Technical Review of Subpart RR MRV Plan for Eastern Wyoming Sequestration Hub

October 2025

Contents

This document summarizes the U.S. Environmental Protection Agency's (EPA's) technical evaluation of the Greenhouse Gas Reporting Program (GHGRP) Subpart RR Monitoring, Reporting, and Verification (MRV) plan submitted by the Eastern Wyoming Sequestration Hub (EWS Hub) for its carbon dioxide (CO_2) capture and storage (CCS) project located in Laramie County, Wyoming. Note that this evaluation pertains only to the Subpart RR MRV plan, and does not in any way replace, remove, or affect Underground Injection Control (UIC) permitting obligations. Furthermore, this decision is applicable only to the MRV plan and does not constitute an EPA endorsement of the project, technologies, or parties involved.

1 Overview of Project

The MRV plan states that Tallgrass High Plains Carbon Storage, LLC (Tallgrass) is developing the High Plains Eastern Wyoming Sequestration Hub. The EWS Hub is a multi-state decarbonization effort focused on permanently sequestering CO_2 from multiple emitters located in Nebraska, Colorado and Wyoming. The EWS Hub consists of six CO_2 injection facilities, each with one injection well (Azalea I-1, Spirea I-1R, Barberry I-1, Old Barberry I-1, Cypress I-1, and Juniper I-1). The MRV plan states that the EWS Hub is designed to store a total of 116.8 million metric tons (MMT). CO_2 will be sourced from a CO_2 collection pipeline from several industrial facilities. The CO_2 will be injected into the Lyons formation for geologic storage. A UIC Class VI injection permit has been authorized by the State of Wyoming for the Juniper injection site (UIC Permit Number 2022-235, Facility Identification [ID] Number WYS-021-00149). The other 5 injection sites have Class VI permits for approval to construct:

- Azalea Project: UIC Permit 2023-264; Facility ID WYS-021-00159
- Spirea Project: UIC Permit 2023-041; Facility ID WYS-021-00155
- Barberry Project: UIC Permit 2023-039; Facility ID WYS-021-00153
- Old Barberry Project: UIC Permit No. 2023-263; Facility ID WYS-021-00158
- Cypress Project: UIC Permit No. 2023-040; Facility ID WYS-021-00154

The MRV plan states that a stratigraphic test well, Juniper M-1 (American Petroleum Institute [API] #49-021-29548), has been drilled at the project area and will be converted into an above confining zone monitoring well. The sequestration program entails injecting into the Lyons formation, a geologic formation spanning approximately 50 to 100 net feet of high porosity and permeable sands at an approximate depth of 9,081 feet true vertical depth (TVD) at the project location.

The MRV plan provides descriptions of the above confining zone, upper confining zone, injection zone, and lower confining zone. The MRV plan states that the above confining zone (i.e., above the upper confining zone) equates to the Sundance formation (8,907 feet TVD), a well-sorted, well-rounded sandstone interval with sufficient permeability to serve as a groundwater aquifer. The upper confining zone equates to the Chugwater formation (9,053 feet TVD) and the Goose Egg formation (maximum 9,257 feet TVD). These TVDs are measured at the Spirea injection well. The Chugwater formation consists of shale, siltstone, and gypsum with an approximate thickness of 250 feet. The Goose Egg formation consists of shale, silt, gypsum, anhydrite, limestone, and dolomite with an approximate thickness of 268 feet. The injection zone equates to the Lyons formation, a well-sorted, fine-grained sandstone with an approximate thickness of 61 feet. The lower confining zone equates to the Satanka formation, an interval consisting of interbedded sandstones, siltstones, and mudstones with anhydrite rich zones that provide an impermeable barrier.

The MRV plan states that Tallgrass and predecessor companies have operated natural gas storage fields for more than 70 years. Tallgrass currently operates 90 wells with 74 billion cubic feet (bcf) of natural gas storage capacity and 20,470 compression horsepower across the Huntsman and East Cheyenne gas storage fields. These gas storage operations provide the facility with critical subsurface working knowledge and skill sets that transfer directly to CO_2 sequestration, specifically the injection, monitoring, and storage of gaseous fluids in porous reservoirs.

The description of the project provides the necessary information for 40 CFR 98.448(a)(6).

2 Delineation of the Maximum Monitoring Area (MMA) and Active Monitoring Area (AMA)

As part of the MRV plan, the reporter must identify and delineate both the MMA and the AMA, pursuant to 40 CFR 98.448(a)(1). Subpart RR defines maximum monitoring area as "the area that must be monitored under this regulation and is defined as equal to or greater than the area expected to contain the free phase CO_2 plume until the CO_2 plume has stabilized plus an all-around buffer zone of at least one-half mile." Subpart RR defines active monitoring area as "the area that will be monitored over a specific time interval from the first year of the period (n) to the last year in the period (t). The boundary of the active monitoring area is established by superimposing two areas: (1) the area projected to contain the free phase CO_2 plume at the end of year t, plus an all-around buffer zone of one-half mile or greater if known leakage pathways extend laterally more than one-half mile; (2) the area projected to contain the free phase CO_2 plume at the end of year t + 5." See 40 CFR 98.449.

The MRV plan states that EWS Hub calculated the required MMA and AMA according to the above stated regulatory definitions. It states that reservoir simulation modeling was used to define the MMA and the AMA. In determining the monitoring areas, the extent of the separate-phase CO_2 plume is equal to the point where the concentration of supercritical-phase CO_2 reaches below 2% saturation.

EWS Hub states that their MMA is equal to or greater than the area expected to contain the free-phase CO_2 plume until the CO_2 plume has stabilized plus an all-around buffer zone of at least 0.5 mile. This MMA is shown in Figure 10 of the MRV plan.

Additionally, EWS Hub states that their AMA boundary was established by superimposing two areas:

- Area #1: The area projected to contain the free-phase CO_2 plume at the end of year t, plus an all-around buffer zone of 0.5 mile or greater if known leakage pathways extend laterally more than 0.5 mile.

- Area #2: The area projected to contain the free-phase CO_2 plume at the end of year t + 5.

The MRV plan states that the AMA boundary was determined for the time period ("t") corresponding to 50 years after the end of injection. Area #1 was taken as the free-phase CO_2 plume at the end of year *t*, plus an all-around buffer zone of 0.5 mile. Area #2 is smaller than or equal to Area #1 in all directions; therefore, EWS Hub defines the final AMA as Area #1. The MRV plan states that EWS Hub has established one AMA boundary for 50 years and does not anticipate any expansion of the monitoring area under 40 CFR § 98.448 under the currently planned operating conditions. Given the definitions used to define the MMA and AMA, the AMA is functionally equivalent to the MMA and is also shown in Figure 10 of the MRV plan.

The delineations of the MMA and AMA are acceptable per the requirements in 40 CFR 98.448(a)(1). The MMA and AMA described in the MRV plan are clearly delineated in the plan and are consistent with the definitions in 40 CFR 98.449.

3 Identification of Potential Surface Leakage Pathways

As part of the MRV plan, the reporter must identify potential surface leakage pathways for CO_2 in the MMA and the likelihood, magnitude, and timing of surface leakage of CO_2 through these pathways pursuant to 40 CFR 98.448(a)(2). In Section 5 of their MRV plan, EWS Hub identified the following potential leakage pathways that required consideration:

- Pipelines/Surface Equipment
- Wellbores
- Leakage through the Confining Zone
- Induced or Natural Seismic Event
- Lateral Migration
- Drilling through the CO_2 Area

3.1 Leakage from Pipelines/Surface Equipment

The MRV plan states that the EWS Hub injector wellheads and pipelines that transport the project's CO_2 are potential pathways to allow CO_2 to leak to the surface. EWS Hub claims that leakage is most likely to be the result of aging and use of surface components over time, with the wear and tear especially at flanged connection points being the most probable cause of leakage. The release of air through relief valves and damage caused by accidents or natural disasters are also referenced as causes for potential CO_2 leakage.

The MRV plan states that the likelihood of leakage via this pathway is minor. Leakage from this pathway is only a concern during the injection operation phase, after this phase is complete surface components will no longer be able to store or transport CO_2. The magnitude of potential leakage varies depending on the component's failure mode. The MRV plan provides the examples of a rapid break releasing a large amount of CO_2 and a slowly deteriorating seal at a flanged connection releasing only a small volume of CO_2. The likelihood of leakage is characterized as minor, leakage is only a concern during injection, and the magnitude of leakage is variable, with leakage from a seal at a flanged connection would likely only release a small volume of CO_2 whereas a break or rupture could release large amounts of CO_2.

Thus, the MRV plan provides an acceptable characterization of CO_2 leakage that could be expected from pipelines/surface equipment.

3.2 Leakage through Wellbores

As stated in the MRV plan, the project-related injection and monitoring wells will be monitored and maintained to prevent wellbore integrity issues. CO_2 migration could occur along an injection or monitoring well due to a degraded cement bond or corrosion of the casing and completion. Any well that penetrates the injection zone creates a possible migration pathway if the CO_2 plume reaches its position.

The MRV plan also states that all the injection and monitoring wells involved in the project will be permitted by the State of Wyoming in accordance with Chapter 24 of the Wyoming Department of Environmental Quality (WDEQ) regulations. Designs for each injection well are engineered to govern the rate and pressure of CO_2 injection. Pressure monitors on the injection well are programmed to flag pressures that statistically deviate from design. Leakage on either the inside or outside of the injection wellbore would cause pressure inflections that would be detected through this approach. Injectors will also be monitored with mechanical integrity tests (MITs) and pressure tests to ensure internal and external integrity.

According to the MRV plan, the likelihood of leakage via this pathway is minor. The probability of leakage from this pathway will be highest during the injection phase. The risk will decrease after injection, especially after the injection well is plugged. The magnitude of leakage from this pathway is considered negligible.

Thus, the MRV plan provides an acceptable characterization of CO_2 leakage that could be expected through wellbores.

3.3 Leakage through the Confining Zone

As stated in the MRV plan, leakage out of the Lyons formation could result in elevated concentrations of indicator parameter(s) in groundwater sample(s) or other evidence of CO_2 leakage into shallow groundwater. Fluid leakage risk is low due to the significant thickness (>7,500 feet) of intervening geologic units above the sequestration zone. EWS Hub conducted a seismic evaluation of 10 quality two-dimensional (2D) lines within the region of the project area to confirm structural mapping and locate any potential faulting or fracturing within the area. The review also incorporated published public domain interpretations of surrounding three-dimensional (3D) surveys for Silo Field, North Mustang Field, and Hereford Field. The 3D surveys were not licensed or purchased, as the surveys do not cover the project area. No faults that intersect the CO_2 plume were identified in the 2D seismic evaluation. Faulting was observed in Hereford Field, located 8 to 10 miles south of the EWS Hub project area, with a general orientation of east to west. These subsurface features have been evaluated and do not appear to intersect the modeled plume migration of any EWS Hub well. No transmissive fractures were identified based on wireline image logs of the Juniper M-1, Juniper I-1, and Azalea I-1 wells.

According to the MRV plan, the likelihood of leakage via this pathway is negligible. The leakage risk will be similar during the operation and post-injection phases of this project. The magnitude of leakage via this pathway is anticipated to be negligible as well.

Thus, the MRV plan provides an acceptable characterization of CO_2 leakage that could be expected through the confining zone.

3.4 Leakage from Induced or Natural Seismic Event

The MRV plan states that the Wyoming State Geological Survey (WSGS) published a seismological characterization report of Laramie County, Wyoming. The probabilistic acceleration map (Figure 11 of the MRV plan) shows that the project area is located in one of the lowest-risk areas of Wyoming. Historical earthquake data obtained from the United States Geological Survey (USGS) Earthquake Hazards database also showed no events within 40 miles of the project area.

According to the MRV plan, the likelihood of leakage via this pathway is highly unlikely. Seismicity risk is negligible; however, pressures will be highest during the injection phase of the project. As a result, if induced seismicity were to occur it would likely correspond to the injection phase of the project. The anticipated leakage magnitude is also negligible.

Thus, the MRV plan provides an acceptable characterization of CO_2 leakage that could be expected from an induced or natural seismic event.

3.5 Leakage through Lateral Migration

The MRV plan states that it is highly improbable that injected CO_2 will migrate laterally outside the modeled plume area due to the buoyant properties of supercritical CO_2, the nature of the geologic structure, and the planned injection approach. There is a structural dip in the injection zone (Lyons formation) towards the west. This structural dip was accounted for in the computational modeling used to define the area of the stabilized CO_2 plume. Although CO_2 is predicted to migrate in the up-dip direction, it is slowed and eventually stopped by capillary trapping mechanisms within the predicted boundaries of the AMA and MMA.

According to the MRV plan, leakage via this pathway is not anticipated. If it were to occur, the risk would be greatest when pressures are highest, which generally occurs at the end of the injection period. The magnitude of leakage from this pathway is considered negligible.

Thus, the MRV plan provides an acceptable characterization of CO_2 leakage that could be expected through lateral migration.

3.6 Leakage from Drilling through the CO_2 Area

The MRV plan states that it is possible that at some point in the future, drilling through the confining zone and into the Lyons formation may occur.

According to the MRV plan, the possibility of this activity creating a leakage pathway is extremely low because no oil and gas resources are identified and future well drilling would be regulated by Wyoming Oil and Gas Conservation Commission (WOGCC) (oil and gas wells, Class II injection wells) or WDEQ (Class VI injection wells, all other UIC well classes), and will, therefore, be subject to requirements that fluids are contained in strata in which they are encountered.

The MRV plan states that the likelihood of leakage is extremely low and the risk would be greatest during future time periods if drilling were to occur. The magnitude of leakage from this pathway is considered negligible.

The MRV plan provides an acceptable characterization of CO_2 leakage that could be expected from drilling through the CO_2 area. In summary, the MRV plan provides an acceptable characterization of potential CO_2 leakage pathways as required by 40 CFR 98.448(a)(2).

4 Strategy for Detection and Quantifying Surface Leakage of CO_2 and for Establishing Expected Baselines for Monitoring

40 CFR 98.448(a)(3) requires that an MRV plan contains a strategy for detecting and quantifying any surface leakage of CO_2, and 40 CFR 98.448(a)(4) requires that an MRV plan includes a strategy for establishing the expected baselines for monitoring potential CO_2 leakage. Section 5 of the MRV plan discusses the strategies EWS Hub will employ for detecting and quantifying surface leakage of CO_2 through the pathways identified in the previous section to meet the requirements of 40 CFR §98.448(a)(3). The MRV plan states that monitoring will occur for a minimum of 50 years after injection ceases.

4.1 Detection of Leakage from Pipelines/Surface Equipment

Section 5.1 of the MRV plan states that routine field inspection and remote pipeline monitoring will be conducted to detect any potential leakage from pipelines and surface facilities. Continuous surface air monitoring (eddy covariance tower) and semiannual soil gas monitoring will also be in place to detect any surface leakage.

The MRV plan also states that should leakage be detected between the flow meter used to measure injection quantity and the injection wellhead, then the mass of released CO_2 will be quantified following the requirements of EPA's GHGRP as referenced at 40 CFR § 98.444(d).

Thus, the MRV plan provides adequate characterization of EWS Hub's approach to detect potential leakage from pipelines/surface equipment as required by 40 CFR 98.448(a)(3).

4.2 Detection of Leakage through Wellbores

Section 5.2 of the MRV plan states that wellbore monitoring will include MITs, injection well pressure and rate monitoring, annulus pressure monitoring, surface and near-surface monitoring, and inspections. An annual temperature log will be conducted in each injection well. Permanent installation of distributed temperature sensing (DTS)/distributed acoustic sensing (DAS) fiber behind casing has been executed or planned in all M-1 wells and will be available in the future should these measurements be needed. Surface air (eddy covariance tower), soil gas, and groundwater monitoring will also be instituted in the vicinity of each injection site.

Thus, the MRV plan provides adequate characterization of EWS Hub's approach to detect potential leakage through wellbores as required by 40 CFR 98.448(a)(3).

4.3 Detection of Leakage through the Confining Zone

Section 5.3 of the MRV plan states that monitoring for leakage through the confining zone will include groundwater monitoring above the confining zone, annual DTS or temperature logs in all injection and M-1 monitoring wells, surface air monitoring (eddy covariance tower), soil gas monitoring, and continuous injection well pressure monitoring.

Thus, the MRV plan provides adequate characterization of EWS Hub's approach to detect potential leakage through the confining zone as required by 40 CFR 98.448(a)(3).

4.4 Detection of Leakage from Induced or Natural Seismic Event

Section 5.4 of the MRV plan states that EWS Hub will monitor the USGS Intermountain West Seismic Network for seismic events.

Thus, the MRV plan provides adequate characterization of EWS Hub's approach to detect potential leakage from an induced or natural seismic event as required by 40 CFR 98.448(a)(3).

4.5 Detection of Leakage through Lateral Migration

Section 5.5 of the MRV plan states that the CO_2 plume will be monitored indirectly using time-lapse 2D seismic, as approved in the Class VI permits. The 2D seismic will be used to detect any risk of lateral migration outside of the EWS Hub modeled plume area.

Thus, the MRV plan provides adequate characterization of EWS Hub's approach to detect potential leakage through lateral migration as required by 40 CFR 98.448(a)(3).

4.6 Detection of Leakage through Drilling Through the CO_2 Area

Section 5.6 of the MRV plan states that EWS Hub has received a unitization order from the WOGCC for a unit area that encompasses the CO_2 area, which is now mapped in the WOGCC records. The MRV plan states that if there is an Application for a Permit to Drill (APD) a well proposed within the High Plains unit area that is proposed to penetrate the caprock, then EWS Hub will be notified by either or both the APD applicant and the WOGCC. The MRV plan also states that EWS Hub will also assess potential drilling activity via the WOGCC online data explorer. In the unlikely event that third party drilling is conducted through the Lyons Formation, EWS Hub will coordinate with the operator regarding wellbore monitoring and, if the site is accessible, wellheads will be added to surface monitoring.

4.7 Monitoring, Response, and Reporting Plan for CO_2 Loss

The MRV plan states that standard GHGRP procedures as referenced at 40 CFR § 98.444(d) will be used to estimate surface leaks from equipment if leakage is detected between the flow meter used to measure injection quantity and the injection wellhead. In addition, an event-driven process will be used to assess, address, track, and, if applicable, quantify potential CO_2 leakage to the surface. Reporting will be completed in accordance with 40 CFR § 98.446(f)(3).

4.8 Quantification of Leakage

The MRV plan states that, to quantify leakage to the surface from injection wells, an estimate of the relevant parameters (e.g., the rate, concentration, and duration of leakage) will be made to quantify the leakage mass. Depending on specific circumstances, these determinations may rely on engineering estimates. An example methodology that may be used for early detection and rate estimation of CO_2 wellbore leakage, based on temperature analysis, is outlined in Mao et al. (2017) and referenced in the MRV plan. Furthermore, for surface air monitoring it states that in the event of leakage detected by the eddy covariance tower, mass will be calculated based on the increased CO_2 subsurface flux rate. It also states that leakage from targeted point sources will be quantified based on leak flow rate and CO_2 gas concentration.

4.9 Determination of Baselines

Section 7 of the MRV plan identifies the strategies that EWS Hub will use to establish the expected baselines for monitoring CO_2 surface leakage per §98.448(a)(4). The strategies EWS Hub will use include visual inspection, the use of handheld CO_2 monitors, field sampling, continuous parameter monitoring, well surveillance, and the use of seismic monitoring stations.

Thus, EWS Hub provides an acceptable approach for detecting and quantifying leakage and for establishing expected baselines in accordance with 40 CFR 98.448(a)(3) and 40 CFR 98.448(a)(4).

5 Considerations Used to Calculate Site-Specific Variables for the Mass Balance Equation

Section 8 of the MRV plan provides the equations that EWS Hub will use to calculate the mass of CO_2 sequestered annually.

Calculation of Mass of CO_2 Received

EWS Hub states that they will use Equation RR-1 to calculate the mass of CO_2 received from the custody-transfer meter immediately downstream of the source (pipeline).

$$CO_{2T,r} = \sum_{p=1}^{4} (Q_{r,p} - S_{r,p}) * C_{CO_{2,p,r}} \quad \text{(Eq. RR-1)}$$

where:

$CO_{2T,r}$ = Net annual mass of CO_2 received through flow meter r (metric tons)

$Q_{r,p}$ = Quarterly mass flow through a receiving flow meter r in quarter p (metric tons)

$S_{r,p}$ = Quarterly mass flow through a receiving flow meter r that is redelivered to another facility without being injected into your well in quarter p (metric tons)

$C_{CO2,p,r}$ = Quarterly CO_2 concentration measurement in flow for flow meter r in quarter p (wt. percent CO_2, expressed as a decimal fraction)

p = Quarter of the year

r = Receiving flow meter

The MRV plan states that EWS Hub will sum the total mass of CO_2 received using Equation RR-3:

$$CO_2 = \sum_{r=1}^{R} CO_{2T,r} \text{ (Eq. RR-3)}$$

where:

CO_2 = Total net annual mass of CO_2 received (metric tons)

$CO_{2T,r}$ = Net annual mass of CO_2 received (metric tons) as calculated in Equation RR-1 for flow meter r

r = Receiving flow meter

EWS Hub provides an acceptable approach for calculating the mass of CO_2 received under Subpart RR.

Calculation of Mass of CO_2 Injected into the Subsurface

EWS Hub states that the mass of CO_2 injected into the subsurface at each injection well will be calculated using Equation RR-4:

$$CO_{2,u} = \sum_{p=1}^{4} Q_{p,u} * C_{CO_{2,p,u}} \quad \text{(Eq. RR-4)}$$

where:

$CO_{2,u}$ = Annual CO_2 mass injected (metric tons) as measured by flow meter u.

$Q_{p,u}$ = Quarterly mass flow rate measurement for flow meter u in quarter p (metric tons per quarter)

$C_{CO2,p,u}$ = Quarterly CO_2 concentration measurement in flow for flow meter u in quarter p (wt. percent CO_2, expressed as a decimal fraction).

p = Quarter of the year.

u = flow meter.

The MRV plan states that aggregated injection at all injection wells will be calculated with Equation RR-6:

$$CO_{2I} = \sum_{u=1}^{U} CO_{2,u} \quad \text{(Eq. RR-6)}$$

where:

CO_{2I} = Total annual CO2 mass injected (metric tons) through all injection wells

$CO_{2,u}$ = Annual CO2 mass injected (metric tons) as measured by flow meter u

u = Flow meter

EWS Hub provides an acceptable approach for calculating the mass of CO_2 injected into the subsurface under Subpart RR.

Calculation of Mass of CO_2 Emitted by Surface Leakage

EWS Hub states that they will calculate and report the total annual mass of CO_2 emitted by surface leakage using an approach that is tailored to specific leakage events and relies on standard GHGRP procedures as listed at 40 CFR § 98.444(d). Additionally, the process for quantifying leakage will entail using industry standard engineering principles or emission factors. The MRV plan states that the facility will use Equation RR-10 to calculate and report the mass of CO_2 emitted by surface leakage.

$$CO_{2E} = \sum_{x=1}^{X} CO_{2,x} \text{ (Eq. RR-10)}$$

where:

CO_{2E} = Total annual CO_2 mass emitted by surface leakage (metric tons) in the reporting year

$CO_{2,x}$ = Annual CO_2 mass emitted (metric tons) at leakage pathway x in the reporting year

x = Leakage pathway

EWS Hub provides an acceptable approach for calculating the mass of CO_2 emitted by surface leakage under Subpart RR.

Calculation of Mass of CO_2 Sequestered in Subsurface Geologic Formations

EWS Hub states that they will use Equation RR-12 to calculate the mass of CO_2 sequestered in subsurface geologic formations in the reporting year.

$$CO_2 = CO_{2I} - CO_{2E} - CO_{2FI} \text{ (Eq. RR-12)}$$

where:

CO_2 = Total annual CO_2 mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year

CO_{2I} = Total annual CO_2 mass injected (metric tons) in the well or group of wells covered by this source category in the reporting year

CO_{2E} = Total annual CO_2 mass emitted (metric tons) by surface leakage in the reporting year

CO_{2FI} = Total annual CO_2 mass emitted (metric tons) from equipment leaks and vented emissions of CO_2 from equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead, for which a calculation procedure is provided in Subpart W

EWS Hub provides an acceptable approach for calculating the mass of CO_2 sequestered in subsurface geologic formations under subpart RR.

6 Summary of Findings

The Subpart RR MRV plan for Eastern Wyoming Sequestration Hub meets the requirements of 40 CFR 98.448. The regulatory provisions of 40 CFR 98.448(a), which specifies the requirements for MRV plans, are summarized below along with a summary of relevant provisions in the EWS Hub MRV plan.

Subpart RR MRV Plan Requirement	EWS Hub MRV Plan
40 CFR 98.448(a)(1): Delineation of the maximum monitoring area (MMA) and the active monitoring area (AMA).	Section 4 of the MRV plan delineates and describes the MMA and AMA. EWS Hub used reservoir simulation modeling for calculation of key project boundaries. While EWS Hub has calculated and identified the MMA and AMA using Subpart RR requirements, they state that the AMA is functionally equivalent to the MMA.
40 CFR 98.448(a)(2): Identification of potential surface leakage pathways for CO_2 in the MMA and the likelihood, magnitude, and timing, of surface leakage of CO_2 through these pathways.	Section 5 of the MRV plan identifies and evaluates potential surface leakage pathways. The MRV plan identifies the following potential pathways: Pipelines/surface equipment, wellbores, leakage through the confining zone, induced or natural seismic event, lateral migration, and drilling through the CO_2 area. The MRV plan analyzes the likelihood, magnitude, and timing of surface leakage through these pathways.
40 CFR 98.448(a)(3): A strategy for detecting and quantifying any surface leakage of CO_2.	Sections 5 and 6 of the MRV plan describe EWS Hub's strategy for detecting and quantifying potential CO_2 leakage to the surface should it occur, such as injection well monitoring, surface air monitoring, groundwater monitoring, and soil gas monitoring. The MRV plan states that an estimate of the relevant parameters (e.g., the rate, concentration, and duration of leakage) will be made to quantify the leakage mass.
40 CFR 98.448(a)(4): A strategy for establishing the expected baselines for monitoring CO_2 surface leakage.	Section 7 of the MRV plan describes EWS Hub's strategy for establishing baselines against which monitoring results will be compared to assess potential surface leakage. EWS Hub will utilize visual inspections, handheld CO_2 monitors, field sampling, continuous parameter monitoring, well surveillance, and seismic monitoring stations to conduct pre-injection (baseline) testing. EWS Hub will implement field sampling

	approximately 1 year prior to injection to establish baselines.
40 CFR 98.448(a)(5): A summary of the considerations you intend to use to calculate site-specific variables for the mass balance equation.	Section 8 of the MRV plan describes EWS Hub's approach for determining the total amount of CO_2 sequestered using the Subpart RR mass balance equations, including calculation of the total annual mass of CO_2 emitted from equipment leakage.
40 CFR 98.448(a)(6): For each injection well, report the well identification number used for the UIC permit (or the permit application) and the UIC permit class.	Section 1 of the MRV plan identifies the UIC permit numbers and permit class (Class VI) for the Azalea I-1, Spirea I-1R, Barberry I-1, Old Barberry I-1, Cypress I-1, and Juniper I-1 wells.
40 CFR 98.448(a)(7): Proposed date to begin collecting data for calculating total amount sequestered according to equation RR-11 or RR-12 of this subpart.	Section 9 of the MRV plan states that EWS Hub will implement the MRV plan upon receiving approval from the EPA, and no later than the day after which the plan becomes final. The MRV plan states that the proposed date to begin collecting data for calculating the total CO_2 sequestered is in June 2025.

