the full distribution list noted at the beginning of this document.

D. Data Validation and Usability

D.1. Data Review, Verification, and Validation

D.1.a Criteria for Accepting, Rejecting, or Qualifying Data

Validation of data will include a review of concentration units, sample holding times, and the review of duplicate, blank, and other appropriate QA/QC results. Longleaf CCS, LLC will hold copies of all laboratory analytical test results and/or reports. Analytical results will be reported as described in Section K of the *Testing and Monitoring Plan*. In the periodic reports, groundwater analysis data will be presented in graphical and tabular formats as appropriate to characterize general groundwater quality and identify intrawell variability with time. After sufficient data have been collected, additional methods, such as those described in the EPA 2009 Unified Guidance[31] will be used to evaluate intrawell variations for groundwater constituents, to evaluate if significant changes have occurred that could be the result of CO_2 or brine seepage beyond the intended storage reservoir.

D.2. Verification and Validation Methods

D.2.a Data Verification and Validation Processes

See Sections D.1.a and B.5. of this *QASP.* Appropriate statistical software will be utilized to determine data consistency.

[31] U.S. Environmental Protection Agency (US EPA), 2009, Statistical analysis of groundwater monitoring data at RCRA facilities—Unified Guidance, US EPA, Office of Solid Waste, Washington, DC.

D.2.b Data Verification and Validation Responsibility

Longleaf CCS, LLC or its designated subcontractor will verify and validate groundwater sampling data.

D.2.c Issue Resolution Process and Responsibility

Longleaf CCS, LLC will designate a Site Coordinator, who will oversee the groundwater data handling, management, and assessment process. Staff involved in these processes will consult with the Coordinator to determine actions required to resolve any issues.

D.2.d Checklist, Forms, and Calculations

Checklists and forms will be developed specifically to meet permit requirements. These checklists will largely depend on the parameters that are being tested as well as standard operating procedures of the subcontractors and laboratories that will be gathering the data and conducting the analyses. Longleaf CCS, LLC will provide these forms and checklists to the UIC Program Director upon request. **Table 17** provides an example of the type of information that may be used for data verification of groundwater quality data.

Table 17: Example table of criteria used to evaluate data quality

MVA ID	Anion charge	Cation charge	Charge balance	CB rating	Calculated TDS	Measured TDS	TDS Ratio	TDS Rating
ICCS_10B_01A	14.4	13.60	-2.84	pass	760.50	785	1.0	pass

D.3. Reconciliation with User Requirements

D.3.a Evaluation of Data Uncertainty

Statistical software will be used to determine groundwater data consistency using methods consistent with EPA 2009 Unified Guidance.[32]

D.3.b Data Limitations Reporting

Each vendor or subcontractor's project manager will be responsible for ensuring that data presented by their respective organizations is developed with the appropriate data-use limitations. Longleaf CCS, LLC will ensure that the data-use limitations are known and presented properly.

[32] U.S. Environmental Protection Agency (US EPA), 2009, Statistical analysis of groundwater monitoring data at RCRA facilities—Unified Guidance, US EPA, Office of Solid Waste, Washington, DC.