Appendix A: Submissions and Responses to Requests for Additional Information

Subpart RR Monitoring, Reporting, and Verification Plan for the Eastern Wyoming Sequestration Hub

Laramie County, Wyoming

Version 5

August 1, 2025

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List of Tables

1. Introduction

Tallgrass High Plains Carbon Storage, LLC (High Plains) has prepared this monitoring, reporting and verification (MRV) plan pursuant to 40 CFR (U.S. Code of Federal Regulations) § 98.440-449 (Subpart RR). High Plains is a subsidiary of Tallgrass Energy, L.P. (Tallgrass). This document describes the MRV activities for the proposed High Plains Eastern Wyoming Sequestration (EWS) Hub, located in Laramie County, Wyoming. The EWS Hub consists of six carbon dioxide (CO_2) injection facilities, each with one injection well (Azalea I-1, Spirea I-1R, Barberry I-1, Old Barberry I-1, Cypress I-1, and Juniper I-1). A previous version of this MRV Plan (Version 3 dated November 22, 2024) has been approved for a single injection well (Juniper I-1) and is being amended to incorporate five additional injection wells in the same field.

The EWS Hub is designed to store a total of 116.8 million metric tons (MMT). CO_2 will be sourced from a CO_2 collection pipeline from several industrial facilities.

The CO_2 will be injected into the Lyons Formation for geologic storage. An individual Underground Injection Control (UIC) Class VI application has been submitted to the State of Wyoming for each of the EWS Hub projects. At the time of this submittal, all six UIC Class VI applications have Class VI permits for approval to construct and the Juniper project has been authorized to inject:

- Juniper Project: UIC Permit 2022-235; Facility [ID] WYS-021-00149
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A stratigraphic test well, Juniper M-1 (American Petroleum Institute [API] #49-021-29548), has been drilled at the project area and will be converted into an above confining zone monitoring well.

This MRV plan is organized into the following sections:

- Section 1: Introduction
- Section 2: Facility Information
- Section 3: Project Description
- Section 4: Delineation of the Monitoring Areas
- Section 5: Identification and Assessment of Potential Surface Leakage Pathways
- Section 6: Monitoring and Considerations for Site-Specific Variables
- Section 7: Approach for Establishing the Expected Baselines

- Section 8: Considerations for Site-Specific Variables for the Mass Balance Equations
- Section 9: MRV Implementation Schedule
- Section 10: Quality Assurance and Quality Control
- Section 11: Records Retention

2. Facility Information

1. Greenhouse Gas Reporting Program (GHGRP) ID number – 589261
2. The Wyoming Department of Environmental Quality (WDEQ) has issued UIC Class VI permits under its Wyoming Statute (W.S.) Sections 35-11-101 through 2005 for the injection wells.
3. Oil- and gas-related wells around the EWS Hub injection facilities, including Class II injection wells and production wells, are regulated by the Wyoming Oil and Gas Conservation Commission (WOGCC). WDEQ is the responsible agency for all other UIC well classes.

   Wells within the EWS Hub area of review (AoR) are identified by name, API number, status, and type. The list of planned wells associated with the EWS Hub projects is provided in **Appendix A**. Any new wells or changes to well status will be indicated in the annual report.
4. Proposed date to begin collecting data for calculating the total CO_2 amount sequestered: June, 2025.

3. Project Description

Tallgrass, headquartered in Leawood, Kansas, is a committed leader at the forefront of decarbonization efforts in the United States (U.S.). Tallgrass is a pipeline and gas storage company that enables a high quality of life through the delivery of energy and services that fuel homes and businesses. As a demonstration of its decarbonization commitment, Tallgrass is developing the sequestration site in Laramie County, Wyoming. The EWS Hub is an innovative, multi-state decarbonization effort focused on permanently sequestering CO_2 from multiple emitters located in Nebraska, Colorado, and Wyoming.

Tallgrass and predecessor companies have operated natural gas storage fields for more than 70 years. Tallgrass currently operates 90 wells with 74 billion cubic feet (bcf) of natural gas storage capacity and 20,470 compression horsepower across the Huntsman and East Cheyenne gas storage fields. These gas storage operations provide Tallgrass with critical subsurface working knowledge and skill sets that transfer directly to CO_2 sequestration, specifically the injection, monitoring, and storage of gaseous fluids in porous reservoirs.

The State of Wyoming previously recognized Tallgrass's commitment to decarbonization when the Wyoming Energy Authority (WEA) awarded High Plains a grant to help fund the development of the injection project. The grant is in addition to the proposed direct investment in the project by High Plains, designed to provide a cost-effective means of sequestering CO_2. "Wyoming is deeply committed to providing decarbonized solutions for the 21st century," said Dr. Glen Murrell, Executive Director of the WEA. "We are pleased to be able to fund Tallgrass's Eastern Wyoming Sequestration Hub project, which has the potential to add an important resource for our net-zero goals."[1]

3.1 Project Characteristics

The EWS Hub project area is ideally suited for CO_2 storage for the following reasons:

- The high permeability and porosity of the Lyons Formation (the injection zone)
- The continuity, low permeability, and ductility of the overlying Chugwater Formation/Goose Egg Formation (confining zone), and Satanka Formation (lower confining zone)
- Few abandoned wells that penetrate the injection zone

Computational modeling to simulate CO_2 sequestration confirms anticipated containment of the injected mass. A robust monitoring program will be established to detect any CO_2 leakage so that any potential leakage may be mitigated.

The EWS Hub Projects will consist of six injection wells, surface facilities, and six above confining zone monitoring wells (**Figure 1**). Additional shallow groundwater monitoring wells will also be placed at each injection project to monitor underground source of drinking water (USDW) aquifers.

[1] https://tallgrass.com/newsroom/press-releases/tallgrass-to-develop-a-commercial-scale-co2-sequestration-hub-in-wyoming

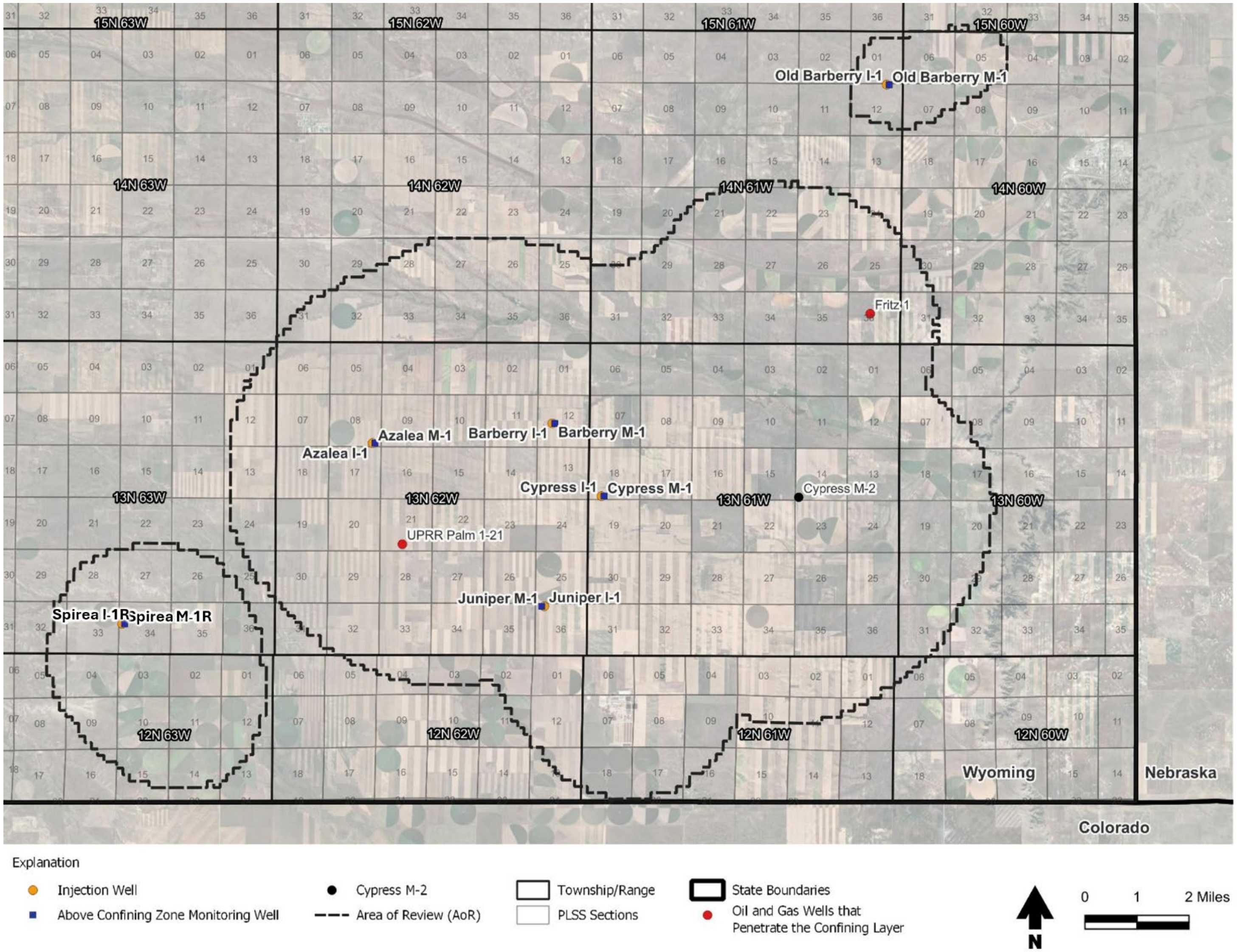

Figure 1. EWS Hub Project Location, Injection Wells and Proposed Above Confining Zone Monitoring Wells, and Abandoned Wells within the AoR that Penetrate the Confining Zone.

3.2 Project Area Geology

The EWS Hub AoR is located in Laramie County in southeastern Wyoming. The site is situated within the Denver Basin, commonly referred to as the Denver-Julesburg Basin, or "DJ Basin." The sequestration program entails injecting into the Lyons Formation, a geologic formation spanning approximately 50 to 100 net feet of high porosity and permeable sands at an approximate average depth of 9,081 feet true vertical depth (TVD) within the EWS Hub AoR.

The DJ Basin consists of shallow Paleozoic through deeper Cenozoic sediments that were deposited unconformably over Precambrian crystalline basement rock. Deposition occurred in a predominantly marine shelf environment that was subject to subsidence for most of the Paleozoic and Mesozoic Eras. As a result, total sediment accumulation can reach thicknesses in excess of 13,000 feet along the synclinal axis. Sediment supply during Pennsylvanian time consisted primarily of shale and carbonate in the basin interior, with sand contribution along the Ancestral Rockies.

Permian through Triassic time was characterized by a broad, low-relief intermittent sea that exhibited depositional environments from fluvial, normal marine to hypersaline. Lithology within the Permian-Triassic strata is dominated by redbeds, evaporites, and anhydritic siltstones (Bethke and Lee, 1994). Triassic sediments were subsequently overlain by shale and sand deposition that dominated the Jurassic and Cretaceous periods. The Western Interior Seaway was relatively deep and present across a significant portion of western North America during the Cretaceous, including the DJ Basin. The Cretaceous was also subject to east-verging thrusts associated with Laramide tectonism.

The combination of the structural setting and depositional environment resulted in accumulation of up to 10,000 feet of Cretaceous shale, sandy shale, and carbonate over Jurassic and Triassic sediments throughout the basin (Sonnenberg and Weimer, 1981; Bethke and Lee, 1994; Taucher et al., 2013). These shales and tight carbonate formations have been identified by the Wyoming State Geological Survey (WSGS) as confining intervals between the injection formation and lowermost potential potable water aquifer.

Figure 2 depicts the stratigraphy of the DJ Basin. The geologic sequence of the EWS Hub includes the following formations, from shallowest to deepest:

- *Above Confining Zone:* Sundance Formation. The Sundance Formation includes well-sorted, well-rounded sandstone intervals that are sufficiently permeable to serve as a groundwater aquifer (Lowry and Crist, 1967; Love and Christiansen, 1985; Taucher et al., 2013).
- *Upper Confining Zone:* Chugwater Formation/Goose Egg Formation.
  - *Chugwater Formation:* The formation consists of reddish-orange shale and siltstone with thin gypsum partings near the base. The average thickness of the Chugwater Formation within the EWS Hub project area is approximately 221 feet.
  - *Goose Egg Formation*: This geologic section consists of red shale and silt interbedded with gypsum, anhydrite, limestone, and dolomite. The average thickness of the Goose Egg Formation within the EWS Hub project area is approximately 268 feet.

- *Injection Zone*: Lyons Formation. The Lyons Formation is described as a well-sorted, fine-grained, eolian quartzose sandstone from outcrops near Lyons, Colorado (Sonnenberg and Weimer, 1981). The Lyons Formation has an approximate thickness of 61 feet in the EWS Hub AoR.
- *Lower Confining Zone*: Satanka Formation. The Satanka Formation contains interbedded red and gray sandstones, gray siltstone, red mudstone, and red anhydritic siltstones. The sandstones contain feldspar and are commonly fine-grained to very fine-grained. The anhydrite-rich upper Satanka provides an impermeable barrier, inhibiting vertical fluid migration (Clayton and Swetland, 1980).

Table 1 lists the approximate formation top depths at the EWS Hub project locations. **Figure 3** is a schematic representing the regional stratigraphy in the vicinity of the EWS Hub project area.

Table 1. Formation Top Depths, EWS Hub Project Site

Formation	Designation	Project Site Approximate Depths (TVD, feet)					
		Azalea	Barberry	Old Barberry	Spirea	Cypress	Juniper
Sundance	Aquifer	8,774	8,658	8,063	8,907	8,602	8,558
Chugwater	Aquitard	8,840	8,724	8,128	9,053	8,655	8,610
Goose Egg	Aquitard	9,071	8,919	8,330	9,257	8,897	8,864
Lyons	Aquifer	9,352	9,211	8,616	9,494	9,150	9,124
Satanka	Aquitard	9,419	9,275	8,689	9,556	9,200	9,175

ERATHEM	SYSTEM AND SERIES		Lithostratigraphic units of Love et al. (1993) in the DJ Basin (MODIFIED)		Hydrogeologic unit for DJ Basin		
CENOZOIC	QUATERNARY	Holocene and Pleistocene	Alluvium and terrace deposits		Quaternary unconsolidated-deposit aquifers		High plains aquifer system
	TERTIARY	Pliocene	*section absent due to erosion or nondeposition*				
		Miocene	Ogallala Formation		Ogallala aquifer		
			Arikaree Formation		Arikaree aquifer		
		Oligocene	White River Formation	Conglomerate	White River Group		
				Lower part			
			White River Group	Brule Formation	White River aquifer/confining unit	Brule	
				Chadron Formation		Chadron	
		Eocene	*section absent due to erosion or nondeposition*				
		Paleocene					
MESOZOIC	CRETACEOUS	Upper Cretaceous	Lance Formation		Lance aquifer		Lance-Fox Hills aquifer
			Fox Hills Sandstone		Fox Hills aquifer		
			Pierre Shale		Pierre confining unit		
			Niobrara Formation		Niobrara confining unit		
			Carlile Shale		Carlile confining unit		
			Greenhorn Formation		Greenhorn confining unit		
			Belle Fourche Shale		Belle Fourche confining unit		
			Mowry Shale		Mowry-Thermopolis confining unit		
		Lower Cretaceous	Muddy Sandstone			Muddy Sandstone aquifer	
			Thermopolis Shale				
			Inyan Kara Group	Fall River Formation	Inyan Kara aquifer		
				Lakota Formation			
	JURASSIC	Upper Jurassic	Morrison Formation		Morrison aquifer and confining unit		
		Middle Jurassic	Sundance Formation		Sundance Aquifer		
	JURASSIC (?) AND TRIASSIC (?)		*section absent due to erosion or nondeposition*				
	TRIASSIC	Upper Triassic	Chugwater Formation of Darton (1908)		Chugwater confining unit		
		Lower Triassic	Lykins Formation		Goose Egg Formation		
PALEOZOIC	PERMIAN		Lyons Sandstone		Hydrogeologic role/unit not defined for study area		
			Satanka Shale		Satanka confining unit		
	PENNSYLVANIAN	Upper Penn	Casper Formation	Hartville Formation	Casper aquifer	Hartville aquifer	Paleozoic aquifer system
		Middle Penn					

Figure 2. Stratigraphic Column of the DJ Basin. The shading indicates freshwater aquifers (underground sources of drinking water [USDWs]) in blue, the proposed injection interval in red, primary confining layers in dark gray, and additional confining layers in light gray (adapted and modified from Taucher et al., 2013).

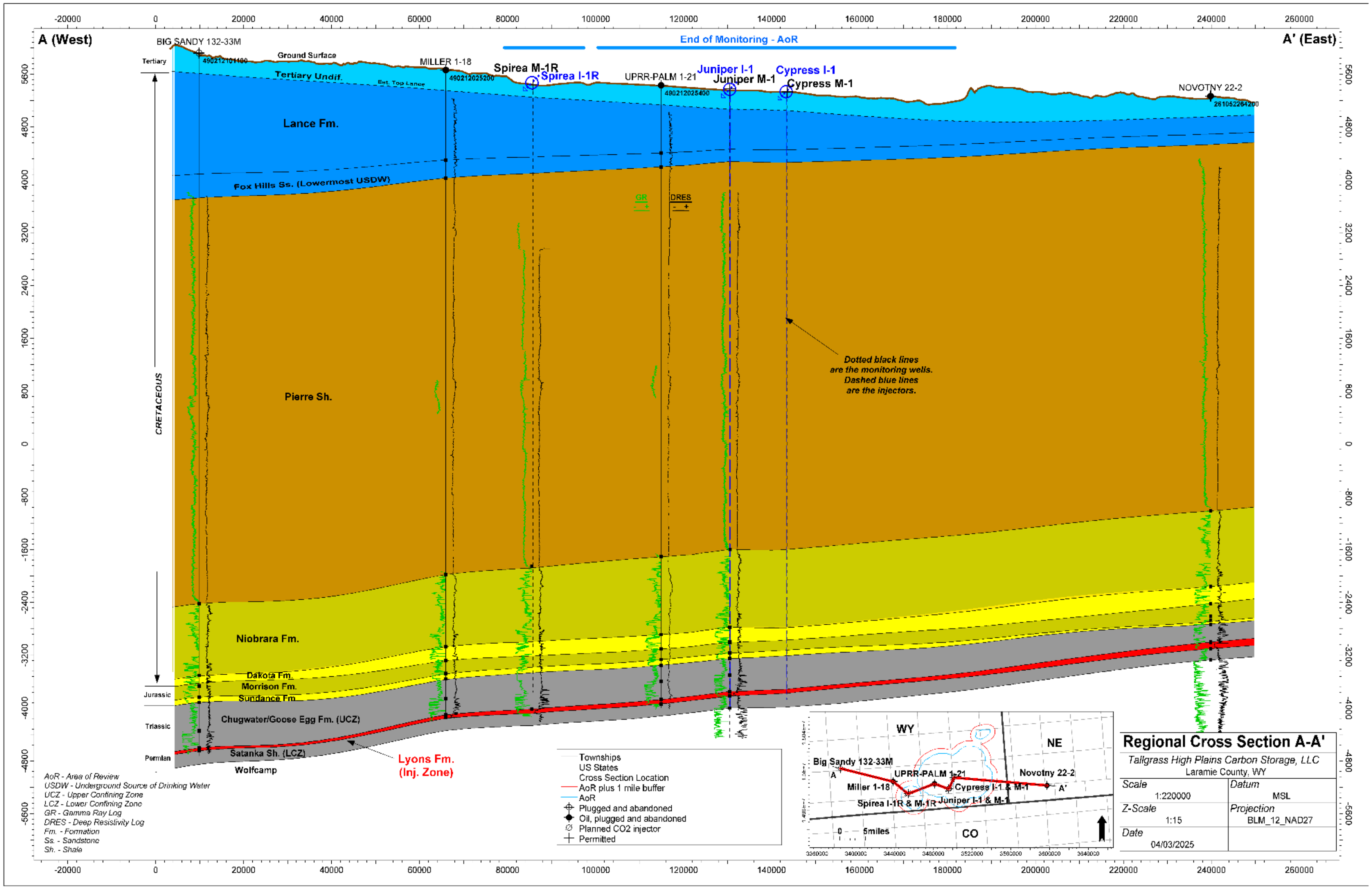

Figure 3. Regional West-East Cross Section A-A'. Gamma ray (left, green) and deep resistivity (right, black) logs are shown.

3.3 Surface Facilities and Injection Process

A simplified flow diagram of surface facilities is provided in **Figure 4a**, and detailed surface facilities diagrams for the Juniper, Cypress, Spirea, Barberry and Azalea projects are provided in **Figures 4b through 4f** (surface facilities for the Old Barberry project are anticipated to be essentially identical to the Cypress project). All facilities will be designed and built to ensure integrity and compatibility with CO_2. The injection wells will be designed and operated in a manner that meet the requirements of WDEQ Chapter 24. Once injection activity is complete, the wells will be plugged according to WDEQ Chapter 24 §23.

The monitoring program (see Section 6) is designed to meet the requirements of Subpart RR and WDEQ Chapter 24 §20, with advanced technologies that allow for the tracking of the injectate plume migration while minimizing the artificial creation of potential pathways for sequestered fluids to escape confinement. The extent of the CO_2 plume will be monitored using two-dimensional (2D) seismic surveys to understand CO_2 saturation changes through time. Above confining zone monitoring wells (Juniper M-1, Azalea M-1, Spirea M-1R, Barberry M-1, Old Barberry M-1 and Cypress M-1) will be used to detect migration above the confining zone.

The following subsections will review the following:

- CO_2 source (Section 3.3.1)
- CO_2 transportation and injection (Section 3.3.2)
- Wells in the Class VI AoR penetrating the upper confining zone (Section 3.3.3)

3.3.1 CO_2 Source

CO_2 will be sourced from a CO_2 collection pipeline from several industrial facilities in Nebraska and surrounding states. Chemistry of the injectate stream will consist of 95 percent or higher CO_2 purity and less than 150 parts per million (ppm) water. **Table 2** shows the planned composition of the injectate stream, per the pipeline specifications.

High Plains has demonstrated the compatibility of the CO_2 stream with the fluids in the injection zone and minerals in both the injection and confining zones based on the results of the formation testing program. The CO_2 streams that High Plains proposes to inject through this Class VI permit are exempt from the U.S. Environmental Protection Agency (EPA) definition of hazardous waste in 40 CFR § 261.4(h). Similarly, the injected CO_2 is not a hazardous or toxic waste or other material under Chapter 8 of WDEQ Water Quality Rules in the Wyoming Code of Regulations (WCR) (020-0011-8 WCR 6). As such, the CO_2 stream that High Plains proposes to inject is not subject to the restrictions in 020-0011-8 WCR 6(c)(ii).

3.3.2 CO_2 Transportation and Injection

CO_2 from the collection pipeline will be distributed to the injection wells with new infrastructure. This distribution infrastructure will allow CO_2 to be injected into the injection wells completed within the Lyons Formation.

The CO_2 injection wells will have automated controls that provide for both control and measurement of the mass flow rate and pressure.

3.3.3 Wells in the AoR Penetrating the Upper Confining Zone

Project injection ("I-1") and above confining zone monitoring ("M-1") wells will penetrate the confining zone; at this time, eight of the EWS Hub project wells have been drilled and penetrate the confining zone (Juniper I-1 and M-1, Azalea I-1 and M-1, Spirea I-1R and Spirea M-1R, Barberry I-1 and Barberry M-1). With the exception of the Juniper M-1 characterization well and the Spirea M-1R, the remaining project M-1 monitoring wells penetrate or will penetrate the confining zone only as necessary to accommodate drilling and logging of shallower formations and approximately 80% of the confining zone is not penetrated by these wells.

Three additional wells penetrate the confining layer or deeper within the EWS Hub maximum monitoring area (MMA; see Section 4.1): Cypress M-2 (API# 49-021-29598), Fritz 1 (API #49-021-05033), and UPRR Palm 1-21 (API #49-021-20254). Fritz 1 and UPRR Palm 1-21 were both drilled and abandoned. The UPRR Palm 1-21 contains adequate cement plugs across relevant zones. Fritz 1 does not provide cement plugs <2,500 feet apart and, per the current WOGCC abandonment regulations (Section 18, Form 4), will need to have remedial work completed prior to CO_2 injection.

Cypress M-2 was drilled by High Plains and has since been plugged back to the surface. The plugging and abandonment operation included a comprehensive design incorporating eight cement plugs, ensuring compliance with standards set by WDEQ, WOGCC, EPA, and the API. Notably, Plug 8 was placed across the Lyons Formation, the intended storage zone, using an acid-resistant cement blend (SLB's EverCrete). This plug was tagged and confirmed with a weight on bit of 10,000 pounds after achieving a compressive strength of 500 pounds per square inch (psi) approximately 15 hours post-placement.

Table 2—Composition of the injectate stream

Constituent	Limit
CO_2	$\geq$ 95 mol%
Carbon monoxide (CO)	$\leq$ 0.4 mol%
Hydrogen (H_2)	$\leq$ 0.5 mol%
Hydrogen Sulfide (H_2S)	$\leq$ 20 ppm
Total Sulfur	$\leq$ 35 ppm
Total nitrogen oxides (NO_x)	$\leq$ 10 ppm
Oxygen (O_2)	$\leq$ 1 mol%
Water (H_2O)	$\leq$ 150 ppm
Hydrocarbons	$\leq$ 4 mol %
Glycol	0.3 gallons/MMCF
Maximum dew point at 400 psig	30°F
Non-condensable gases	$\leq$ 5% mol%

psig = pounds per square inch gauge
MMCF = million cubic feet

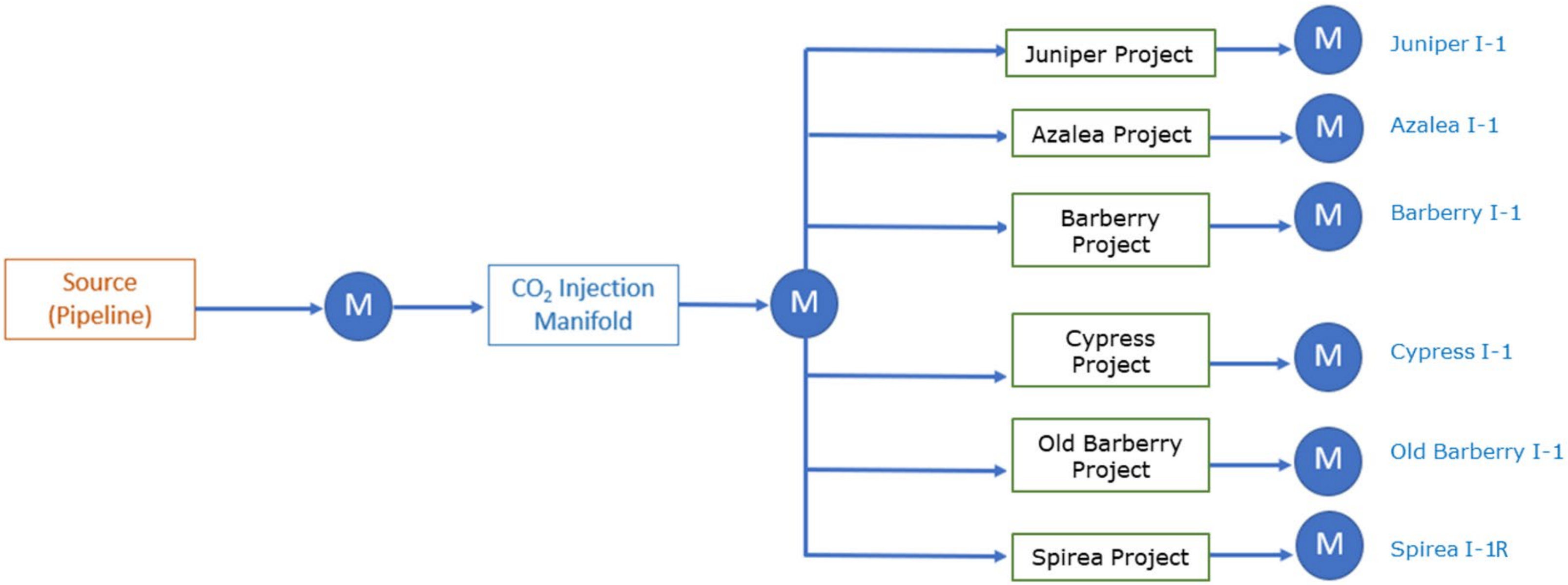

Figure 4a. Simplified Facilities Flow Diagram for High Plains EWS Hub. Blue "M" symbols denote meter locations.

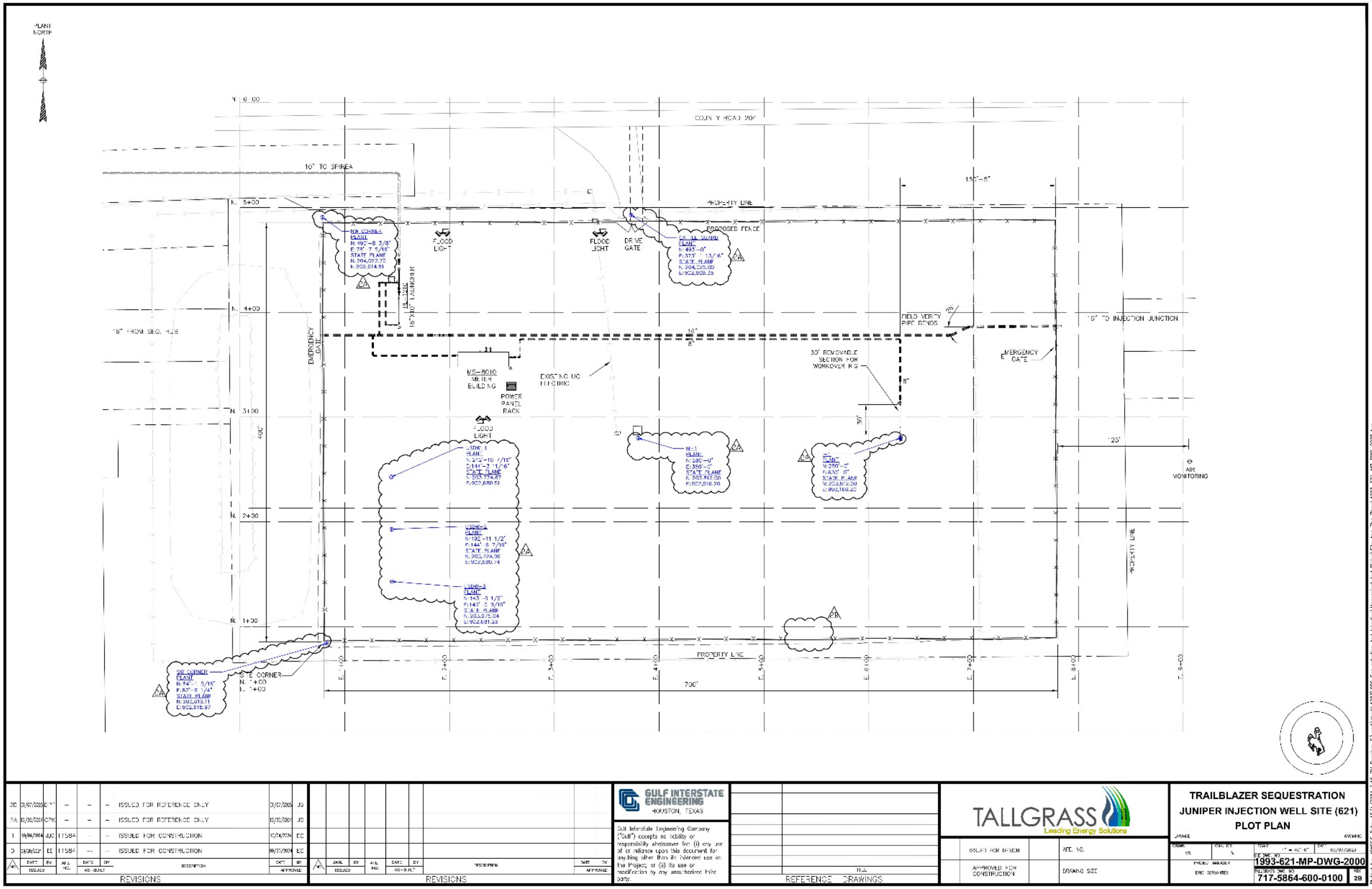

Figure 4b. Juniper Injection Well Site Plot Plan.

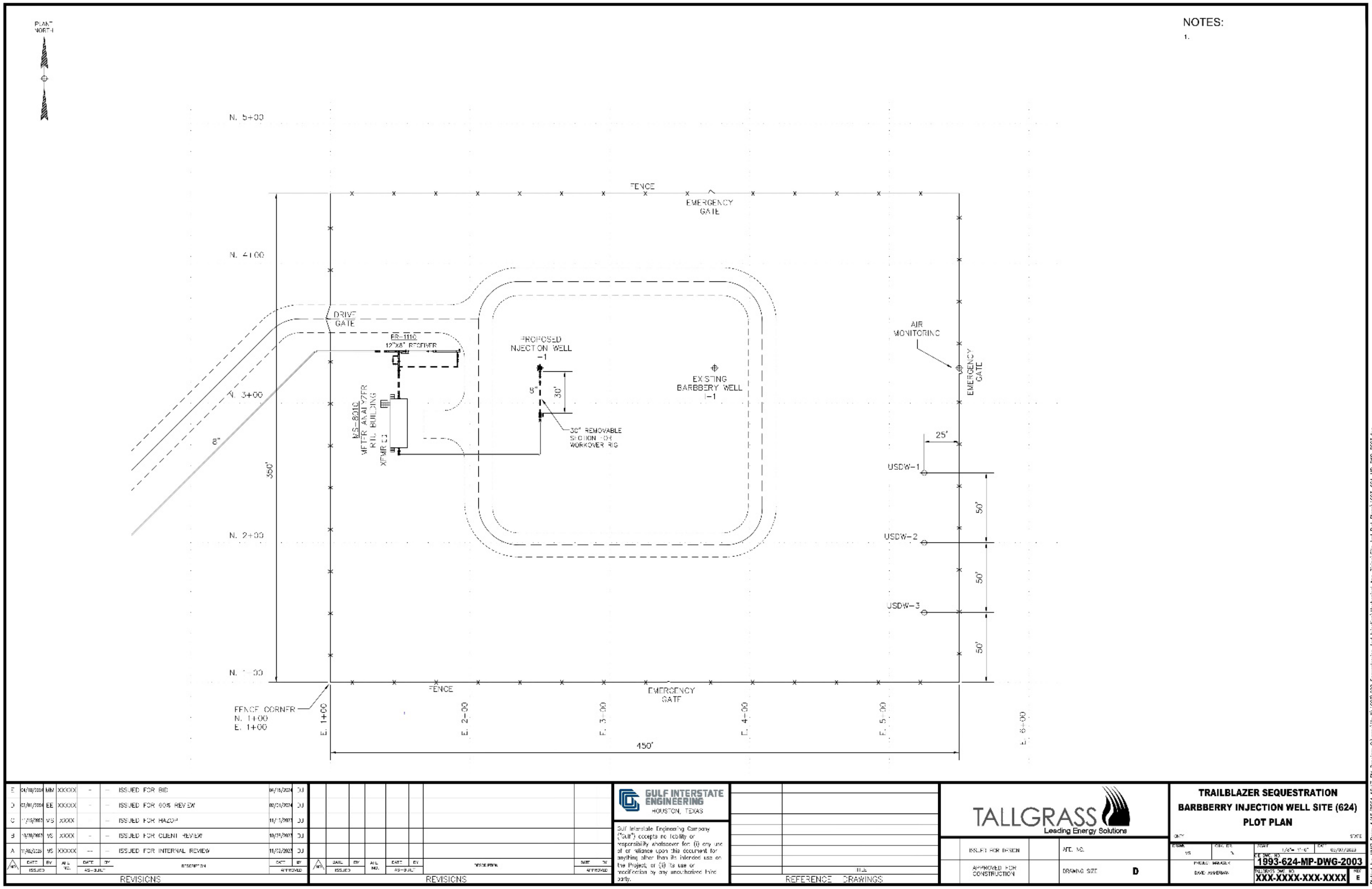

Figure 4c. Barberry Injection Well Site Plot Plan.

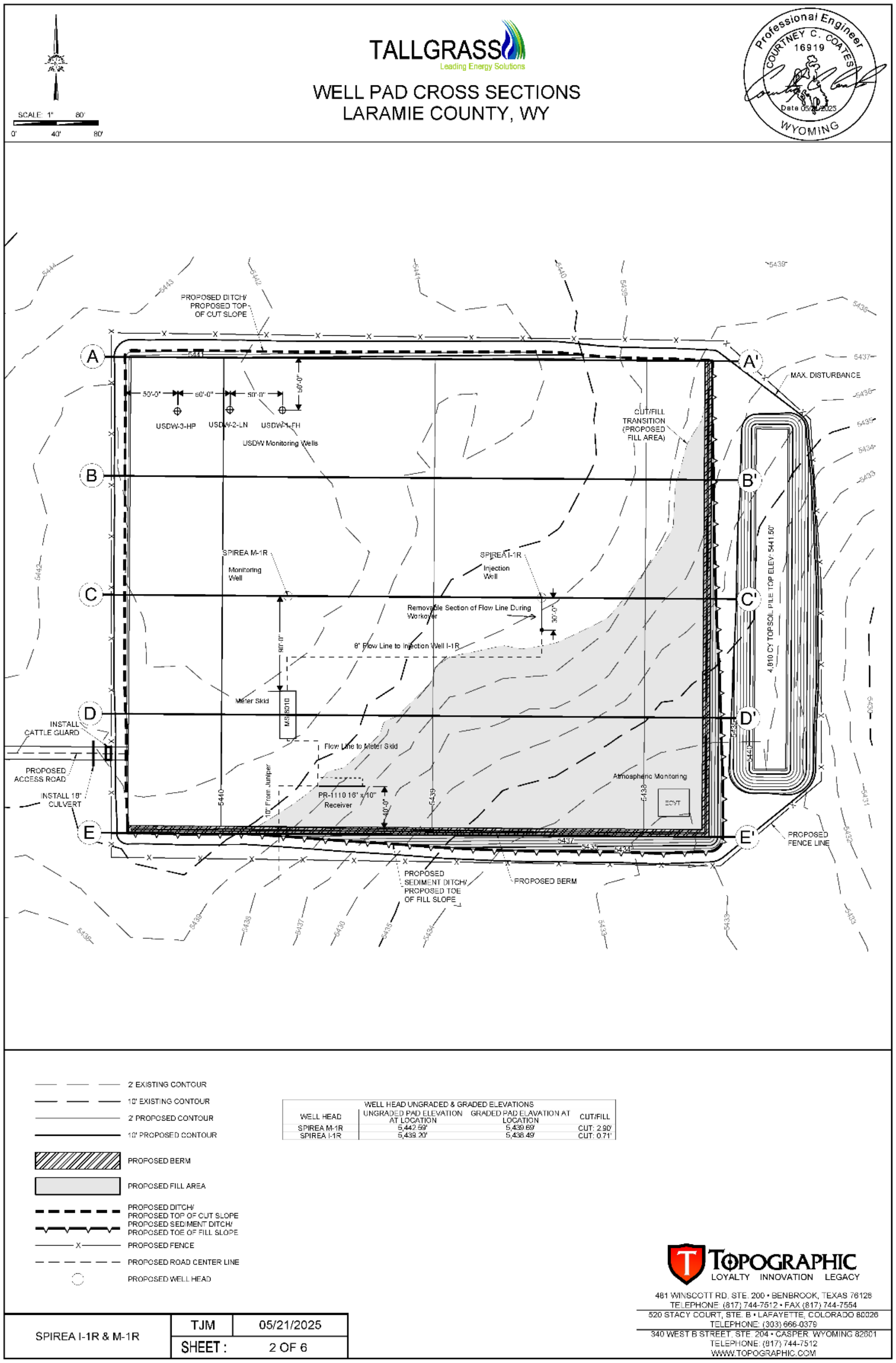

Figure 4d. **Spirea Injection Well Site Plot Plan.**

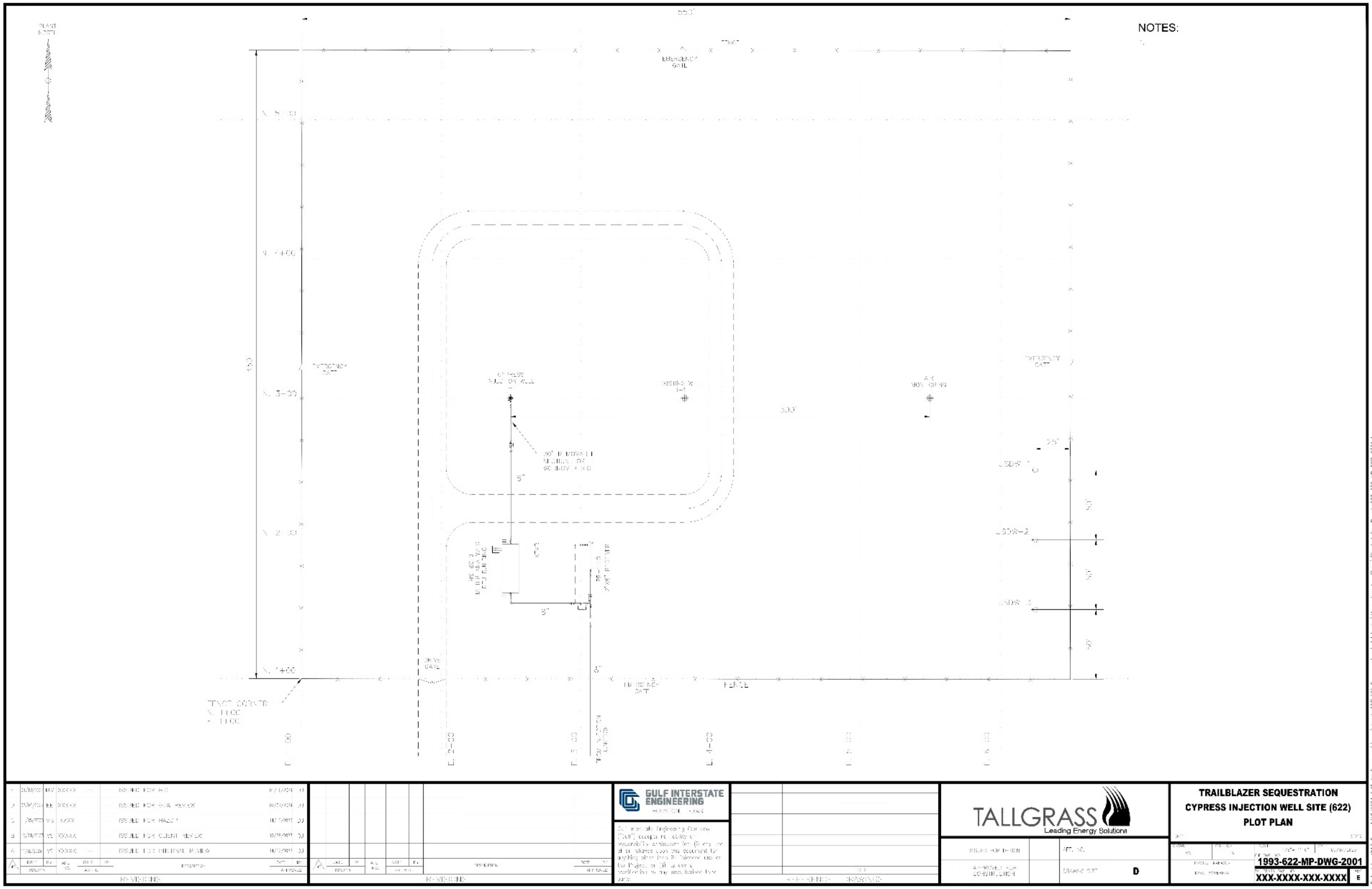

Figure 4e. Cypress Injection Well Site Plot Plan.

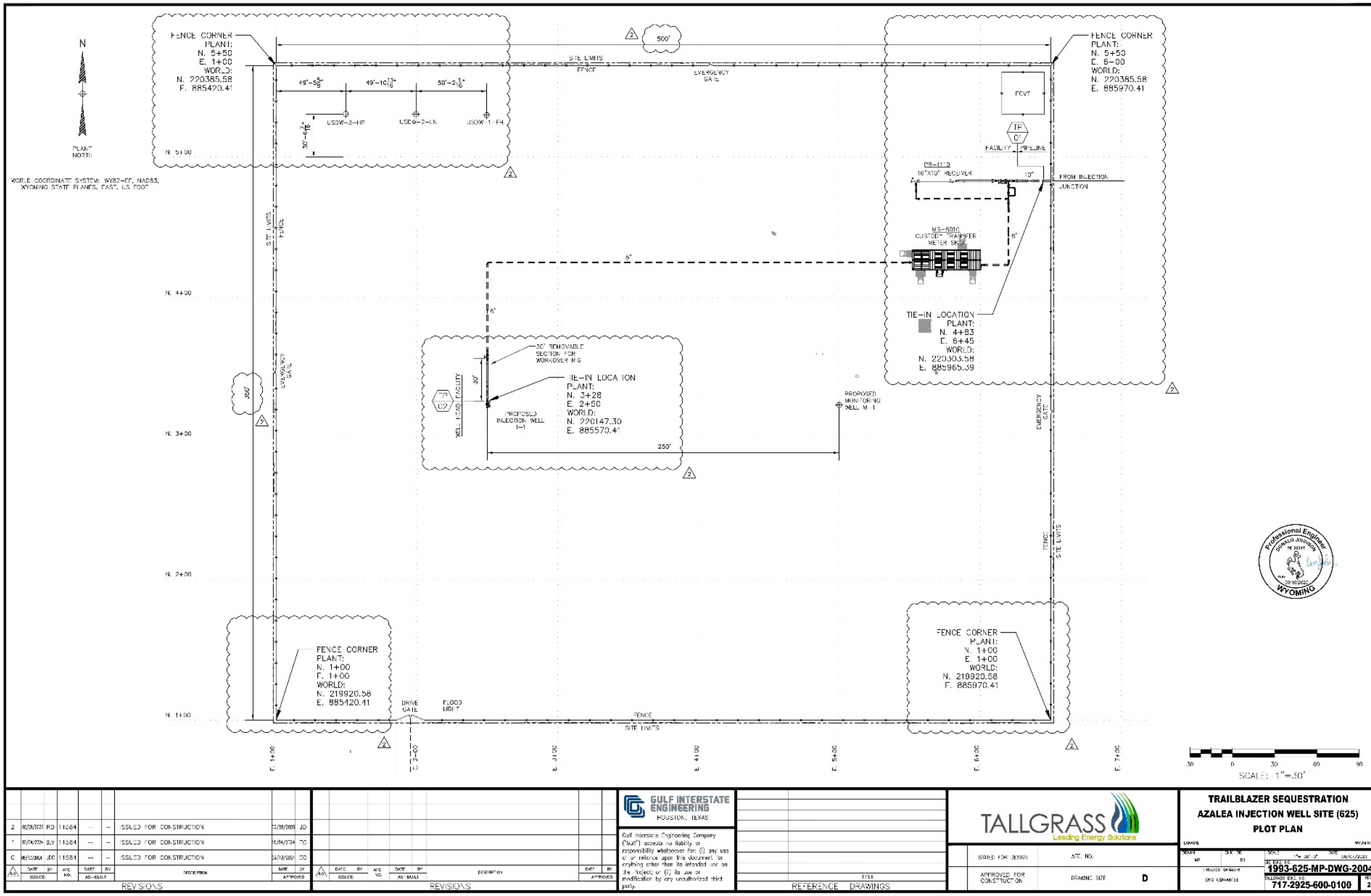

Figure 4f. Azalea Injection Well Site Plot Plan.

3.4 Reservoir Simulation Model

Reservoir modeling included development of a static geologic model and dynamic reservoir model. The reservoir simulation model was used to define the site AoR (CO_2 plume) and the MRV monitoring areas (Section 4).

The following subsections further describe these topics:

- Data Sources (Section 3.4.1)
- Model Platform (Section 3.4.2)
- Structural Framework (Section 3.4.3)
- Initial Conditions (Section 3.4.4)
- Fracture Gradient (Section 3.4.5)
- CO_2 (Section 3.4.6)
- Injection (Section 3.4.7)
- Boundary Conditions (Section 3.4.8)
- Modeling Results (Section 3.4.9)

3.4.1 Data Sources

Data sources used to build the geologic model include well logs, 2D seismic data, core, and publicly available literature. Publicly available open-hole log data including gamma ray, spontaneous potential, resistivity, porosity (sonic, neutron, density), photoelectric factor, and the caliper log were used to pick stratigraphic tops and perform petrophysical analyses. Petrophysical analyses were performed on a total of 47 wells with triple combo log suites (gamma ray, porosity, and resistivity logs) within the EWS Hub area. Well logs were also used as control points in the geologic model to distribute rock property values.

2D seismic data were tied in with well log formation tops to model the geologic structure. The seismic analysis was further used to identify any faulting, structural changes, or reservoir thickness not identified from well logs. No faults were identified in the project area.

3.4.2 Model Platform

Schlumberger's Petrel™ Software was chosen to build the geologic model. Petrel is a state-of-the-art software package that is used worldwide, incorporating log and seismic data to create a geostatistical representation of the reservoir. The geologic model developed using Petrel represents the subsurface characteristics of the proposed carbon sequestration site. It consists of the Chugwater (upper seal), Goose Egg (upper seal), and Lyons (injection zone).

The geologic model was then used as an input into Computer Modeling Group's (CMG's) GEM 2022.10 (GEM) simulator, which is one of the most accurate and technically sound reservoir simulation software packages for conventional, unconventional, and secondary recovery. GEM uses equation-of-state (EOS) algorithms, along with some of the most advanced computational methods, to evaluate compositional, chemical, and geochemical processes and characteristics to produce highly accurate and reliable simulation models for carbon sequestration. GEM was used to accurately simulate the movement of supercritical CO_2 and the increase in reservoir pressure due to injection operations.

3.4.3 Structural Framework

The structure model was built from formation tops as determined from log analysis and seismic interpretation. A three-dimensional (3D) model was constructed in Petrel from interpreted geologic horizons and mapped regional faulting. Petrel employs simple kriging methods, with the well logs as control points, to distribute property values across the modeled formations. The primary distributed properties were permeability and porosity estimates.

The geocellular model consists of 500-foot by 500-foot hexahedral grid cells. The model covers an area of 102 miles by 57 miles. Surfaces for the four primary zones of interest—Chugwater, Goose Egg, Lyons, and Satanka—were interpreted from well logs and seismic data (**Figure 5**). An average cell thickness of 4.52 feet was used to characterize the Lyons Formation.

Additional layering for the model was defined through isopach maps and well tops, resulting in vertical cells of varying thickness ranging from 2 to 40 feet. The isopach maps honored significant features observed from seismic data including facies changes. Because no faults were observed in the area of interest, the model contains no fault planes.

Petrophysical analyses conducted on 47 wells within the model boundary were used to determine porosity and permeability for each stratigraphic zone. Using the values derived from log analysis, properties in the geocellular static model were assigned by taking the continuous range of the property and upscaling the value to match the final grid cell resolution using the arithmetic average over each cell. Property distribution in the Lyons Formation consisted of applying a kriging algorithm from upscaled logs, guided by an experimental spherical variogram, with major and minor range of 100,000 feet and a vertical range of 50 feet for each zone. Property distribution consisted of applying the kriging algorithm from upscaled porosity logs, guided by variograms for each zone as seen in **Figure 6**.

3.4.4 Initial Conditions

The model is a pseudo-infinite acting reservoir that is 100 percent brine filled. Based on 2D seismic interpretation and log information collected at Juniper M-1, the sands within the Lyons Formation have an average gross thickness of 55 feet. Based on pressure gauges in Juniper M-1, it was determined that the reservoir has a pressure gradient of 0.34 pound per square inch per foot (psi/ft). A reservoir temperature gradient of 2.07°F per 100 feet with a mean surface temperature of 60°F was used. Average salinity of the brine fluid in the reservoir was measured at Juniper M-1 with a value of approximately 230,000 milligrams per liter (mg/L).

3.4.5 Permeability and Porosity

Permeability was distributed along corresponding porosity values. Air permeability was correlated to ambient porosity. The correlation of porosity to permeability is defined by the best-fit trend line of the measured data taken from Razor 26J-2633L (API #051233749500), Marathon-Avalo 1-32

(API #05123106700) and Juniper M-1 (API #490212954800) as shown on **Figure 7**. An equation was created with a best-fit trend line to calculate permeability based on the distributed porosity. These values were then converted into brine permeability based on the Swanson K_{air}/K_{brine} relationship (Swanson 1981). In the study, if the brine permeability was greater than the air permeability, the authors chose to use the air permeability to provide a more conservative estimate in the model.

Permeability and porosity values were distributed across the model. Observed values of porosity calculated from offset well logs can be in excess of 30 percent, yielding permeabilities of 1,029 millidarcies (mD). To constrain these anomalously high values of permeability, a cutoff of 1,029 mD was applied to the model to remove any extremities that could be derived from the permeability-porosity relationship.

3.4.6 Fracture Gradient

A fracture gradient for the Lyons Formation was successfully measured from the Juniper I-1 injection well during a mini-fracture test. The fracture gradient value is 0.59 psi/ft. The maximum injection pressure gradient was calculated as 90 percent of the fracture gradient, resulting in a maximum injection pressure gradient of 0.53 psi/ft.

3.4.7 CO_2 Phase

There are numerous advantages to storing CO_2 under supercritical conditions. Supercritical fluids have significantly higher density that allows for a greater mass of molecules to be stored in the same space. CO_2 also has a low viscosity which lowers the pressure required to store it. For this project, CO_2 will be injected in a supercritical state and, based on the pressure and temperature of the Lyons Formation, will remain as a supercritical fluid throughout the life of the project.

3.4.8 Injection

High Plains is permitted to construct and operate six injection wells designed to sequester 1.5 MMT/yr per well for the EWS Hub. **Table 3** summarizes planned injection for each EWS Hub project.

3.4.9 Boundary Conditions

The initial conditions for the simulation model are assumed to be in a pseudo-infinite acting reservoir fully saturated with brine water. From well log and seismic analysis, the Lyons Formation sandstone was determined to pinch out to the northwest and to the southeast of the area of interest. Therefore, the northwest and southeast edges have been established as no-flow boundaries for modeling purposes. Conversely, the northeast and southwest edges of the model have volume modifiers in place, allowing them to act as open boundaries. To simulate a pseudo-infinite acting boundary and pinch-out of the Lyons Formation sandstone, the red grid blocks at the east and west edges of the model are adjusted with a volume multiplier equal to 739 times the volume of the blue grid blocks in the interior of the model. The volume multiplier simulates 70 miles of additional pore volume from the model edge.

3.4.10 Modeling Results

Once all variables were input, the simulation model was run with the primary objective to maximize storage capacity and minimize the lateral extent of CO_2 plume. The objectives were achieved by optimizing injection patterns and well placement, as well as performing sensitivity analyses. The maximum extent of the plume is assumed to be the point where the concentration of supercritical-phase CO_2 reaches below 2 percent saturation.

The Lyons Formation sands were upscaled into eight distinct 7-foot layers that were all simultaneously injected with supercritical CO_2. The top of the Lyons Formation is bound by an upper shale (Chugwater) that is a physical trap preventing the upward migration of CO_2. Supercritical CO_2 is more buoyant than water; thus, the CO_2 migrates to the upper 7-foot layer of the modeled Lyons Formation. The maximum extent of the plume was measured from this uppermost layer.

Figure 8 shows modeling results of the predicted CO_2 plume radius over time. As indicated by negligible change after 2065 (10 years after the end of injection), the plumes are considered stabilized by that time.

The increase in pressure experienced from injection operations was also modeled. **Figure 9** represents the pressure buildup at the end of injection. In the model, the reservoir experiences a maximum pressure buildup of 1,100 psi. This buildup does not exceed 90 percent of the fracture pressure at that location, allowing for safe injection of supercritical CO_2.

Table 3. Injection Details

Plume	Total Sequestered Volume (MMT)	Injection Begins (Year)	Injection Ends (Year)	Injection Total (Years)
Juniper	13*	2025	2043	18
Old Barberry	2	2025	2026	1.5
Barberry	31.3	2025	2050	25
Spirea	10	2025	2040	15
Azalea	45	2025	2055	30
Cypress	15.5	2025	2040	15

*Anticipated volumes after permit modification approval to incorporate Juniper into the EWS Hub

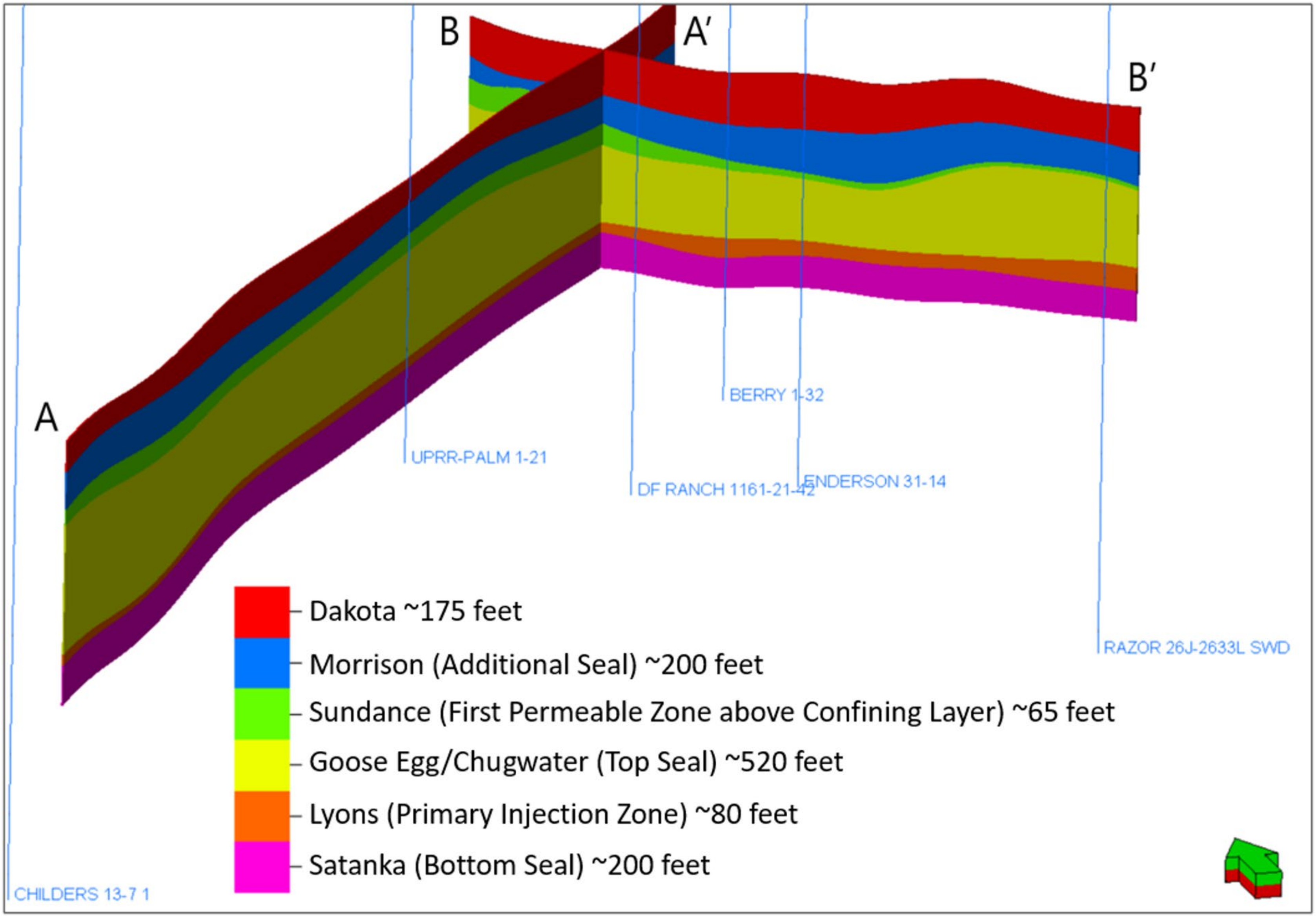

Figure 5. Model Layers.

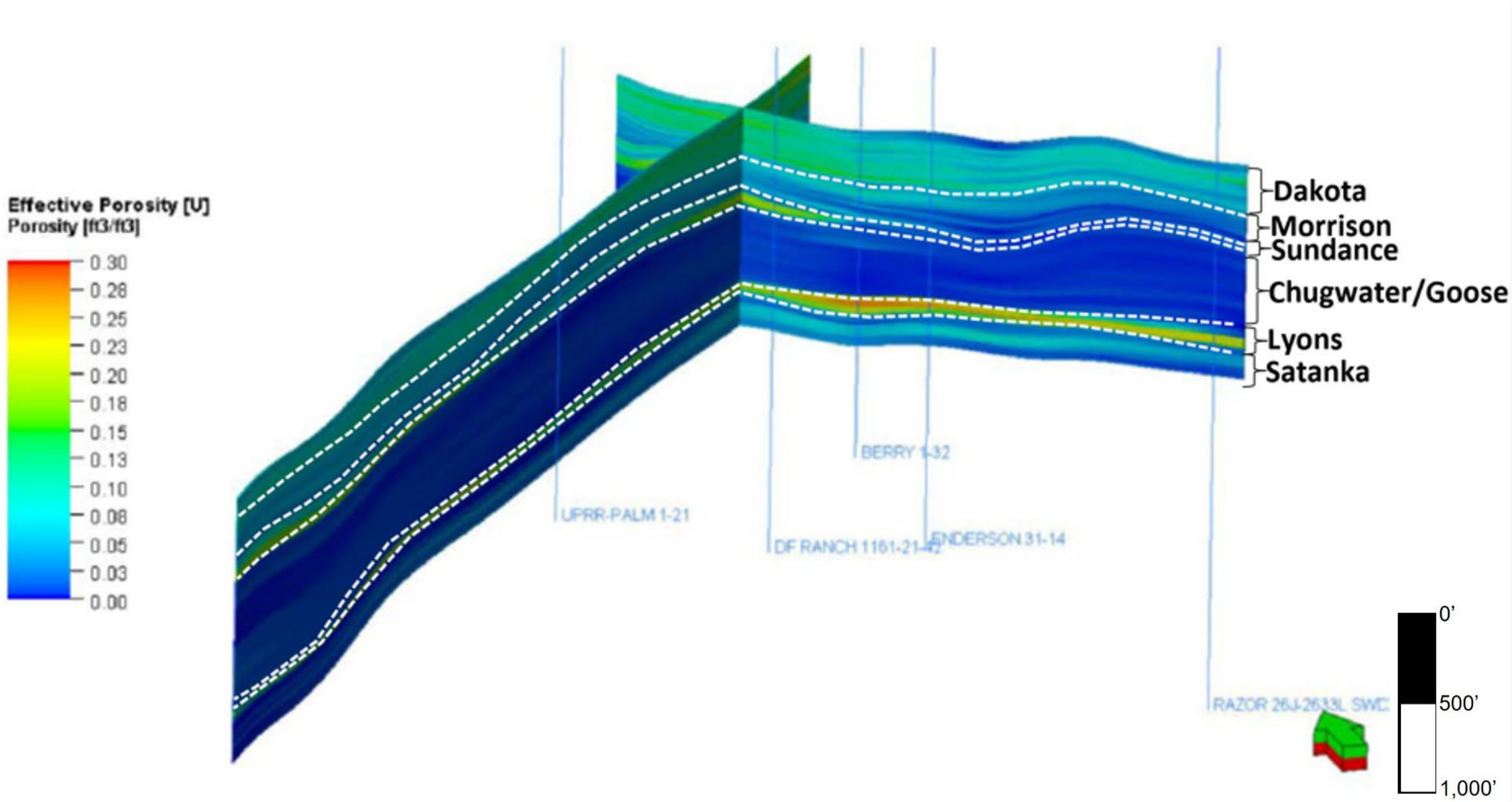

Figure 6. Distribution of Porosity Using Simple Kriging Methodology.

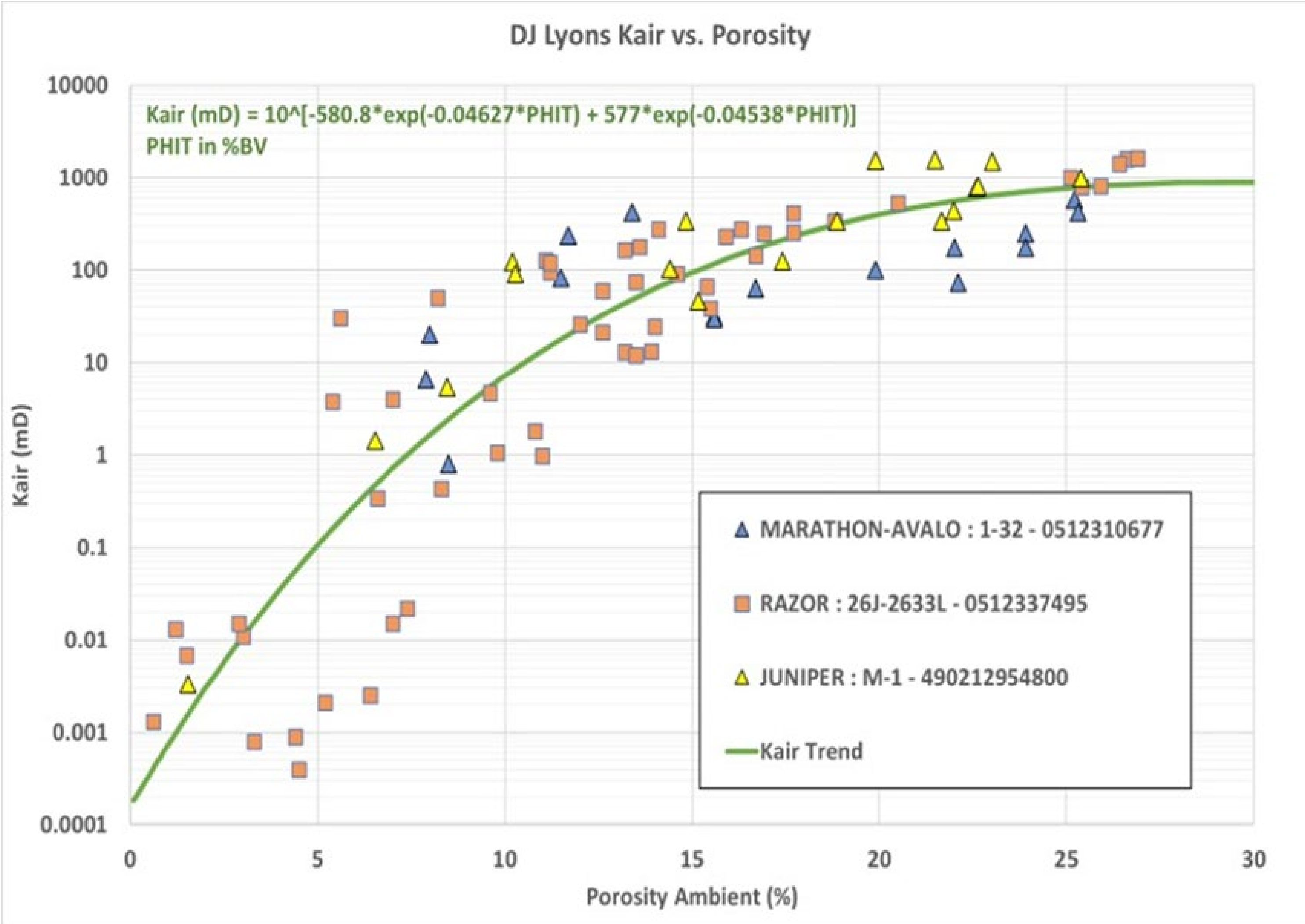

Figure 7. Porosity and Permeability Relationship.

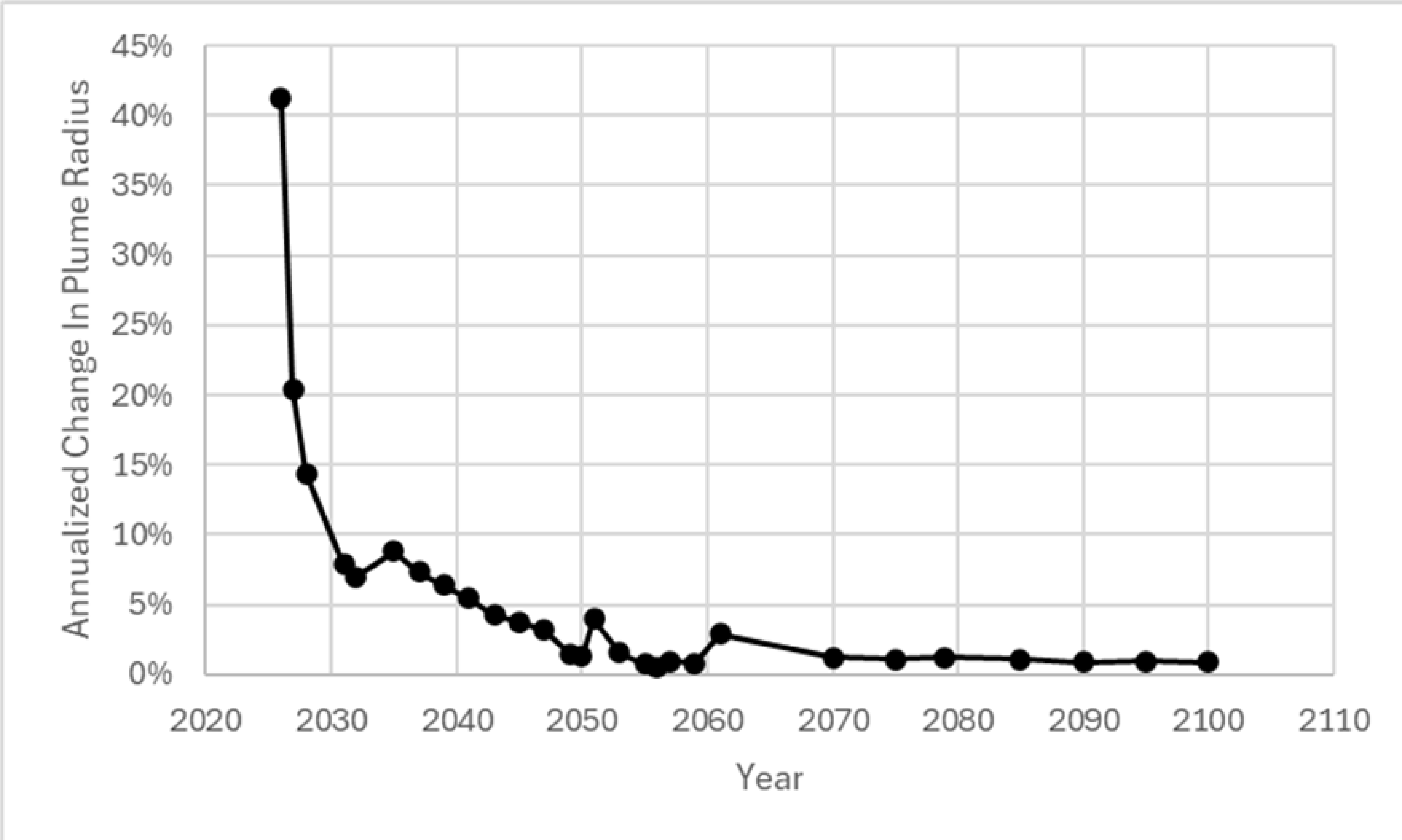

Figure 8. **Modeled Change in Plume Radius, EWS Hub.** Annualized percent change in plume radius from the first year of injection through the end of post-injection site care (site closure), combined plume. Uses the plume area with saturation greater than 2 percent and assumes that the area is a circle.

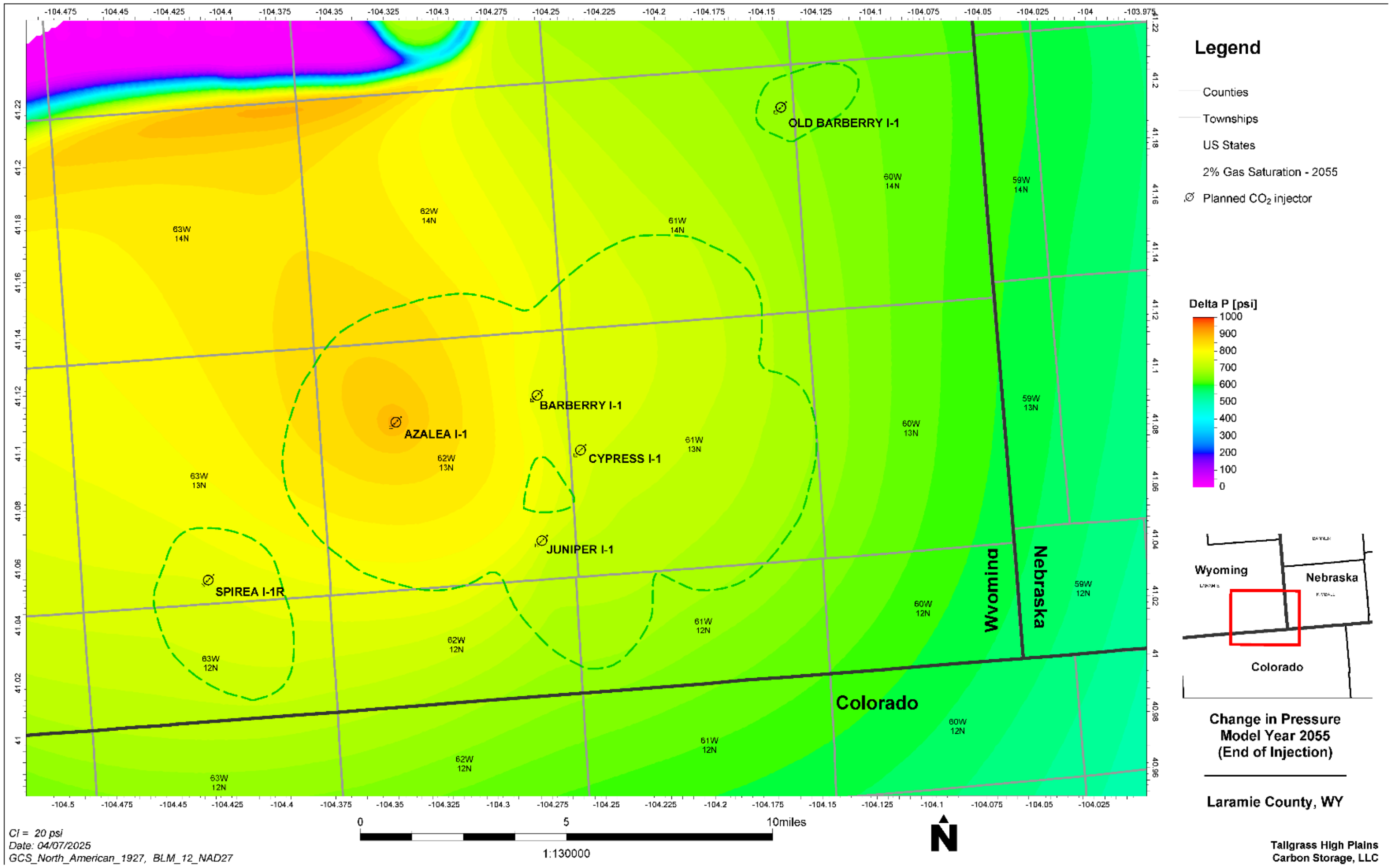

Figure 9. Change in Pressure, Model Year 2055 (End of Injection). Represents the pressure buildup seen within the reservoir after thirty years of injection, year 2025 to 2055.

4. Delineation of the Monitoring Areas

Reservoir simulation modeling (Section 3.4) was used to define the MMA and the active monitoring area (AMA), as described in Sections 4.1 and 4.2. In determining the monitoring areas, the extent of the separate-phase CO_2 plume is equal to the point where the concentration of supercritical-phase CO_2 reaches below 2 percent saturation.

The monitoring time frame will be the same as the post-injection site care (PISC) time frame in the Class VI permit. At the conclusion of the PISC period, a request for discontinuation of Subpart RR reporting will be submitted including a demonstration that current monitoring and modeling show that the cumulative mass of CO_2 reported as sequestered is not expected to migrate in the future or encounter leakage pathways.

4.1 Maximum Monitoring Area

As defined in Subpart RR, the MMA is equal to or greater than the area expected to contain the free-phase CO_2 plume until the CO_2 plume has stabilized plus an all-around buffer zone of at least 0.5 mile. **Figure 10** shows the MMA as defined by the final extent of the stabilized CO_2 plume (50 years after the end of injection) plus a 0.5-mile buffer.

4.2 Active Monitoring Area

The AMA boundary was established by superimposing two areas (40 CFR § 98.449):

- *Area #1:* The area projected to contain the free-phase CO_2 plume at the end of year *t*, plus an all-around buffer zone of 0.5 mile or greater if known leakage pathways extend laterally more than 0.5 mile.
- *Area #2:* The area projected to contain the free-phase CO_2 plume at the end of year $t + 5$.

The AMA boundary was determined for the time period ("*t*") corresponding to 50 years after the end of injection. Area #1 was taken as the plume area plus an all-around buffer zone of 0.5 mile. Area #2 is smaller or equal in all directions; therefore, the final AMA was defined as Area #1 (**Figure 10**).

High Plains has established one AMA boundary for 50 years after injection ends and does not anticipate any expansion of the monitoring area under 40 CFR § 98.448 under the currently planned project operating conditions. Given the definitions used to define the MMA and AMA, the AMA is functionally equivalent to the MMA. Instituting monitoring throughout the entire MMA boundary provides maximum operational flexibility.

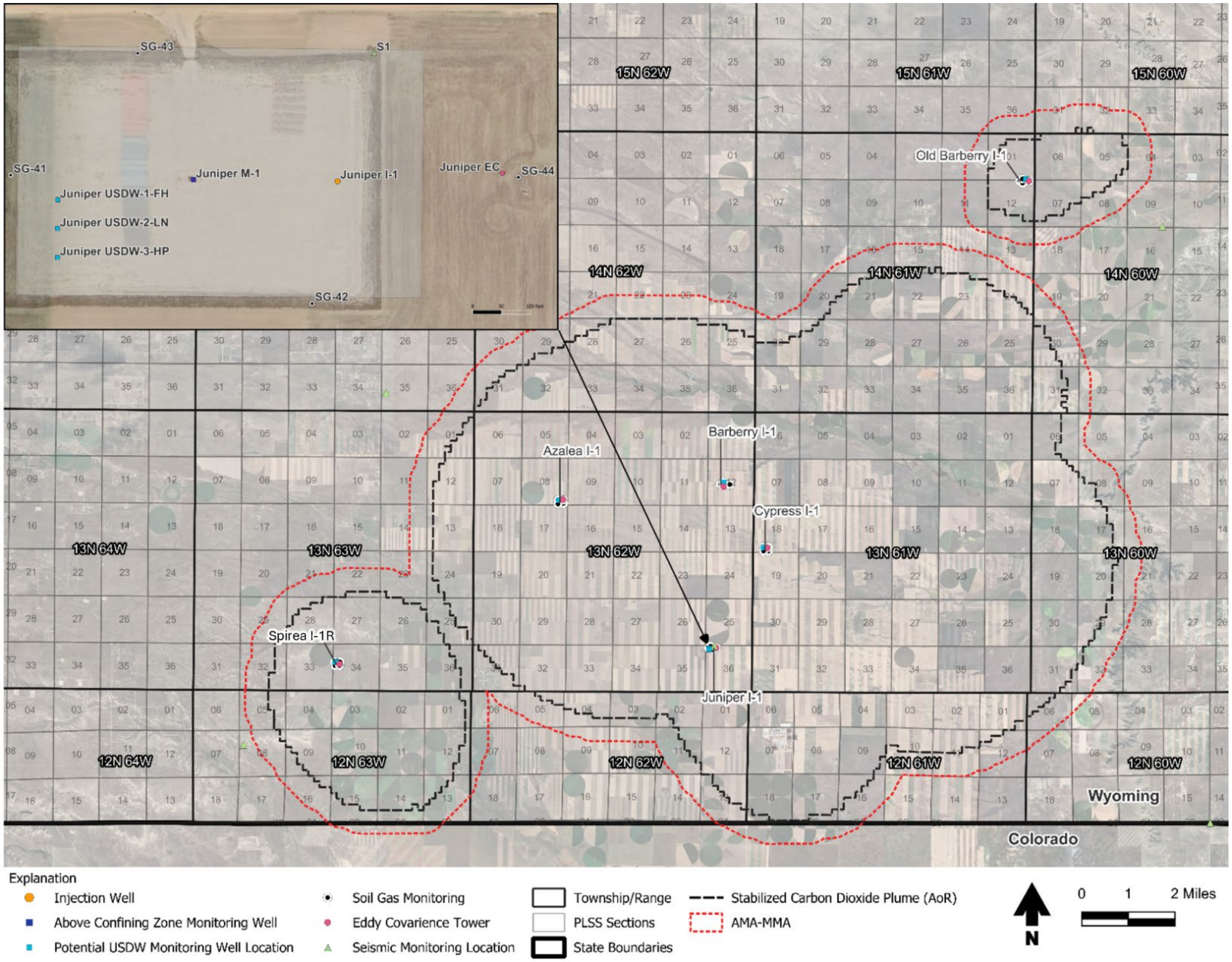

Figure 10. Project Location, Monitoring Locations, and AMA-MMA. Eddy covariance monitoring is discussed in Section 6.4.2 and soil gas monitoring is discussed in Section 6.5.2. Each project will include monitoring locations in orientation similar to that shown for Juniper inset.

5. Identification and Assessment of Potential Surface Leakage Pathways

This section assesses potential pathways for leakage of stored CO_2 to the surface. Monitoring protocols that will be in place for each potential pathway are discussed. Section 6 describes how High Plains will develop the inputs used in the Subpart RR mass-balance equation (Equation RR-12). Any incidents that result in CO_2 leakage through the wellbore and into the atmosphere will be quantified as described in Section 6.

5.1 Pipelines/Surface Equipment

The EWS Hub injector wellheads and the pipelines that transport CO_2 are potential pathways to allow CO_2 to leak to the surface. Leakage is most likely to be the result of aging and use of the surface components over time. The accumulation of wear and tear on the surface components, especially at the flanged connection points, is the most probable cause of the leakage. Another possible cause of leakage is the release of air through relief valves, which are designed to alleviate pipeline overpressure. Leakage can also occur when the surface components are damaged by an accident or natural disaster, causing CO_2 to be released. Therefore, High Plains infers that there is minor potential for leakage via this route.

There is a possibility of fugitive emissions from surface equipment in the event of equipment failure. CO_2 will occasionally need to be vented from surface equipment for operational maintenance. High Plains will monitor and report this CO_2 as part of its reporting requirements under 40 CFR § 98.446(f)(3).

Likelihood: Compliance with applicable pipeline and UIC regulations ensures that likelihood of leakage via this pathway is minor.

Timing*:* Surface component leakage is only a concern during the injection operation phase. Once the injection phase is complete, the surface components will no longer be able to store or transport CO_2, eliminating any potential risk of leakage.

Magnitude*:* Depending on the component's failure mode, the magnitude of the leak can vary greatly. For example, a rapid break or rupture could release large amounts of CO_2 into the atmosphere almost instantly, while a slowly deteriorating seal at a flanged connection could release only a small volume of CO_2 over several hours or days.

Should leakage be detected between the flow meter used to measure injection quantity and the injection wellhead, the mass of released CO_2 will be quantified following the requirements of EPA's GHGRP as referenced in 40 CFR § 98.444(d).

Monitoring*:* Routine field inspection and remote pipeline monitoring will be conducted to detect any potential leakage from pipelines and surface facilities. Continuous surface air monitoring (eddy covariance tower) and semiannual soil gas monitoring will also be in place to detect any surface leakage.

5.2 Wellbores

The project-related injection and monitoring wells will be monitored and maintained to prevent wellbore integrity issues. CO_2 migration could occur along an injection or monitoring well due to a degraded cement bond or corrosion of the casing and completion. Any well that penetrates the injection zone creates a possible migration pathway if the CO_2 plume reaches its position.

All of the injection and monitoring wells involved in the project will be permitted by the State of Wyoming in accordance with Chapter 24 of the WDEQ regulations. High Plains is required to demonstrate to WDEQ that Class VI wellbores do not pose a threat of leakage. Injection well tubing and casing pressures will be monitored continuously. Designs for each injection well are engineered to govern the rate and pressure of CO_2 injection. Pressure monitors on the injection wells are programmed to flag pressures that statistically deviate from design. Leakage on either the inside or outside of the injection wellbore would cause pressure inflections that would be detected through this approach. Injectors will also be monitored with mechanical integrity tests (MITs) and pressure tests to ensure internal and external integrity. If monitoring data lead to identification of a well integrity issue, High Plains will address the issue with corrective actions.

***Likelihood**:* The probability that an existing or new well causes leakage to surface is minor. There are three abandoned wells within the CO_2 plume area that penetrate the injection zone (Cypress M-2 [API# 49-021-29598], Fritz 1 [API #49-021-05033], and UPRR Palm 1-21 [API #49-021-20254], and the injection and monitoring wells are designed, operated, and monitored according to WDEQ regulations. The monitoring program assesses the mechanical integrity of wells to ensure that well integrity is maintained.

***Timing**:* Wellbore leakage risk from project wells will be highest during the injection phase. Risk will decrease after injection, most notably when the injection wells are plugged. The wells will be plugged to WDEQ Class VI standards.

***Magnitude**:* Leakage of CO_2 mass from project wellbores is considered to be negligible for the reasons previously described in this section (Section 5.2).

***Monitoring**:* Wellbore monitoring will include MITs, injection well pressure and rate monitoring, annulus pressure monitoring, surface and near-surface (USDW) monitoring, and inspections. An annual temperature log via wireline will be conducted in each injection well. Permanent installation of distributed temperature sensing (DTS)/distributed acoustic sensing (DAS) fiber behind casing has been executed or planned in all M-1 wells and will allow for future utility should these measurements be needed. Surface air (eddy covariance tower), soil gas, and USDW groundwater monitoring will also be instituted in the vicinity of each injection site.

5.3 Leakage through the Confining Zone

Leakage out of the Lyons Formation could result in elevated concentrations of indicator parameter(s) in groundwater sample(s) or other evidence of CO_2 leakage into shallow groundwater. Fluid leakage risk is low due to the significant thickness (>7,500 feet) of intervening geologic units above the sequestration zone.

High Plains conducted a seismic evaluation of 10 quality 2D lines within the region of the project area to confirm structural mapping and locate any potential faulting or fracturing within the area. The review also incorporated published public domain interpretations of surrounding 3D surveys for Silo Field, North Mustang Field, and Hereford Field. The 3D surveys were not licensed or purchased, as the surveys do not cover the project area. No faults that intersect the CO_2 plume were identified in the 2D seismic evaluation. Faulting was observed in Hereford Field, located 8 to 10 miles south of the EWS Hub project area, with a general orientation of east to west. These subsurface features have been evaluated and do not appear to intersect the modeled plume migration of any of the EWS Hub injection project locations. No transmissive fractures were identified based on wireline image logs of Juniper M-1, Juniper I-1 and Azalea I-1.

Diffusion of CO_2 through the upper confining zone (Goose Egg and Chugwater Formations) is not expected to result in significant loss from the storage reservoir given the low permeability (0.001 mD) and thickness (>480 feet) of these zones.

High Plains will operate the project to ensure containment of CO_2. Leakage will be avoided by ensuring injection well integrity through the following means:

- Conducting well maintenance and MITs
- Maintaining the injection pressure below 90 percent of the fracture gradient of the confining unit
- Assessing monitoring data to ensure competency of the confining layer
- Monitoring the Sundance Formation interval that overlies the confining unit to identify leakage before migration to shallower aquifers

Likelihood: Negligible for the reasons previously described in this section (Section 5.3).

Timing: Leakage risk will be similar via this pathway during the operation and post-injection project phases.

Magnitude: For reasons previously given in this section (Section 5.3), anticipated leakage magnitude is negligible.

Monitoring: Monitoring for leakage through the confining zone will include groundwater monitoring above the confining zone, annual DTS or temperature logs in all injection wells (Juniper I-1, Azalea I-1, Barberry I-1, Old Barberry I-1, Cypress I-1, and Spirea I-1R) and M-1 monitoring wells (Juniper M-1, Azalea M-1, Barberry M-1, Old Barberry M-1, Cypress M-1, and Spirea M-1R), surface air monitoring (eddy covariance tower), soil gas monitoring, and continuous injection well pressure monitoring.

5.4 Induced or Natural Seismic Event

In 2002, WSGS published a report on basic seismological characterization of Laramie County, Wyoming. The study analyzed historical seismicity, short- and long-term seismic probability, nearby faulting, and the Uniform Building Code to improve understating of potential risks of seismicity in Wyoming and their potential to incur damage. Findings from the study suggest that the 2,500-year probabilistic map of Wyoming should be referenced for Laramie County seismic analyses, as the map represents a conservative approach in the interest of public safety. The probabilistic acceleration map, shown in **Figure 11**, illustrates that the EWS Hub project area is located in one of the lowest-risk areas of Wyoming. Historical earthquake data were obtained from the USGS Earthquake Hazards database (USGS, 2022) for recorded earthquakes in the regional vicinity of the EWS Hub project area in the last 100 years. The search results, shown in **Figure 12**, identified no events within 40 miles of the EWS Hub project area.

Average depth of prior seismic hazard in the region based on reviewed historical seismicity has been approximately 3.7 miles, which is significantly deeper than the proposed injection zone.

***Likelihood**:* A probabilistic analysis indicates that the project is located in one of the lowest-risk areas of Wyoming for natural seismicity. Based on project operating conditions, it is highly unlikely that injection operations would ever induce a seismic event.

***Timing**:* Seismicity risk is negligible; however, pressures will be highest during the injection phase of the project. As a result, if induced seismicity were to occur it would likely correspond to the injection phase of the project.

***Magnitude**:* For reasons previously given in this section (Section 5.4), anticipated leakage magnitude is negligible.

***Monitoring**:* High Plains will monitor the USGS Intermountain West Seismic Network for seismic events.

5.5 Lateral Migration

It is highly improbable that injected CO_2 will migrate laterally outside the modeled plume area due to the buoyant properties of supercritical CO_2, the nature of the geologic structure, and the planned injection approach. As displayed in **Figure 3**, there is a structural dip in the injection zone (Lyons Formation) towards the west. This structural dip was accounted for in the computational modeling used to define the area of the stabilized CO_2 plume. Although CO_2 is predicted to migrate in the updip direction, it is slowed and eventually stopped by capillary trapping mechanisms within the predicted boundaries of the AMA-MMA (e.g., Zhao et al., 2014).

***Likelihood**:* Leakage via the lateral migration pathway is not anticipated.

***Timing**:* Although leakage via lateral migration is not anticipated, the risk is greatest when pressures are highest (generally at the end of the injection period).

***Magnitude**:* Magnitude of any leakage is considered negligible, as leakage via lateral migration is not anticipated.

***Monitoring**:* The CO_2 plume will be monitored indirectly through time-lapse 2D seismic, as listed in the Class VI permits. The 2D seismic will be used to detect any risk of lateral migration outside of the EWS Hub modeled plume area.

5.6 Drilling Through the CO_2 Area

It is possible that at some point in the future, drilling through the confining zone and into the Lyons Formation may occur.

Likelihood: The possibility of this activity creating a leakage pathway is extremely low because no oil and gas resources are identified and future well drilling would be regulated by WOGCC (oil and gas wells, Class II injection wells) or WDEQ (Class VI injection wells, all other UIC well classes), and will therefore be subject to requirements that fluids are contained in strata in which they are encountered.

Timing: Leakage via this pathway is not anticipated; however, leakage risk is greatest during future time periods if drilling through the confining zone and into the injection zone were to occur.

Magnitude: Leakage via this pathway is not anticipated to occur; therefore, magnitude of any leakage is considered negligible.

Monitoring: In the state of Wyoming, High Plains has received a unitization order from the WOGCC for a unit area that encompasses the AoR (CO_2 Area), which is now mapped in their records. If there is an application for a permit to drill a well (APD) proposed within a High Plains unit area that is proposed to penetrate the caprock, then High Plains will be notified by either or both the APD applicant and the WOGCC. High Plains will also assess potential drilling activity via the WOGCC online data explorer. In the unlikely event that third party drilling is conducted through the Lyons Formation High Plains will coordinate with the operator regarding wellbore monitoring (Section 5.2) and if the site is accessible wellheads will be added to surface monitoring (Section 5.1).

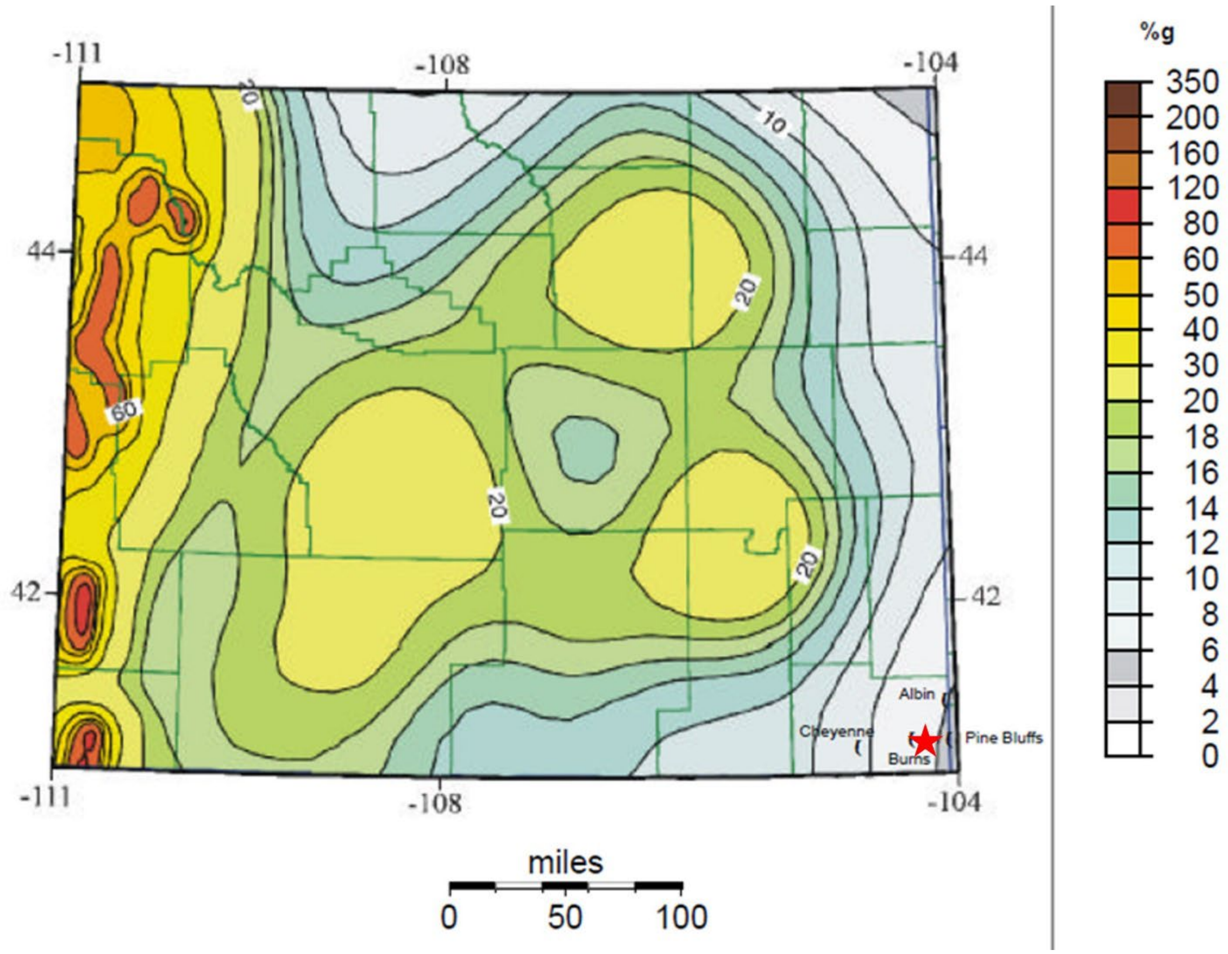

Figure 11. USGS 2,500-Year Probabilistic Acceleration Map of Wyoming. The contours represent a 2 percent probability of exceedance in 50 years. The red star is the approximate location of the EWS Hub project area (USGS, 2002).

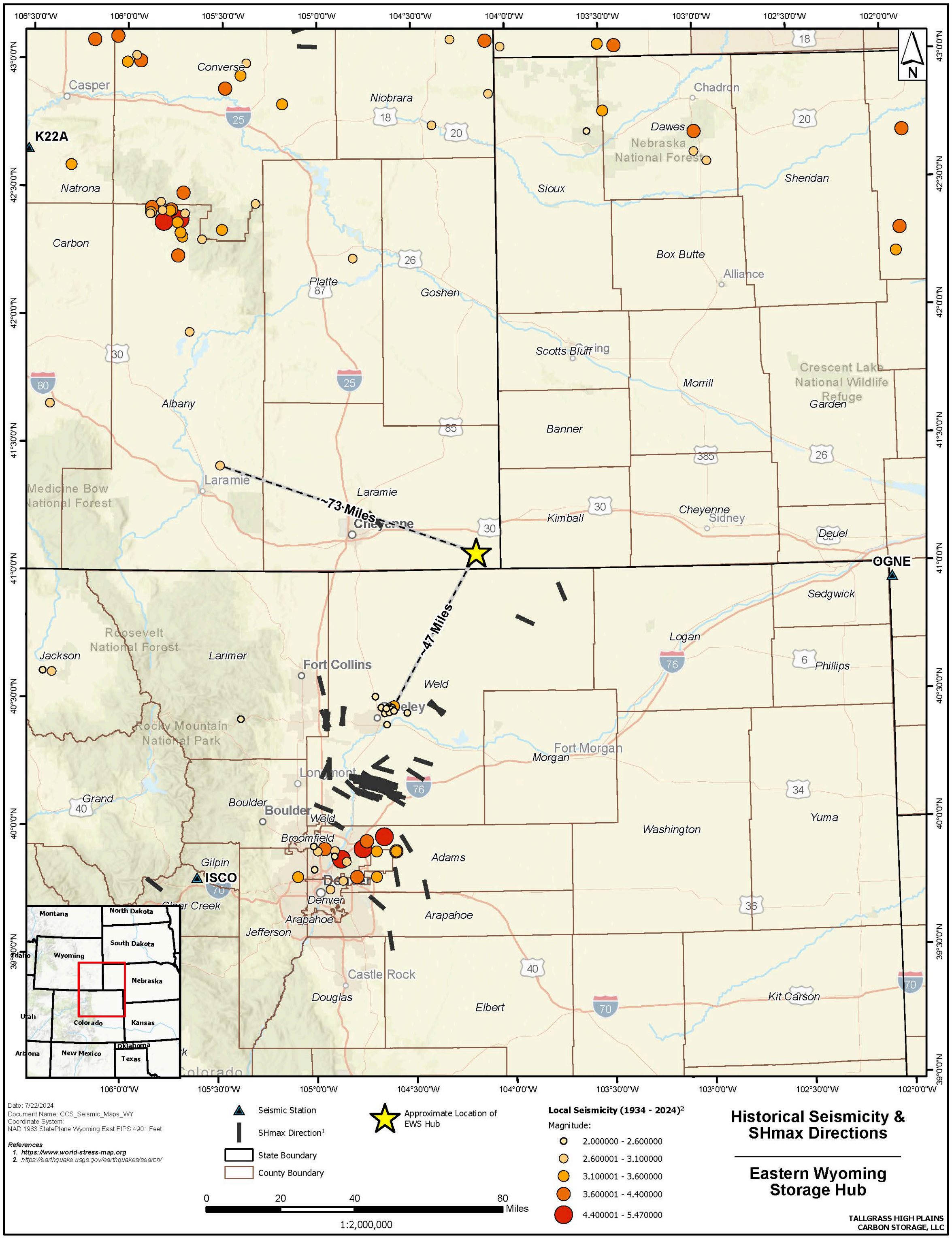

Figure 12. USGS-Reported Earthquakes Over the Past 100 Years. The yellow star is the approximate location of the EWS Hub Project Area.

6. Monitoring and Considerations for Calculating Site-Specific Variables

High Plains will establish a Central Control Center to ensure that personnel have access to the continuous data being acquired during operations. The Central Control Center will receive CO_2 metering data and continuous surface-air monitoring data (eddy covariance tower). **Figure 4a** identifies the meters that will be used to evaluate, monitor, and report on the injection project.

6.1 CO_2 Received

A custody-transfer meter will be used at the CO_2 source (pipeline) to continuously measure the mass and composition of CO_2 received at each EWS Hub injection site. Metering protocols will follow the prevailing industry standard(s).

6.2 CO_2 Injected into the Subsurface

Injected CO_2 associated with geologic sequestration will be calculated using flow meters monitoring the injection wells (Juniper I-1, Spirea I-1R, Azalea I-1, Barberry I-1, Old Barberry I-1, and Cypress I-1).

6.3 CO_2 Produced, Entrained in Products, and Recycled

No CO_2 will be produced, entrained in products, or recycled.

6.4 CO_2 Emitted by Surface Leakage

As discussed in Section 5.1, standard GHGRP procedures as referenced at 40 CFR § 98.444(d) will be used to estimate surface leaks from equipment if leakage is detected between the flow meter used to measure injection quantity and the injection wellhead. In addition, an event-driven process will be used to assess, address, track, and, if applicable, quantify potential CO_2 leakage to the surface. Reporting will be completed in accordance with 40 CFR § 98.446(f)(3).

6.4.1 Injection Well Monitoring

Injection well pressure, temperature, and injection rate will be continuously monitored. If the measurements of injection pressure or rate exceed the specified set-points determined for any of the EWS Hub Injection wells, a data flag will automatically trigger, and field personnel will investigate and resolve the issue. These deviations will be reviewed by well management personnel to determine if CO_2 leakage may be occurring. Deviations are not necessarily indicators of leaks, but they indicate that injection rates and pressures are not conforming to the planned pattern of injection. In many cases, problems are straightforward to fix (e.g., recalibrating a meter), and there is no CO_2 leakage. If issues that are not readily resolved arise, a more detailed investigation and response will be initiated. To quantify leakage to the surface, an estimate of the relevant parameters (e.g., the rate, concentration, and duration of leakage) will be made to quantify the leakage mass. Depending on specific circumstances, these determinations may rely on engineering estimates. An example methodology that may be used for early detection and rate estimation of CO_2 wellbore leakage, based on temperature analysis, is outlined in Mao et al. (2017).

6.4.2 Broad Continuous Surface Air Monitoring

Broad aerial surface air monitoring will be conducted with permanently installed eddy covariance towers (**Figure 10**). The eddy covariance towers will consist of a solar-powered 3D sonic anemometer and open-path gas analyzer. The tower will be installed downwind of the prevailing wind direction from the injection wells and injection zone monitoring wells. Annual average prevailing wind direction in the vicinity is from the west (WRCC, 2022; Cheyenne AP KCYS station). All eddy covariance tower locations are chosen to be downwind (east) of the injection wells and injection zone monitoring wells and in a location with access for equipment installation and servicing.

Monitoring equipment will be installed at a height of approximately 4 to 5 meters (13 feet). In general, the upwind distance represented by the tower height can be determined by the 1:100 rule. In this case, with a 4-meter tower height, the majority of measured flux will come from an oval-shaped area from near the tower to 400 meters (1,312 feet) upwind (Burba, 2013).

Gas emission rate is calculated from air density, vertical wind speed, and dry CO_2 mole fraction. Air density fluctuation is assumed to be negligible (Burba, 2013). Wind speed will be measured with the sonic anemometer. CO_2 mole fraction will be measured with the gas analyzer. Eddy covariance tower instrumentation will be installed consistent with protocols listed in Burba (2013). The sonic anemometer will be a Campbell Scientific CSAT3 or equivalent. The CO_2 gas analyzer will be a LI-COR Biosciences LI-7500A or equivalent. The gas analyzer will be positioned at or slightly below the sonic anemometer level, with a separation distance less than 20 centimeters. Vibration will be minimized by the use of several guy wires attached at the middle of the tower.

Manual cleaning of the gas analyzer will be performed on an as-needed basis when anomalous readings or excessive zero-drift in the data is observed. Factory calibration is assumed to be stable for at least several years, and will be checked once every six months as a precaution.

Data processing will be conducted with the automated open-source package EddyPro (LI-COR Biosciences, 2021), and will be presented as hourly averaged CO_2 concentrations and gas emission rates. Detection of anomalous and increasing CO_2 concentrations will lead to eddy covariance tower equipment testing and further targeted surface air investigation (described in Sections 6.4.3 and 6.4.4). In the event of leakage detected by the eddy covariance tower, mass will be calculated based on the increased CO_2 subsurface flux rate.

6.4.3 Targeted Point Source Monitoring

Targeted monitoring of potential CO_2 point sources will be conducted at injection wellheads, as well as at pipelines/delivery systems within the MMA. Three artificial penetrations within the AoR penetrate the confining zone. Remedial work will be completed on Fritz 1 prior to injection. UPRR-Palm 21 contains adequate cement plugs across relevant formations and does not require corrective action. Cypress M-2 was drilled by High Plains and has since been plugged back to the surface.

Intermittent point-source monitoring will occur at a minimum of once per quarter at the injection wells and above confining zone monitoring wells, and once per year at other locations. Targeted point-source monitoring will also be triggered by indications of leakage from eddy covariance monitoring and/or other monitoring results. Point-source measurement will be conducted with a portable non-dispersive infrared (NDIR) CO_2 meter. CO_2 concentration, relative humidity, and temperature will be recorded at each location and collected with an attached USB Data Logger. Measurement location will be recorded with a handheld global positioning system (GPS) unit, and corresponding wellhead or other infrastructure location will also be recorded. Leakage will be quantified based on leak flow rate and CO_2 gas concentration.

6.4.4 Inspection and Leak Detection

High Plains will perform inspection of wellheads, valves, and piping, including the following:

- Field inspections will be conducted on a routine basis by field personnel. Field personnel will be trained to identify visual indications of leaking CO_2 and other potential problems in the field.
- Injection well wellheads will be inspected on a quarterly basis, which will include the following and will be recorded on a well inspection data sheet:
    - Visual inspection for general condition of the wellhead system, including for external corrosion/coating damage and mechanical damage
    - Inspection of all bolts for needed replacement
    - Reenergizing wellhead seals as needed, reapplying screw and nut torque as needed, replacement of any needed fittings, packing, hand wheels, pins, or bearings
    - Visual inspection of all pipelines within 100 feet of the injection wells
    - Identification of faulty valves or gasket leaks
    - Verification of adequate fittings for wireline equipment and CO_2 injection
    - CO_2 gas analysis with a handheld meter at the wellhead and pipelines within 100 feet of the wellhead (pSense High Accuracy portable CO_2 meter or equivalent, with CO_2 measurement range of 0 to 9,999 ppm and accuracy of 30 ppm).
- Instrumentation will be installed on pipelines and facilities that allow the 24/7 operations staff to monitor the process and potentially spot leaks. High Plains will use a supervisory control and data acquisition (SCADA) software system to implement operational control decisions on a real-time basis throughout the project area to assure the safety of field operations and compliance with monitoring and reporting requirements in existing permits. Both manual and automatic shutdowns will be installed in the MMA to ensure that leaks are addressed in a timely manner. Potential leakage identified with dynamic modeling will be assessed in the field, including by visual inspection and gas analysis, as well as by soil gas analysis in the case of buried pipelines.
- Biannual testing of surface safety valve systems will be conducted to ensure their ability to hold anticipated pressure. Surface valve testing will be consistent with API Specification 6AV1. Annual testing of master valve and wellhead isolation valves will be conducted for proper function and verification of the valves' ability to isolate the well.

Upon finding that a surface safety valve is inoperable, High Plains will immediately shut in the well and repair the valve within 90 days, or will determine an appropriate alternative time frame for testing a valve or addressing an inoperable surface or subsurface safety valve. Documentation of all inspections, tests, and results will be maintained by High Plains and will be available for EPA review during the active life of the project.

6.5 Monitoring for Potential Leakage from the Injection Zone

In addition to the surface-based monitoring previously described in Section 6.4, additional monitoring for potential leakage from the subsurface will include groundwater and soil gas monitoring. Annual temperature logging will occur in all EWS Hub injection wells.

6.5.1 Groundwater Monitoring

Monitoring wells to directly measure pressure, temperature, and fluid composition will be dedicated to geologic sequestration. These dedicated wells will monitor above the confining zones in the overlying USDWs (above confining zone monitoring wells Juniper M-1, Azalea M-1, Barberry M-1, Cypress M-1, Spirea M-1R, Old Barberry M-1; pad-associated shallow aquifer wells USDW-1, USDW-2 and USDW-3; locations shown on **Figure 10**). Baseline analysis will be established for each of these wells. Any deviation from the baseline analysis will be assessed for potential indications of leakage. CO_2 leakage rates will be quantified based on measured increases in CO_2 concentration in formation fluids above the AoR.

Monitoring well locations are shown on **Figure 10** and are listed in **Appendix A**. Monitoring well details including chemistry monitoring parameters are listed in **Appendix B**. Monitoring well data collection procedures will be consistent with protocols listed in the Class VI permit application.

6.5.2 Soil Gas Monitoring

High Plains will perform soil gas monitoring including sampling of CO_2 and ratio of CO_2 to methane (CH_4) during the injection period. Soil gas composition monitoring will also be performed prior to injection to establish a baseline.

Soil gas monitoring will be performed with the portable flux accumulation chamber method, which offers the advantage of flexibility in sampling locations if leak detection survey monitoring is required, as well as real-time data collection. Baseline soil gas sampling locations are shown in **Figure 10**. If potential leakage is detected during the injection phase, soil gas monitoring locations will be determined based on the available data regarding the location of the potential leakage. In the case of potential leakage via an active well or buried pipeline, soil gas flux will be assessed within 10 feet of the wellbore/pipeline. For potential leakage indicated by broad aerial monitoring, soil gas measurements will be located within the area indicated by the atmospheric monitoring data.

Soil gas monitoring will be conducted with a portable self-powered flux accumulation chamber (LI-COR 8200-01S or equivalent) paired with a CO_2 and CH_4 gas analyzer (LI-7810 CH_4/CO_2/H_2O Trace Gas Analyzer or equivalent). The flux chamber computes real-time soil gas flux. Data will be digitally collected and integrated with GPS coordinates, soil moisture, and soil temperature (Stevens HydraProbe or equivalent). Soil gas flux will be measured at each location until steady-state flux is observed in the real-time observed data. Flux-accumulation chamber collars will be field deployed at each sampling location at least 24 hours prior to sample collection. Data will be processed and digitally stored with the SoilFluxPro software or equivalent. CO_2 flux and gas ratios will be compared to data collected during the baseline period to evaluate potential atmospheric leakage through the soil profile.

6.6 CO_2 Plume Tracking

The extent of the CO_2 plume will be monitored using 2D seismic surveys to understand CO_2 saturation changes through time. The existing seismic surveys, 2D and 3D, will establish a baseline view of the injection interval. One survey will be performed during the injection phase to confirm plume movement and direction. One survey will be performed to confirm plume stabilization after downhole pressure and temperature measurements indicate that the plume has stabilized. The results will be compared to those from the baseline surveys to determine the extent of the CO_2 plumes within the project area.

6.7 Seismicity Monitoring

High Plains will monitor the Intermountain West Seismic Network for seismic events. Historical seismicity within the area will be accounted for in the baseline assessment.

6.7.1 Baseline Analysis

Historical seismicity data from the Intermountain West Seismic Network will be reviewed to establish the baseline. These data will help establish historical natural seismic event depth, magnitude, and frequency to distinguish between naturally occurring seismicity and induced seismicity resulting from CO_2 injection.

6.7.2 Seismic Monitoring Analysis

Throughout the injection phase, monitoring for natural and induced seismic activity will be performed by monitoring data from the USGS Intermountain West Seismic Network.

6.8 Vented Emissions of CO_2 from Surface Equipment

Monitoring efforts will evaluate and estimate leaks from equipment and vented CO_2 as required under 40 CFR § 98.444(d).

7. Approach for Establishing the Expected Baselines

High Plains will use the Central Control Center to continuously monitor operating parameters and to identify any excursions from normal operating conditions that may indicate leakage of CO_2. The following bullets describe the High Plains strategy for collecting baseline information:

- *Visual Inspection:* High Plains field personnel conduct frequent periodic inspections of all surface equipment, providing opportunities to ensure facility and well integrity as described in Section 6.4.

- *Handheld CO_2 Monitors:* High Plains will perform leakage detection at wellheads, valves, and piping in the MMA as defined in Section 6.4.
- *Field Sampling:* Field sampling activities to monitor CO_2 at each EWS Hub injection well will include periodic well (groundwater and gas) and atmospheric sampling from the MMA around the injection wells. Pre-injection data will be collected for one year prior to injection to establish baselines.
- *Continuous Parameter Monitoring:* The Central Control Center will monitor injection rates, pressures, and composition on a continuous basis. High and low set points are programmed, and engineering and operations are alerted if a parameter is outside the allowable window. If a parameter is outside the allowable window, this will trigger further investigation to determine if the issue poses a leak threat.
- *Well Surveillance:* High Plains will adhere to the requirements of WDEQ governing the construction, operation, and closing of a Class VI well, including the requirement for testing and monitoring to ensure mechanical integrity. High Plains routine operation and maintenance procedures for all EWS Hub injection wells will ensure frequent periodic inspection of the wells and opportunities to detect leaks and implement corrective action.
- *Seismic Monitoring Stations:* High Plains will perform seismic monitoring as listed in Section 6.7, including pre-injection data collection from the USGS Intermountain West Seismic Network to establish baselines.

8. Considerations for Site-Specific Variables for the Mass Balance Equations

The following subsections describe how each element of the mass-balance equation (Equation RR-12) will be calculated.

8.1 Mass of CO_2 Received

High Plains will use Equation RR-1 as indicated in 40 CFR § 98.443 to calculate the mass of CO_2 received from the custody-transfer meter immediately downstream of the source (pipeline).

$$CO_{2T,r} = \sum_{p=1}^{4} (Q_{r,p} - S_{r,p}) * C_{CO_{2,p,r}} \qquad \text{(Eq. RR-1)}$$

where $CO_{2T,r}$ = Net annual mass of CO_2 received through flow meter r (metric tons)

$Q_{r,p}$ = Quarterly mass flow through a receiving flow meter r in quarter p (metric tons)

$S_{r,p}$ = Quarterly mass flow through a receiving flow meter r that is redelivered to another facility without being injected into your well in quarter p (metric tons)

$C_{CO_{2,p,r}}$ = Quarterly CO_2 concentration measurement in flow for flow meter r in quarter p (wt. percent CO_2, expressed as a decimal fraction)

p = Quarter of the year

r = Receiving flow meter

Given the method by which High Plains will receive CO_2 and the requirements of 40 CFR § 98.444(a):

- All delivery to the EWS Hub Injection Facilities is used (or vented if needed), so quarterly flow redelivered, $S_{r,p}$, is zero (0), and will not be included in the equation.
- Quarterly CO_2 concentration will be taken from the gas measurement database.

High Plains will sum to total mass of CO_2 received using Equation RR-3 in 40 CFR § 98.443:

$$CO_2 = \sum_{r=1}^{R} CO_{2T,r} \text{ (Eq. RR-3)}$$

where CO_2 = Total net annual mass of CO_2 received (metric tons)

$CO_{2T,r}$ = Net annual mass of CO_2 received (metric tons) as calculated in Equation RR-1 for flow meter r

r = Receiving flow meter

8.2 Mass of CO_2 Injected into the Subsurface

Mass of CO_2 injected into the subsurface at each injection well will be calculated with Equation RR-4:

$$CO_{2,u} = \sum_{p=1}^{4} Q_{p,u} * C_{CO_{2,p,u}} \text{ (Eq. RR-4)}$$

where $CO_{2,u}$ = Annual CO_2 mass injected (metric tons) as measured by flow meter u

$Q_{p,u}$ = Quarterly mass flow rate measurement for flow meter u in quarter p (metric tons per quarter)

$C_{CO2,p,u}$ = Quarterly CO_2 concentration measurement in flow for flow meter u in quarter p (wt. percent CO_2, expressed as a decimal fraction)

p = Quarter of the year

u = Flow meter

Aggregated injection at all injection wells will be calculated with Equation RR-6:

$$CO_{2I} = \sum_{u=1}^{U} CO_{2,u} \text{ (Eq. RR-6)}$$

where CO_{2I} = Total annual CO_2 mass injected (metric tons) through all injection wells

$CO_{2,u}$ = Annual CO_2 mass injected (metric tons) as measured by flow meter u

u = Flow meter

8.3 Mass of CO_2 Emitted by Surface Leakage

High Plains will calculate and report the total annual mass of CO_2 emitted by surface leakage using an approach that is tailored to specific leakage events and relies on standard GHGRP procedures as listed at 40 CFR § 98.444(d). Operators will be prepared to address the potential for leakage in a variety of settings. Estimates of the amount of CO_2 leaked to the surface will depend on several site-specific factors, including measurements, engineering estimates, and emission factors, depending on the source and nature of the leakage.

The process for quantifying leakage will entail using industry standard engineering principles or emission factors. Some approaches for quantification of potential types of leaks that may occur are discussed in Section 6.4. In the event leakage to the surface occurs, the quantity and leakage amounts will be reported, and records will be retained that describe the methods used to estimate or measure the mass leaked as reported in the annual Subpart RR report.

Equation RR-10 in 40 CFR § 98.443 will be used to calculate and report the mass of CO_2 emitted by surface leakage:

$$\mathrm{CO}_{2E} = \sum_{x=1}^{X} \mathrm{CO}_{2,x} \text{ (Eq. RR-10)}$$

where CO_{2E} = Total annual CO_2 mass emitted by surface leakage (metric tons) in the reporting year

$CO_{2,x}$ = Annual CO_2 mass emitted (metric tons) at leakage pathway x in the reporting year

x = Leakage pathway

8.4 Mass of CO_2 Sequestered in Subsurface Geologic Formations

Equation RR-12 in 40 CFR § 98.443 will be used to calculate the mass of CO_2 sequestered in subsurface geologic formations in the reporting year as follows:

$$\mathrm{CO}_2 = \mathrm{CO}_{2I} - \mathrm{CO}_{2E} - \mathrm{CO}_{2\,\mathrm{FI}} \text{ (Eq. RR-12)}$$

where CO_2 = Total annual CO_2 mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year

CO_{2I} = Total annual CO_2 mass injected (metric tons) in the well or group of wells covered by this source category in the reporting year

CO_{2E} = Total annual CO_2 mass emitted (metric tons) by surface leakage in the reporting year

CO_{2FI} = Total annual CO_2 mass emitted (metric tons) from equipment leaks and vented emissions of CO_2 from equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead, for which a calculation procedure is provided in Subpart W

Figure 4a illustrates that CO_2 supplied for geological storage will be metered between the CO_2 source and the injection meter.

8.5 Cumulative Mass of CO_2 Reported as Sequestered in Subsurface Geologic Formations

A sum of the total annual mass obtained using RR-12 in 40 CFR § 98.443 will be used to calculate the cumulative mass of CO_2 sequestered in subsurface geologic formations.

8.6 Data Reporting

High Plains will report all data per regulations listed in 40 CFR § 98.446, including the CO_2 facility source(s) to the pipeline per the following categories: (1) CO_2 production wells, (2) electric generating unit, (3) ethanol plant, (4) pulp and paper mill, (5) natural gas processing, (6) gasification operations, (7) other anthropogenic source, (8) discontinued enhanced oil and gas recovery project, or (9) unknown.

9. MRV Implementation Schedule

The final MRV plan will be implemented upon receiving approval from the EPA, and no later than the day after the day on which the plan becomes final, as described in 40 CFR § 98.448(c). After all the injection wells are drilled, High Plains will reevaluate the MRV plan and, if any modifications are a material change per 40 CFR § 98.448(d)(1), High Plains will submit a revised MRV plan as required by 40 CFR § 98.448(d). The injection wells that have been drilled as of this MRV plan date include the Juniper I-1, Azalea I-1, Spirea I-1R and Barberry I-1.

10. Quality Assurance and Quality Control

High Plains will meet the monitoring and quality assurance and quality control (QA/QC) requirements of 40 CFR § 98.444 of Subpart RR.

10.1 Greenhouse Gas Monitoring

As required by 40 CFR § 98.3(g)(5)(i), High Plains internal documentation regarding the collection of emissions data includes the following:

- Identification of positions of responsibility (i.e., job titles) for collection of the emissions data
- Explanation of the processes and methods used to collect the necessary data for the greenhouse gas (GHG) calculations
- Description of the procedures and methods that are used for quality assurance, maintenance, and repair of all continuous monitoring systems, flow meters, and other instrumentation used to provide data for the GHGs reported

10.2 Measurement of CO_2 Concentration

All measurements of CO_2 concentrations of any CO_2 quantity will be conducted according to an appropriate standard method published by a consensus-based standards organization or an industry standard practice. All measurements of CO_2 concentrations of CO_2 received will meet the requirements of 40 CFR § 98.444(a)(3).

10.3 Measurement of CO_2 Mass

Daily CO_2 received is recorded by totalizers on the mass flow meters on each of the pipelines listed in Section 8 using accepted flow calculations for CO_2. Daily CO_2 injected is recorded by totalizers on the mass flow meters using accepted flow calculations for CO_2.

High Plains does not produce CO_2 at the surface facility; therefore, no QA/QC procedures are necessary for produced CO_2 mass.

As required by 40 CFR § 98.444(d), High Plains will follow the monitoring and QA/QC requirements specified in the GHGRP for equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead.

As required by 40 CFR § 98.444(e), High Plains will ensure that:

- All flow meters are operated continuously except as necessary for maintenance and calibration.
- All flow meters used to measure quantities reported are calibrated according to the calibration and accuracy requirements in 40 CFR § 98.3(i), Subpart A of the GHGRP.
- All measurement devices are operated according to an appropriate standard method published by a consensus-based standards organization or an industry standard practice. Consensus-based standards organizations include, but are not limited to, the following:
    - ◇ ASTM International
    - ◇ American National Standards Institute (ANSI)
    - ◇ American Gas Association (AGA)
    - ◇ American Society of Mechanical Engineers (ASME)
    - ◇ API
    - ◇ North American Energy Standards Board (NAESB)
- All flow meter calibrations performed are National Institute of Standards and Technology (NIST) traceable.

10.4 QA/QC Procedures

High Plains will adhere to all QA/QC requirements in Subpart RR as required in the development of this MRV plan under Subpart RR. Any measurement devices used to acquire data will be operated and maintained according to the relevant industry standards.

10.5 Estimating Missing Data

High Plains will estimate any missing data according to the following procedures in 40 CFR § 98.445, Subpart RR of the GHGRP, as required:

- A quarterly flow rate of CO_2 received that is missing would be estimated using invoices, purchase statements, or a representative flow rate value from the nearest previous time period.

- A quarterly CO_2 concentration of a CO_2 stream received that is missing would be estimated using invoices, purchase statements, or a representative concentration value from the nearest previous time period.
- A quarterly quantity of CO_2 injected that is missing would be estimated using a representative quantity of CO_2 injected from the nearest previous period of time at a similar injection pressure.
- For any values associated with CO_2 emissions from equipment leaks and vented emissions of CO_2 from surface equipment at the facility that are reported in Subpart RR, standard GHGRP missing data estimation procedures specified in 40 CFR § 98.445(e) would be followed.

10.6 Revisions of the MRV Plan

High Plains will revise the MRV plan as needed for any of the following reasons:

- To reflect changes in monitoring instrumentation and quality assurance procedures
- To improve procedures for the maintenance and repair of monitoring systems to reduce the frequency of monitoring equipment downtime
- To address additional requirements as directed by U.S. EPA or the State of Wyoming

If any operational changes constitute a material change as described in 40 CFR § 98.448(d)(1), High Plains will submit a revised MRV plan addressing the material change.

11. Records Retention

High Plains will meet the recordkeeping requirements of paragraph 40 CFR 98.3(g), Subpart A of the GHGRP. As required by 40 CFR § 98.3(g) and 40 CFR § 98.447, High Plains will retain the following documents:

- A list of all units, operations, processes, and activities for which GHG emissions were calculated.
- The data used to calculate the GHG emissions for each unit, operation, process, and activity. These data include:
  - The GHG emissions calculations and methods used
  - Analytical results for the development of site-specific emissions factors, if applicable
  - The results of all required analyses
  - Any facility operating data or process information used for the GHG emission calculations
- The annual GHG reports.
- Missing data computations. For each missing data event, High Plains will retain a record of the cause of the event and the corrective actions taken to restore malfunctioning monitoring equipment.
- A copy of the most recent revision of this MRV plan.

- The results of all required certification and quality assurance tests of continuous monitoring systems, fuel flow meters, and other instrumentation used to provide data for the GHGs reported.
- Maintenance records for all continuous monitoring systems, flow meters, and other instrumentation used to provide data for the GHGs reported.
- Quarterly records of CO_2 received, including mass flow rate of contents of container at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- Quarterly records of injected CO_2 including mass flow at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- Annual records of information used to calculate the CO_2 emitted by surface leakage from leakage pathways.
- Annual records of information used to calculate the CO_2 emitted from equipment leaks and vented emissions of CO_2 from equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead.
- Any other records as specified for retention in this EPA-approved MRV plan.

References

Bethke, C.M. and M.K. Lee. 1994. Groundwater flow, late cementation, and petroleum accumulation in the Permian Lyons sandstone. *Denver Basin: AAPG Bulletin* 78(2): 221-241.

Burba, G. 2013. *Eddy covariance method for scientific, industrial, agricultural and regulatory applications: A field book on measuring ecosystem gas exchange and areal emission rates*. LI-Cor Biosciences.

Clayton, J.L. and P.J. Swetland. 1980. Petroleum Generation and Migration in Denver Basin. AAPG Bulletin (1980) 64 (10) p.1613-1633.

LI-COR Biosciences. 2021. Eddy covariance processing software (Version 7.0.8) [Software]. Available at <www.licor.com/EddyPro>.

Love J.D. and A.C. Christiansen. 1985. *Geologic map of Wyoming*. U.S. Geological Survey. Scale 1:500,000.

Lowry, M. and M. Crist. 1967. *Geology and ground-water resources of Laramie County, Wyoming*. U.S. Geological Survey Report.

Mao, Y., M Zeidouni, I. Duncan, 2017. Temperature analysis for early detection and rate estimation of CO_2 wellbore leakage, International Journal of Greenhouse Gas Control, Volume 67, 2017, https://doi.org/10.1016/j.ijggc.2017.09.021.

Sonnenberg, S.A. and R.J. Weimer. 1981. Tectonics, sedimentation, land petroleum potential, northern Denver basin, Colorado, Wyoming, and Nebraska. *Colorado School of Mines Quarterly* (76): 35–36.

Swanson, B.F. 1981. A simple correlation between permeabilities and mercury capillary pressures. *Journal of Petroleum Technology* 33(12): 2498–2504.

Taucher, P., T.T. Bartos, and K.G. Taboga. 2013. *Platte River Basin water plan update, level I (2009–2013), available groundwater determination*. WSGS Technical Memorandum 5.

U.S. Geological Survey (USGS). 2022. Earthquake Hazards Program. <https://earthquake.usgs.gov/>.

Western Regional Climate Center (WRCC). 2023. Prevailing wind direction. <https://wrcc.dri.edu/Climate/comp_table_show.php?stype=wind_dir_avg>. Accessed June 2023.

Zhao, B., C.W. MacMinn, and R. Juanes. 2014. Residual trapping, solubility trapping and capillary pinning complement each other to limit CO_2 migration in deep saline aquifers. Energy Procedia 63, p.3833-3839.

Appendix A Project Well List

Injection wells	Azalea I-1 Old Barberry I-1 Barberry I-1 Cypress I-1 Spirea I-1R Juniper I-1	
Monitoring wells	Azalea M-1	Above confining-zone monitoring
	Azalea USDW-1-FH Azalea USDW-2-LN Azalea USDW-3-HP	USDW monitoring
	Barberry M-1	Above confining-zone monitoring
	Barberry USDW-1-FH Barberry USDW-2-LN Barberry USDW-3-HP	USDW monitoring
	Old Barberry M-1	Above confining-zone monitoring
	Old Barberry USDW-1-FH Old Barberry USDW-2-LN Old Barberry USDW-3-HP	USDW monitoring
	Cypress M-1	Above confining-zone monitoring
	Cypress USDW-1-FH Cypress USDW-2-LN Cypress USDW-3-HP	USDW monitoring
	Spirea M-1R	Above confining-zone monitoring
	Spirea USDW-1-FH Spirea USDW-2-LN Spirea USDW-3-HP	USDW monitoring
	Juniper M-1	Above confining-zone monitoring
	Juniper USDW-1-FH Juniper USDW-2-LN Juniper USDW-3-HP	USDW Monitoring

Appendix B Groundwater Monitoring Details

Table B-1. Project Monitoring of Groundwater Quality and Geochemical Changes Above the Confining Zone

Activity	Location(s)	Method	Analytical Technique	Pre-injection Baseline	Operation Period	PISC Period	Purpose
Fluid sampling above confining zone	Azalea USDW-1-FH Azalea USDW-2-LN Azalea USDW-3-HP Azalea M-1 Barberry USDW-1-FH Barberry USDW-2-LN Barberry USDW-3-HP Barberry M-1 Old Barberry USDW-1-FH Old Barberry USDW-2-LN Old Barberry USDW-3-HP Old Barberry M-1 Cypress USDW-1-FH Cypress USDW-2-LN Cypress USDW-3-HP Cypress M-1 Spirea USDW-1-FH Spirea USDW-2-LN Spirea USDW-3-HP Spirea M-1R Juniper USDW-1-FH Juniper USDW-2-LN Juniper USDW-3-HP Juniper M-1	Direct sampling	Chemical analysis	Semi-annual	Semi-annual	Annual	Monitor water quality
Pressure/ Temperature (Above Confining Zone)	Azalea M-1, Barberry M-1, Old Barberry M-1, Cypress M-1, Spirea M-1R, Juniper M-1	Gauge	Direct measurement	Continuous	Continuous	Continuous	Monitor pressure / temperature

Table B-2. Analytical and Field Parameters for Fluid Samples

Parameters	Analytical Methods
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb, Se, and Tl, Ca, Fe, K, Mg, Na, and Si	EPA Methods 200.7, 200.8, 245.1
Anions: Br, Cl, F, NO_3, and SO_4	EPA Method 300.0
Dissolved CO_2	RSK 175
Hydrogen Sulfide	SM4500 S2 H, SM4500 S2 D
Total Dissolved Solids	2540C, Calculated
Alkalinity	SM 2320B
pH	SM4500 H + B
Specific conductance	SM 2510B
Temperature (field)	Thermocouple

Note: An equivalent method or variance to the constituent list may be executed per the UIC Program Director.

Request for Additional Information: Eastern Wyoming Sequestration Hub
July 1, 2025 TG Response August 1, 2025

Instructions: Please enter responses into this table and make corresponding revisions to the MRV Plan as necessary. Any long responses, references, or supplemental information may be attached to the end of the table as an appendix. This table may be uploaded to the Electronic Greenhouse Gas Reporting Tool (e-GGRT) in addition to any MRV Plan resubmissions.

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
1.	3.3.2	9	"CO_2 from the collection pipeline will be distributed to the injection well with new infrastructure. This distribution infrastructure will allow CO_2 to be injected into the injection wells completed within the Lyons Formation." We recommend reviewing the MRV plan to ensure that the language (e.g., singular/plural) reflects the new wells.	The MRV plan has been updated to improve inclusive language regarding the new wells.
2.	3.4.4	18	"Average salinity of the brine fluid in the reservoir was measured at Juniper M-1 with a value of approximately 230,000 milligrams per liter (mg/L)." The TDS value in the previous plan was 150,000 ppm. Please clarify why these values are different.	The Lyons formation (injection zone) TDS value was 150,000 ppm in the previous MRV plan (Juniper I-1 submittal) because the formation fluid from the Juniper M-1 characterization well had not been processed by the lab at time of MRV plan submission. The 150,000 ppm was a mapped estimate utilizing somewhat sparse regional well data. The lab results from the Juniper M-1 characterization well fluid analysis indicated a TDS value of 230,000 ppm, which has since been integrated into Juniper I-1 Class VI permit updates and all other EWS Hub injector permits.

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
3.	3.4.6	19	"A value of 0.57 psi/ft was calculated and used as the fracture gradient of the Lyons Formation." This value was 0.47 psi/ft in the previous plan Please clarify why these values are different.	The 0.47 psi/ft fracture gradient was initially derived and incorporated into the Juniper I-1 Class VI permit application and MRV plan prior to drilling the Juniper M-1 characterization well. This value was an estimate based on limited regional stress data and empirical correlations. Subsequently, the Juniper M-1 well was drilled, and a step rate test was conducted, during which the bottomhole injection pressure was increased to 0.57 psi/ft without observing any hydraulic fracturing signatures in the data. As a result, the 0.57 psi/ft fracture pressure gradient was proposed as the best estimate in the following five EWS Hub well Class VI permit applications and was reflected in the former MRV plan. Since the initial submittal of this document, a mini-fracture test was successfully performed on the Juniper I-1. The test measured a fracture gradient of 0.59 psi/ft in the Lyons Formation, which will now serve as the injection pressure limitation threshold for the EWS Hub project. This update is detailed in *Section 3.4.6 Fracture Gradient*.
4.	Table 3	20	Please clarify whether the footnote in Table 3 should also reference the new wells added to the MRV plan.	The objective of the footnote in *Table 3* is to specifically identify the change in Juniper I-1 injection volumes from what was reported in the previous MRV plan. The previous plan was for the standalone Juniper I-1 injection well, which was originally intended to inject 1.5 MMT of CO_2 for 5 years, not to exceed a total of 7 MMT. Now with Juniper I-1 being incorporated into the greater EWS Hub, the volumes are being adjusted to 1.5 MMT of CO_2 for 18 years, not to exceed a total of 13 MMT, as noted in *Table 3***.**

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
5.	5.3	30	"No transmissive fractures were identified based on a wireline image log of Juniper M-1 and Azalea I-1." Please clarify whether logs from other wells were analyzed for this project.	To date the wireline image logs used for fracture identification are the Juniper M-1, Azalea I-1, and Juniper I-1 wells. The inclusion of Juniper I-1 has been added to the text in *Section 5.3.* No transmissive fractures were identified in these wells. Additional image logs have recently been acquired for the Spirea I-1 well (renamed Spirea M-1R) and will be collected for the upcoming Barberry I-1 and Cypress I-1 wells. Once the data is processed, interpretations will be conducted to identify and report any transmissive fracturing in those wells.
6.	5.3	30	"Diffusion of CO_2 through the upper confining zone (Goose Egg and Chugwater Formations) is not expected to result in significant loss from the storage reservoir given the low permeability (0.001 mD) and thickness (>480 feet) of these zones." The previous plan listed a permeability value of 0.00001 mD. Please clarify why this value has changed.	The permeability value of 0.00001 mD listed in the previous plan was petrophysically derived from offset wells prior to the drilling and analysis of the Juniper M-1 characterization well. The permeability value of 0.001 mD presented in this plan reflects the average permeability obtained from a petrophysical model calibrated with Juniper M-1 core data. This petrophysical model currently incorporates wireline logs from the Juniper M-1, Juniper I-1, and Azalea I-1 wells, all of which demonstrate consistent permeability results.
7.	6.5.1	38	The previous plan referenced the use of indirect monitoring above the confining zone, but this has been removed in the current submission. Please clarify why this change was made.	Following the submission and approval of the previous MRV plan, the Wyoming Department of Environmental Quality (WDEQ) clarified direct fluid sampling from the first permeable zone (FPZ) above the confining zone was required because at this location, the FPZ corresponds to the lowermost USDW. Consequently, the groundwater monitoring program was revised to include direct fluid sampling from the lowermost USDW instead of relying on indirect pulsed neutron logging (PNL) methods. The remainder of the groundwater monitoring plan remains unchanged, continuing to include direct fluid sampling of three distinct near-surface aquifers, as well as continuously recording pressure and temperature gauges installed in the lowermost FPZ/USDW.

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
8.	8.2	41	“CO_2 = Total annual CO_2 mass injected (metric tons) through all injection wells” In Equation RR-6, this variable is “ = Total annual CO_2 mass injected (metric tons) through all injection wells” Please revise this section and ensure that all equations listed are consistent with the text in 40 CFR 98.443.	This equation has been revised in the text to reflect “CO_{2I}” rather than “CO_2”.
9.	9	43	“After the injection wells are drilled, High Plains will reevaluate the MRV plan and, if any modifications are a material change per 40 CFR § 98.448(d)(1), High Plains will submit a revised MRV plan as required by 40 CFR § 98.448(d).” Please clarify whether the wells in the MRV plan are already drilled or planned to be drilled.	The injection wells that have been drilled at the time of this MRV plan RFAI submission date include the Juniper I-1, Azalea I-1, Barberry I-1, and the Spirea I-1R.
10.	3.3.3	43	N/A	“Project injection (“I-1”) and injection-zone monitoring (“M-1”) wells…” has been revised to “Project injection (“I-1”) and above confining zone monitoring (“M-1”) wells…”. The monitoring wells will monitor above the confining zone, not the injection zone.

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
11.			N/A	Due to operational challenges encountered during the drilling of the Spirea I-1 injection well, the names and locations of the Spirea I-1 injection well and Spirea M-1 monitoring well have been revised. The original Spirea I-1 well was plugged back and repurposed as the Spirea project's above-confining-zone monitoring well, now designated Spirea M-1R, following approval from the Wyoming Department of Water Quality. A new injection well, named Spirea I-1R, was drilled approximately 240 feet east of the original Spirea I-1 (now Spirea M-1R), near the originally proposed location for Spirea M-1. The Spirea M-1 well will no longer be drilled, as Spirea M-1R will fulfill the monitoring well role. Please note that these well location changes are minor, essentially swapping the locations, and all site monitoring methods remain unchanged. All references to Spirea I-1 and Spirea M-1 in the MRV Plan—including text, tables, and figures—have been updated to Spirea I-1R and Spirea M-1R, respectively. Section 3.3.3, "Wells in the AoR Penetrating the Upper Confining Zone," has been revised to include Spirea M-1R as a well penetrating the confining zone, similar to the Juniper M-1 characterization well. *Figure 4d* includes an updated well site plot plan reflecting these location changes.
12.			N/A	High Plains has now received a unitization order from the WOGCC for a unit area that encompasses the AoR (CO2 Area). This project update has been included in *Section 5.6 Monitoring*.

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
13.			N/A	Total Sequestered Volume has been slightly adjusted for enhanced accuracy (we’re replacing rounded numbers with more accurate decimals). Specifically, the Barberry injection well total volumes increased from 31 to 31.3 MMT and the Cypress has increased from 15 to 15.5 MMT. This is reflected in *Table 3. Injection Details*.

Subpart RR Monitoring, Reporting, and Verification Plan for the Eastern Wyoming Sequestration Hub

Laramie County, Wyoming

Version 4

May 1, 2025

Contents

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List of Tables

1. Introduction

Tallgrass High Plains Carbon Storage, LLC (High Plains) has prepared this monitoring, reporting and verification (MRV) plan pursuant to 40 CFR (U.S. Code of Federal Regulations) § 98.440-449 (Subpart RR). High Plains is a subsidiary of Tallgrass Energy, L.P. (Tallgrass). This document describes the MRV activities for the proposed High Plains Eastern Wyoming Sequestration (EWS) Hub, located in Laramie County, Wyoming. The EWS Hub consists of six carbon dioxide (CO_2) injection facilities, each with one injection well (Azalea I-1, Spirea I-1, Barberry I-1, Old Barberry I-1, Cypress I-1, and Juniper I-1). A previous version of this MRV Plan (Version 3 dated November 22, 2024) has been approved for a single injection well (Juniper I-1) and is being amended to incorporate five additional injection wells in the same field.

The EWS Hub is designed to store a total of 116 million metric tons (MMT). CO_2 will be sourced from a CO_2 collection pipeline from several industrial facilities.

The CO_2 will be injected into the Lyons Formation for geologic storage. An individual Underground Injection Control (UIC) Class VI application has been submitted to the State of Wyoming for each of the EWS Hub projects. At the time of this submittal, all six UIC Class VI applications have Class VI permits for approval to construct:

- Juniper Project: UIC Permit 2022-235; Facility [ID] WYS-021-00149
- Azalea Project: UIC Permit 2023-264; Facility ID WYS-021-00159
- Spirea Project: UIC Permit 2023-041; Facility ID WYS-021-00155
- Barberry Project: UIC Permit 2023-039; Facility ID WYS-021-00153
- Old Barberry Project: UIC Permit No. 2023-263; Facility ID WYS-021-00158
- Cypress Project: UIC Permit No. 2023-040; Facility ID WYS-021-00154

A stratigraphic test well, Juniper M-1 (American Petroleum Institute [API] #49-021-29548), has been drilled at the project area and will be converted into an above confining zone monitoring well.

This MRV plan is organized into the following sections:

- Section 1: Introduction
- Section 2: Facility Information
- Section 3: Project Description
- Section 4: Delineation of the Monitoring Areas
- Section 5: Identification and Assessment of Potential Surface Leakage Pathways
- Section 6: Monitoring and Considerations for Site-Specific Variables
- Section 7: Approach for Establishing the Expected Baselines
- Section 8: Considerations for Site-Specific Variables for the Mass Balance Equations

- Section 9: MRV Implementation Schedule
- Section 10: Quality Assurance and Quality Control
- Section 11: Records Retention

2. Facility Information

1. Greenhouse Gas Reporting Program (GHGRP) ID number – 589261
2. The Wyoming Department of Environmental Quality (WDEQ) has issued UIC Class VI permits under its Wyoming Statute (W.S.) Sections 35-11-101 through 2005 for the injection wells.
3. Oil- and gas-related wells around the EWS Hub injection facilities, including Class II injection wells and production wells, are regulated by the Wyoming Oil and Gas Conservation Commission (WOGCC). WDEQ is the responsible agency for all other UIC well classes.

   Wells within the EWS Hub area of review (AoR) are identified by name, API number, status, and type. The list of planned wells associated with the EWS Hub projects is provided in **Appendix A**. Any new wells or changes to well status will be indicated in the annual report.
4. Proposed date to begin collecting data for calculating the total CO_2 amount sequestered: June, 2025.

3. Project Description

Tallgrass, headquartered in Leawood, Kansas, is a committed leader at the forefront of decarbonization efforts in the United States (U.S.). Tallgrass is a pipeline and gas storage company that enables a high quality of life through the delivery of energy and services that fuel homes and businesses. As a demonstration of its decarbonization commitment, Tallgrass is developing the sequestration site in Laramie County, Wyoming. The EWS Hub is an innovative, multi-state decarbonization effort focused on permanently sequestering CO_2 from multiple emitters located in Nebraska, Colorado, and Wyoming.

Tallgrass and predecessor companies have operated natural gas storage fields for more than 70 years. Tallgrass currently operates 90 wells with 74 billion cubic feet (bcf) of natural gas storage capacity and 20,470 compression horsepower across the Huntsman and East Cheyenne gas storage fields. These gas storage operations provide Tallgrass with critical subsurface working knowledge and skill sets that transfer directly to CO_2 sequestration, specifically the injection, monitoring, and storage of gaseous fluids in porous reservoirs.

The State of Wyoming previously recognized Tallgrass's commitment to decarbonization when the Wyoming Energy Authority (WEA) awarded High Plains a grant to help fund the development of the injection project. The grant is in addition to the proposed direct investment in the project by High Plains, designed to provide a cost-effective means of sequestering CO_2. "Wyoming is deeply committed to providing decarbonized solutions for the 21st century," said Dr. Glen Murrell, Executive Director of the WEA. "We are pleased to be able to fund Tallgrass's Eastern Wyoming

Sequestration Hub project, which has the potential to add an important resource for our net-zero goals."[1]

3.1 Project Characteristics

The EWS Hub project area is ideally suited for CO_2 storage for the following reasons:

- The high permeability and porosity of the Lyons Formation (the injection zone)
- The continuity, low permeability, and ductility of the overlying Chugwater Formation/Goose Egg Formation (confining zone), and Satanka Formation (lower confining zone)
- Few abandoned wells that penetrate the injection zone

Computational modeling to simulate CO_2 sequestration confirms anticipated containment of the injected mass. A robust monitoring program will be established to detect any CO_2 leakage so that any potential leakage may be mitigated.

The EWS Hub Projects will consist of six injection wells, surface facilities, and six above confining zone monitoring wells (**Figure 1**). Additional shallow groundwater monitoring wells will also be placed at each injection project to monitor underground source of drinking water (USDW) aquifers.

[1] https://tallgrass.com/newsroom/press-releases/tallgrass-to-develop-a-commercial-scale-co2-sequestration-hub-in-wyoming

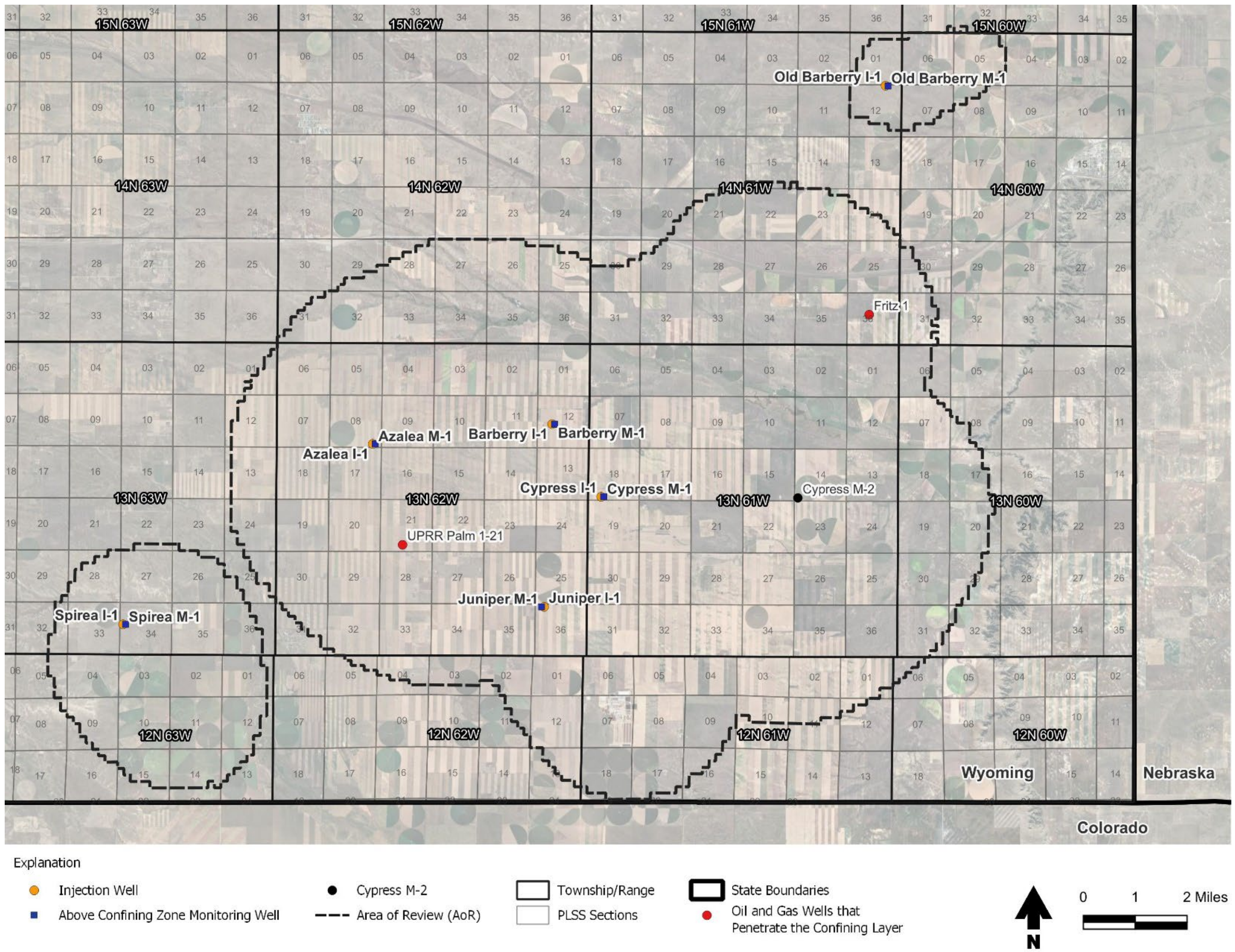

Figure 1. EWS Hub Project Location, Injection Wells and Proposed Above Confining Zone Monitoring Wells, and Abandoned Wells within the AoR that Penetrate the Confining Zone.

3.2 Project Area Geology

The EWS Hub AoR is located in Laramie County in southeastern Wyoming. The site is situated within the Denver Basin, commonly referred to as the Denver-Julesburg Basin, or "DJ Basin." The sequestration program entails injecting into the Lyons Formation, a geologic formation spanning approximately 50 to 100 net feet of high porosity and permeable sands at an approximate average depth of 9,081 feet true vertical depth (TVD) within the EWS Hub AoR.

The DJ Basin consists of shallow Paleozoic through deeper Cenozoic sediments that were deposited unconformably over Precambrian crystalline basement rock. Deposition occurred in a predominantly marine shelf environment that was subject to subsidence for most of the Paleozoic and Mesozoic Eras. As a result, total sediment accumulation can reach thicknesses in excess of 13,000 feet along the synclinal axis. Sediment supply during Pennsylvanian time consisted primarily of shale and carbonate in the basin interior, with sand contribution along the Ancestral Rockies.

Permian through Triassic time was characterized by a broad, low-relief intermittent sea that exhibited depositional environments from fluvial, normal marine to hypersaline. Lithology within the Permian-Triassic strata is dominated by redbeds, evaporites, and anhydritic siltstones (Bethke and Lee, 1994). Triassic sediments were subsequently overlain by shale and sand deposition that dominated the Jurassic and Cretaceous periods. The Western Interior Seaway was relatively deep and present across a significant portion of western North America during the Cretaceous, including the DJ Basin. The Cretaceous was also subject to east-verging thrusts associated with Laramide tectonism.

The combination of the structural setting and depositional environment resulted in accumulation of up to 10,000 feet of Cretaceous shale, sandy shale, and carbonate over Jurassic and Triassic sediments throughout the basin (Sonnenberg and Weimer, 1981; Bethke and Lee, 1994; Taucher et al., 2013). These shales and tight carbonate formations have been identified by the Wyoming State Geological Survey (WSGS) as confining intervals between the injection formation and lowermost potential potable water aquifer.

Figure 2 depicts the stratigraphy of the DJ Basin. The geologic sequence of the EWS Hub includes the following formations, from shallowest to deepest:

- *Above Confining Zone:* Sundance Formation. The Sundance Formation includes well-sorted, well-rounded sandstone intervals that are sufficiently permeable to serve as a groundwater aquifer (Lowry and Crist, 1967; Love and Christiansen, 1985; Taucher et al., 2013).
- *Upper Confining Zone:* Chugwater Formation/Goose Egg Formation.
    - *Chugwater Formation:* The formation consists of reddish-orange shale and siltstone with thin gypsum partings near the base. The average thickness of the Chugwater Formation within the EWS Hub project area is approximately 221 feet.
    - *Goose Egg Formation*: This geologic section consists of red shale and silt interbedded with gypsum, anhydrite, limestone, and dolomite. The average thickness of the Goose Egg Formation within the EWS Hub project area is approximately 268 feet.

- *Injection Zone*: Lyons Formation. The Lyons Formation is described as a well-sorted, fine-grained, eolian quartzose sandstone from outcrops near Lyons, Colorado (Sonnenberg and Weimer, 1981). The Lyons Formation has an approximate thickness of 61 feet in the EWS Hub AoR.
- *Lower Confining Zone*: Satanka Formation. The Satanka Formation contains interbedded red and gray sandstones, gray siltstone, red mudstone, and red anhydritic siltstones. The sandstones contain feldspar and are commonly fine-grained to very fine-grained. The anhydrite-rich upper Satanka provides an impermeable barrier, inhibiting vertical fluid migration (Clayton and Swetland, 1980).

Table 1 lists the approximate formation top depths at the EWS Hub project locations. **Figure 3** is a schematic representing the regional stratigraphy in the vicinity of the EWS Hub project area.

Table 1. Formation Top Depths, EWS Hub Project Site

Formation	Designation	Project Site Approximate Depths (TVD, feet)					
		Azalea	Barberry	Old Barberry	Spirea	Cypress	Juniper
Sundance	Aquifer	8,774	8,658	8,063	8,907	8,602	8,558
Chugwater	Aquitard	8,840	8,724	8,128	9,053	8,655	8,610
Goose Egg	Aquitard	9,071	8,919	8,330	9,257	8,897	8,864
Lyons	Aquifer	9,352	9,211	8,616	9,494	9,150	9,124
Satanka	Aquitard	9,419	9,275	8,689	9,556	9,200	9,175

ERATHEM	SYSTEM AND SERIES		Lithostratigraphic units of Love et al. (1993) in the DJ Basin (MODIFIED)		Hydrogeologic unit for DJ Basin		
CENOZOIC	QUATERNARY	Holocene and Pleistocene	Alluvium and terrace deposits		Quaternary unconsolidated-deposit aquifers		High plains aquifer system
	TERTIARY	Pliocene	*section absent due to erosion or nondeposition*				
		Miocene	Ogallala Formation		Ogallala aquifer		
			Arikaree Formation		Arikaree aquifer		
		Oligocene	White River Formation — Conglomerate	White River Group	White River Group		
			White River Formation — Lower part	White River Group — Brule Formation	White River aquifer/confining unit	Brule	
				White River Group — Chadron Formation		Chadron	
		Eocene	*section absent due to erosion or nondeposition*				
		Paleocene					
MESOZOIC	CRETACEOUS	Upper Cretaceous	Lance Formation		Lance aquifer		Lance-Fox Hills aquifer
			Fox Hills Sandstone		Fox Hills aquifer		
			Pierre Shale		Pierre confining unit		
			Niobrara Formation		Niobrara confining unit		
			Carlile Shale		Carlile confining unit		
			Greenhorn Formation		Greenhorn confining unit		
			Belle Fourche Shale		Belle Fourche confining unit		
			Mowry Shale		Mowry-Thermopolis confining unit		
		Lower Cretaceous	Muddy Sandstone			Muddy Sandstone aquifer	
			Thermopolis Shale				
			Inyan Kara Group	Fall River Formation	Inyan Kara aquifer		
				Lakota Formation			
	JURASSIC	Upper Jurassic	Morrison Formation		Morrison aquifer and confining unit		
		Middle Jurassic	Sundance Formation		Sundance Aquifer		
	JURASSIC (?) AND TRIASSIC (?)		*section absent due to erosion or nondeposition*				
	TRIASSIC	Upper Triassic	Chugwater Formation of Darton (1908)		Chugwater confining unit		
		Lower Triassic	Lykins Formation		Goose Egg Formation		
PALEOZOIC	PERMIAN		Lyons Sandstone		Hydrogeologic role/unit not defined for study area		
			Satanka Shale		Satanka confining unit		
	PENNSYLVANIAN	Upper Penn / Middle Penn	Casper Formation	Hartville Formation	Casper aquifer	Hartville aquifer	Paleozoic aquifer system

Figure 2. **Stratigraphic Column of the DJ Basin.** The shading indicates freshwater aquifers (underground sources of drinking water [USDWs]) in blue, the proposed injection interval in red, primary confining layers in dark gray, and additional confining layers in light gray (adapted and modified from Taucher et al., 2013).

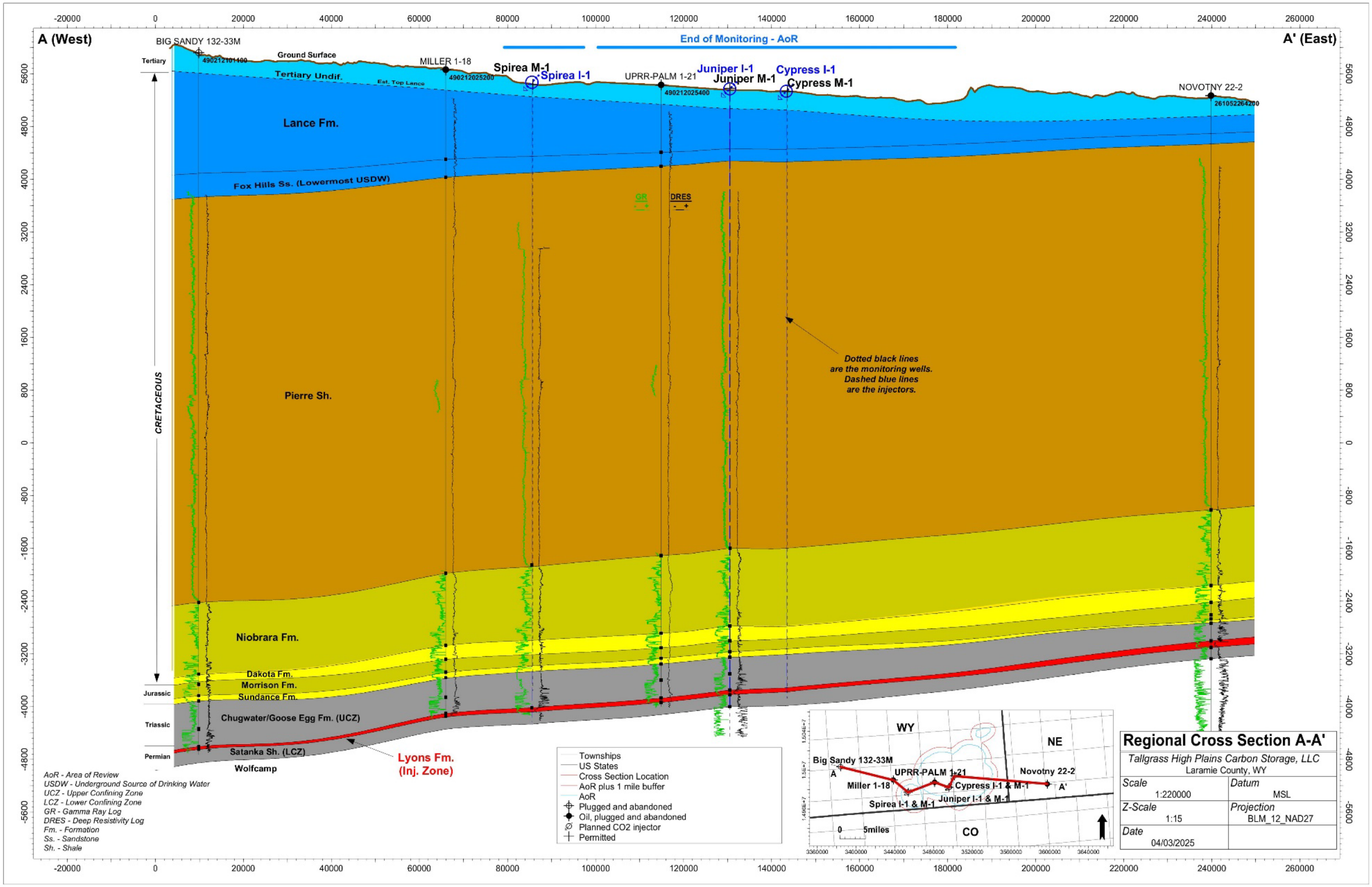

Figure 3. Regional West-East Cross Section A-A'. Gamma ray (left, green) and deep resistivity (right, black) logs are shown.

3.3 Surface Facilities and Injection Process

A simplified flow diagram of surface facilities is provided in **Figure 4a**, and detailed surface facilities diagrams for the Juniper, Cypress, Spirea, Barberry and Azalea projects are provided in **Figures 4b through 4f** (surface facilities for the Old Barberry project are anticipated to be essentially identical to the Cypress project). All facilities will be designed and built to ensure integrity and compatibility with CO_2. The injection wells will be designed and operated in a manner that meet the requirements of WDEQ Chapter 24. Once injection activity is complete, the wells will be plugged according to WDEQ Chapter 24 §23.

The monitoring program (see Section 6) is designed to meet the requirements of Subpart RR and WDEQ Chapter 24 §20, with advanced technologies that allow for the tracking of the injectate plume migration while minimizing the artificial creation of potential pathways for sequestered fluids to escape confinement. The extent of the CO_2 plume will be monitored using two-dimensional (2D) seismic surveys to understand CO_2 saturation changes through time. Above confining zone monitoring wells (Juniper M-1, Azalea M-1, Spirea M-1, Barberry M-1, Old Barberry M-1 and Cypress M-1) will be used to detect migration above the confining zone.

The following subsections will review the following:

- CO_2 source (Section 3.3.1)
- CO_2 transportation and injection (Section 3.3.2)
- Wells in the Class VI AoR penetrating the upper confining zone (Section 3.3.3)

3.3.1 CO_2 Source

CO_2 will be sourced from a CO_2 collection pipeline from several industrial facilities in Nebraska and surrounding states. Chemistry of the injectate stream will consist of 95 percent or higher CO_2 purity and less than 150 parts per million (ppm) water. **Table 2** shows the planned composition of the injectate stream, per the pipeline specifications.

High Plains has demonstrated the compatibility of the CO_2 stream with the fluids in the injection zone and minerals in both the injection and confining zones based on the results of the formation testing program. The CO_2 streams that High Plains proposes to inject through this Class VI permit are exempt from the U.S. Environmental Protection Agency (EPA) definition of hazardous waste in 40 CFR § 261.4(h). Similarly, the injected CO_2 is not a hazardous or toxic waste or other material under Chapter 8 of WDEQ Water Quality Rules in the Wyoming Code of Regulations (WCR) (020-0011-8 WCR 6). As such, the CO_2 stream that High Plains proposes to inject is not subject to the restrictions in 020-0011-8 WCR 6(c)(ii).

3.3.2 CO_2 Transportation and Injection

CO_2 from the collection pipeline will be distributed to the injection well with new infrastructure. This distribution infrastructure will allow CO_2 to be injected into the injection wells completed within the Lyons Formation.

The CO_2 injection wells will have automated controls that provide for both control and measurement of the mass flow rate and pressure.

3.3.3 Wells in the AoR Penetrating the Upper Confining Zone

Project injection (“I-1”) and injection-zone monitoring (“M-1”) wells will penetrate the confining zone; at this time, five of the EWS Hub project wells have been drilled and penetrate the confining zone (Juniper I-1 and M-1, Azalea I-1 and M-1, and Spirea I-1). With the exception of the Juniper M-1 characterization well, the remaining project M-1 monitoring wells penetrate or will penetrate the confining zone only as necessary to accommodate drilling and logging of shallower formations and approximately 80% of the confining zone is not penetrated by these wells.

Three additional wells penetrate the confining layer or deeper within the EWS Hub maximum monitoring area (MMA; see Section 4.1): Cypress M-2 (API# 49-021-29598), Fritz 1 (API #49-021-05033), and UPRR Palm 1-21 (API #49-021-20254). Fritz 1 and UPRR Palm 1-21 were both drilled and abandoned. The UPRR Palm 1-21 contains adequate cement plugs across relevant zones. Fritz 1 does not provide cement plugs <2,500 feet apart and, per the current WOGCC abandonment regulations (Section 18, Form 4), will need to have remedial work completed prior to CO_2 injection.

Cypress M-2 was drilled by High Plains and has since been plugged back to the surface. The plugging and abandonment operation included a comprehensive design incorporating eight cement plugs, ensuring compliance with standards set by WDEQ, WOGCC, EPA, and the API. Notably, Plug 8 was placed across the Lyons Formation, the intended storage zone, using an acid-resistant cement blend (SLB's EverCrete). This plug was tagged and confirmed with a weight on bit of 10,000 pounds after achieving a compressive strength of 500 pounds per square inch (psi) approximately 15 hours post-placement.

Table 2—Composition of the injectate stream

Constituent	Limit
CO_2	$\geq$ 95 mol%
Carbon monoxide (CO)	$\leq$ 0.4 mol%
Hydrogen (H_2)	$\leq$ 0.5 mol%
Hydrogen Sulfide (H_2S)	$\leq$ 20 ppm
Total Sulfur	$\leq$ 35 ppm
Total nitrogen oxides (NO_x)	$\leq$ 10 ppm
Oxygen (O_2)	$\leq$ 1 mol%
Water (H_2O)	$\leq$ 150 ppm
Hydrocarbons	$\leq$ 4 mol %
Glycol	0.3 gallons/MMCF
Maximum dew point at 400 psig	30°F
Non-condensable gases	$\leq$ 5% mol%

psig = pounds per square inch gauge
MMCF = million cubic feet

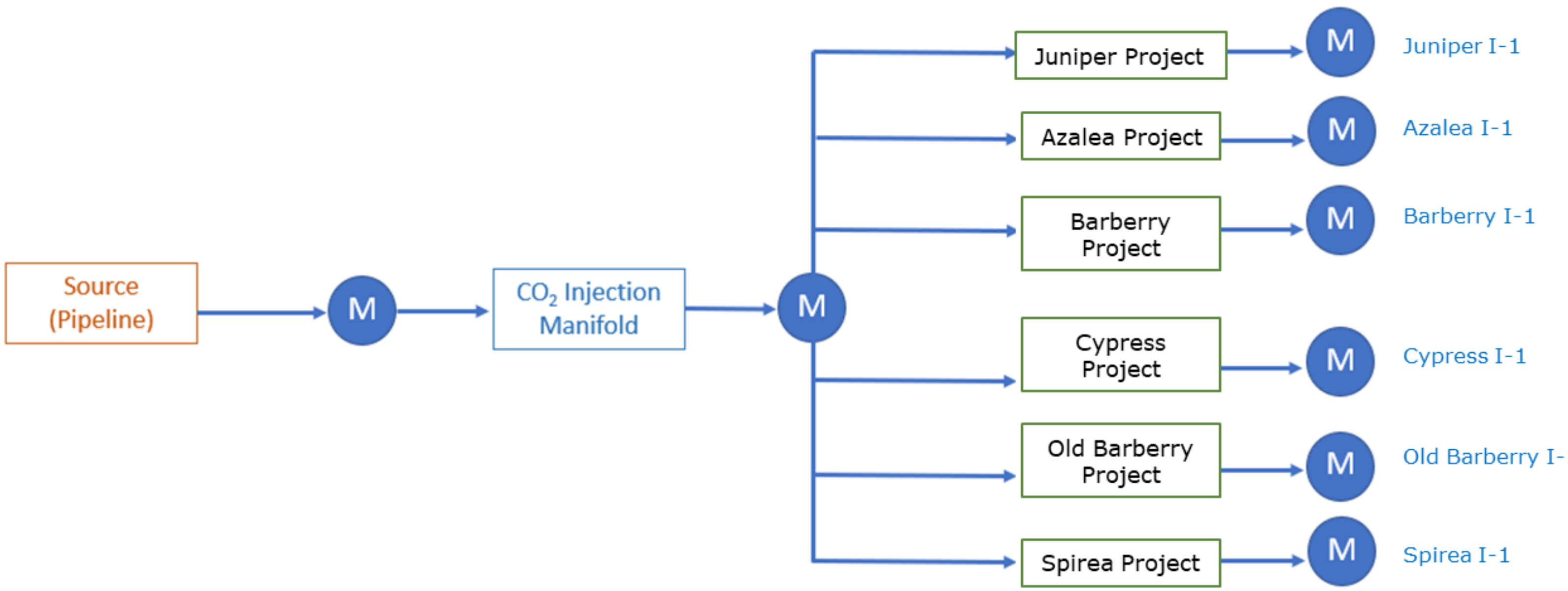

Figure 4a. Simplified Facilities Flow Diagram for High Plains EWS Hub. Blue "M" symbols denote meter locations.

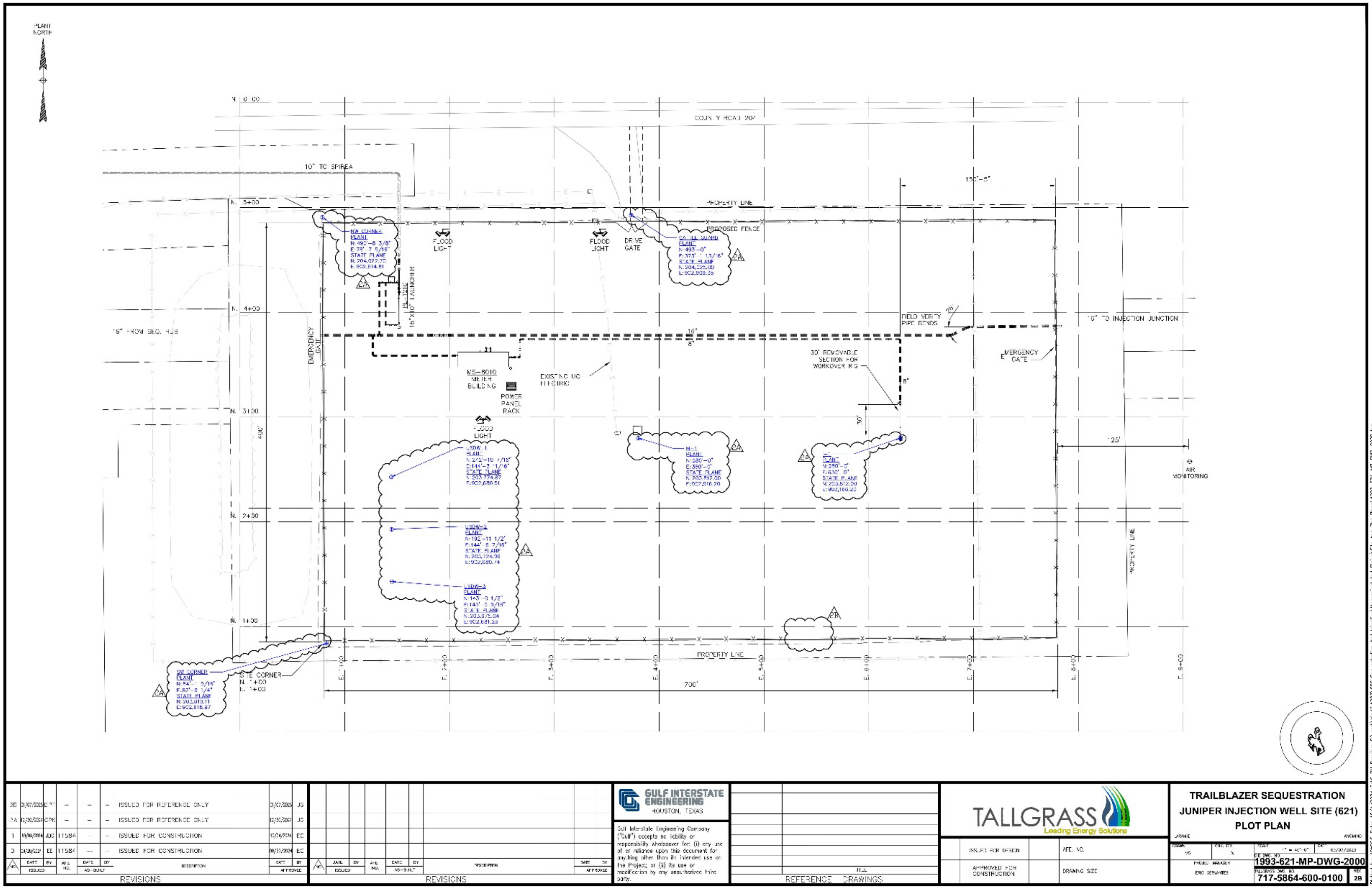

Figure 4b. Juniper Injection Well Site Plot Plan.

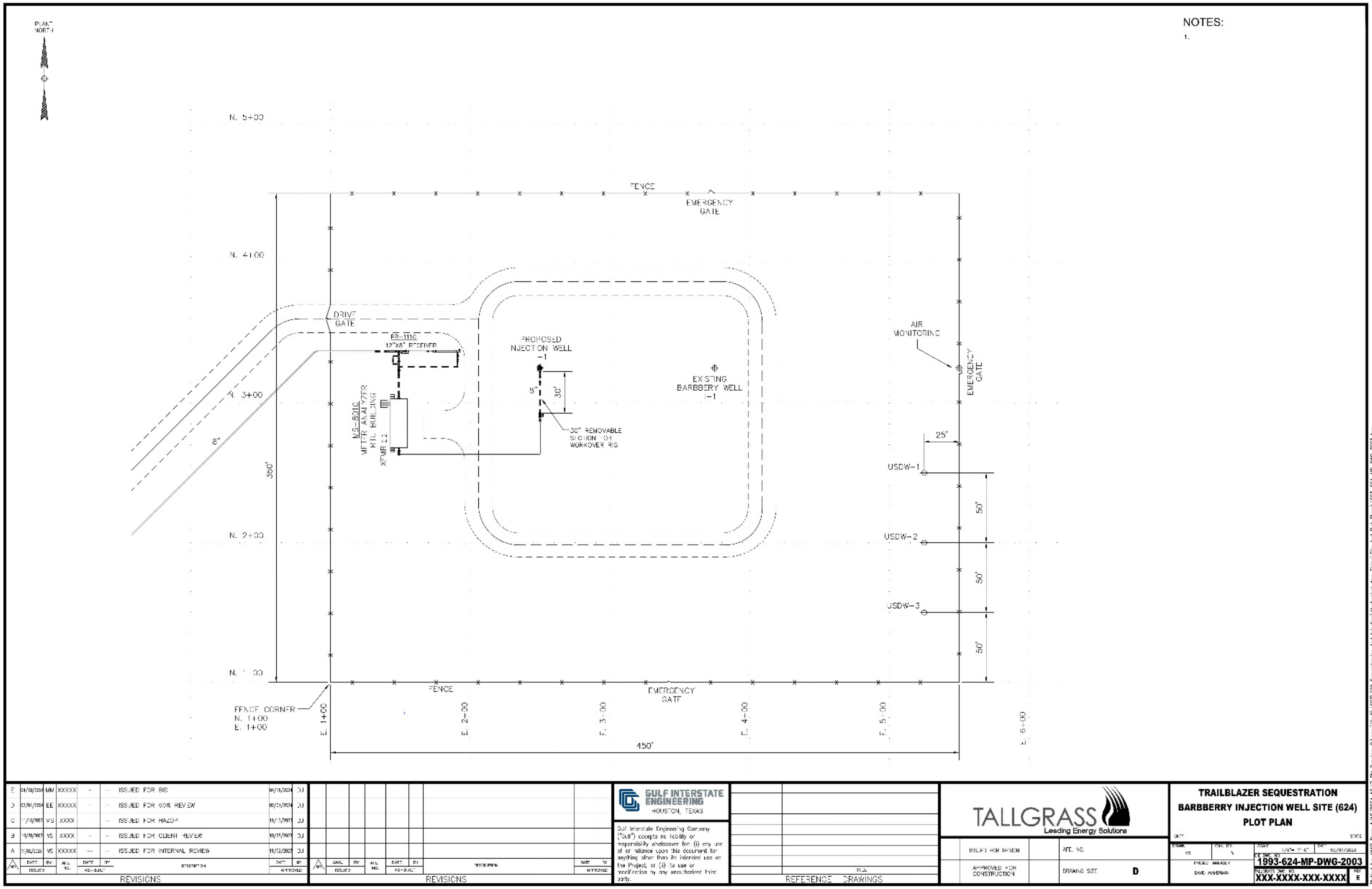

Figure 4c. Barberry Injection Well Site Plot Plan.

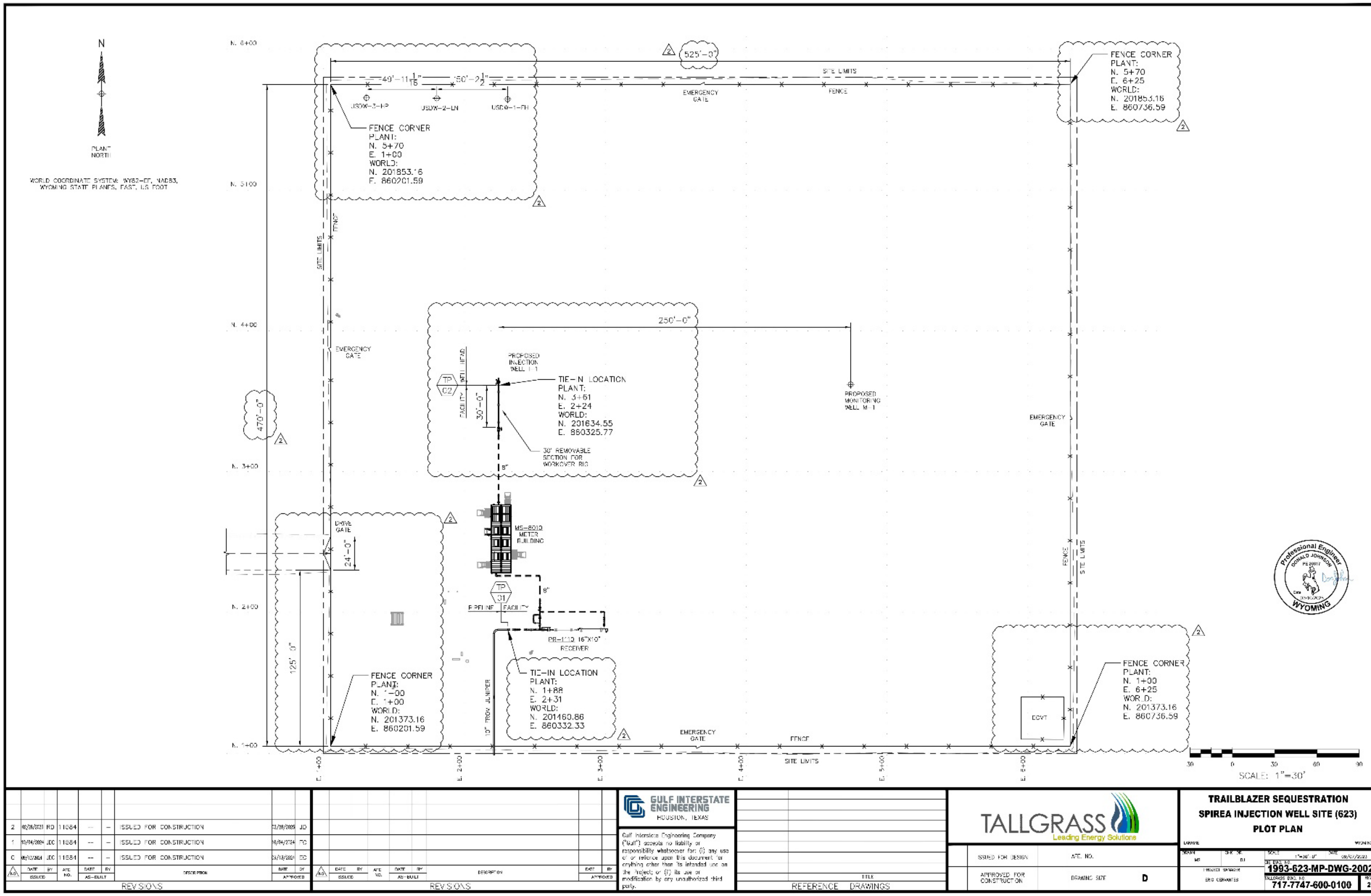

Figure 4d. **Spirea Injection Well Site Plot Plan.**

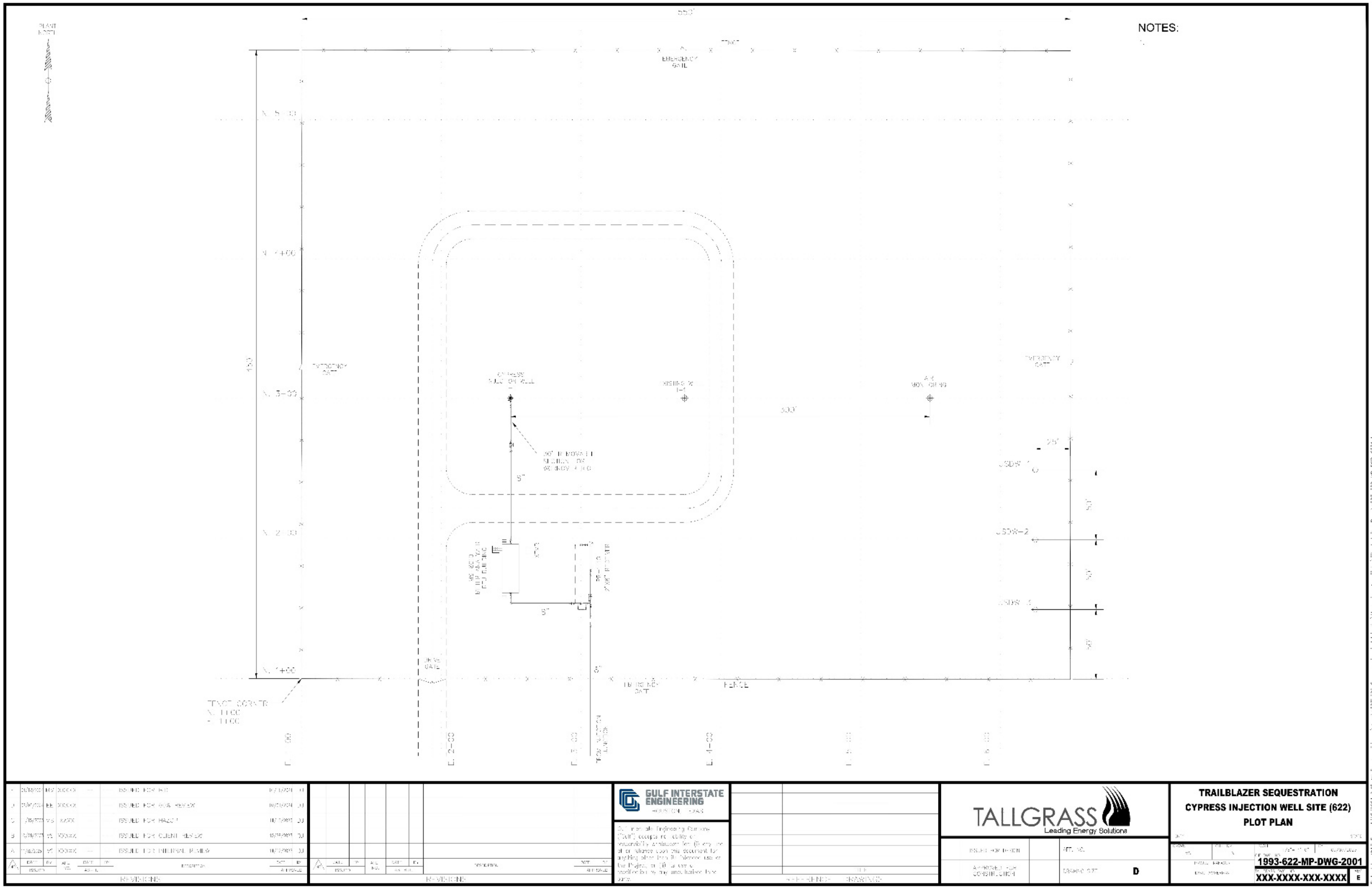

Figure 4e. **Cypress Injection Well Site Plot Plan.**

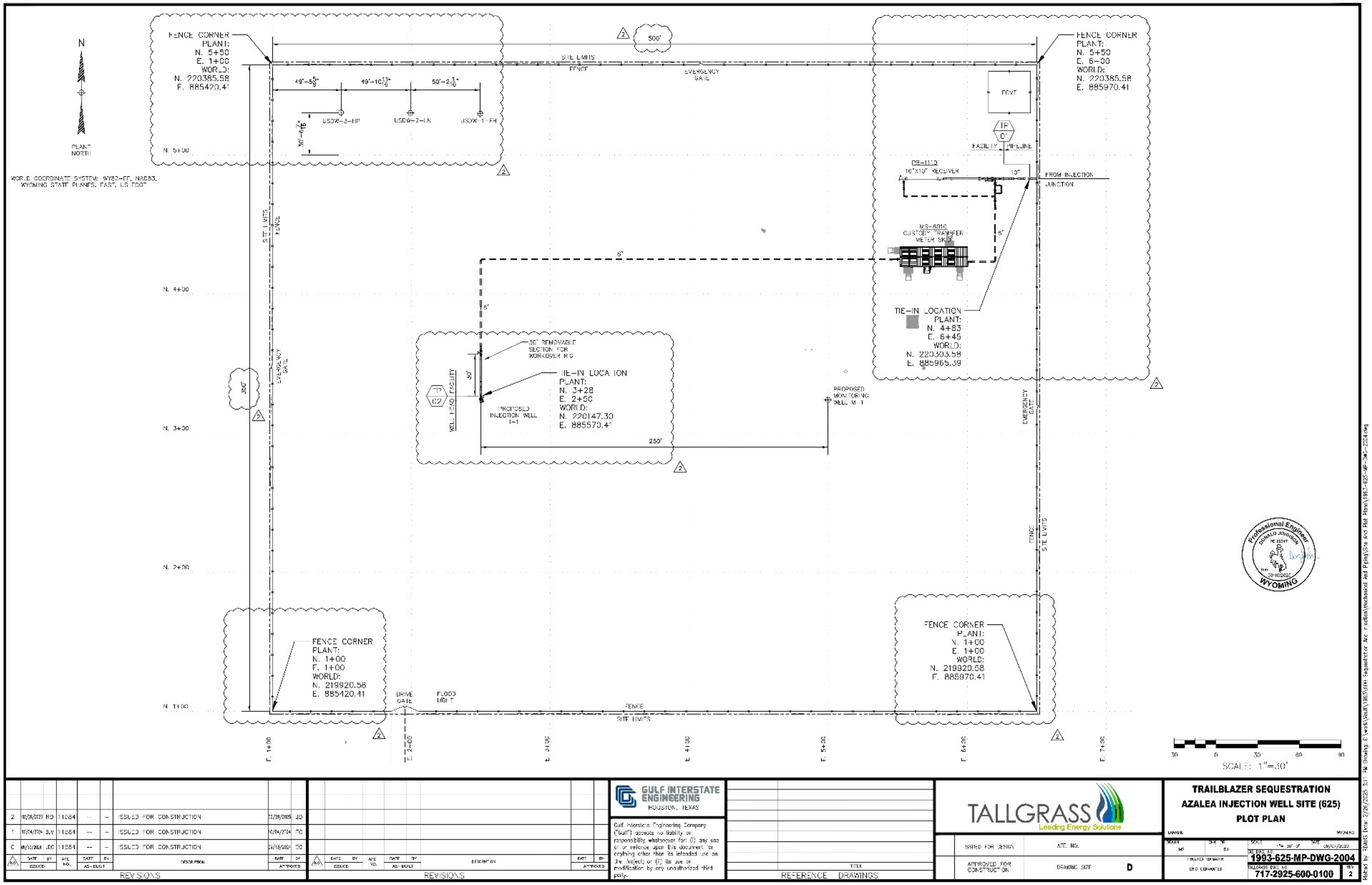

Figure 4f. **Azalea Injection Well Site Plot Plan.**

3.4 Reservoir Simulation Model

Reservoir modeling included development of a static geologic model and dynamic reservoir model. The reservoir simulation model was used to define the site AoR (CO_2 plume) and the MRV monitoring areas (Section 4).

The following subsections further describe these topics:

- Data Sources (Section 3.4.1)
- Model Platform (Section 3.4.2)
- Structural Framework (Section 3.4.3)
- Initial Conditions (Section 3.4.4)
- Fracture Gradient (Section 3.4.5)
- CO_2 (Section 3.4.6)
- Injection (Section 3.4.7)
- Boundary Conditions (Section 3.4.8)
- Modeling Results (Section 3.4.9)

3.4.1 Data Sources

Data sources used to build the geologic model include well logs, 2D seismic data, core, and publicly available literature. Publicly available open-hole log data including gamma ray, spontaneous potential, resistivity, porosity (sonic, neutron, density), photoelectric factor, and the caliper log were used to pick stratigraphic tops and perform petrophysical analyses. Petrophysical analyses were performed on a total of 47 wells with triple combo log suites (gamma ray, porosity, and resistivity logs) within the EWS Hub area. Well logs were also used as control points in the geologic model to distribute rock property values.

2D seismic data were tied in with well log formation tops to model the geologic structure. The seismic analysis was further used to identify any faulting, structural changes, or reservoir thickness not identified from well logs. No faults were identified in the project area.

3.4.2 Model Platform

Schlumberger's Petrel™ Software was chosen to build the geologic model. Petrel is a state-of-the-art software package that is used worldwide, incorporating log and seismic data to create a geostatistical representation of the reservoir. The geologic model developed using Petrel represents the subsurface characteristics of the proposed carbon sequestration site. It consists of the Chugwater (upper seal), Goose Egg (upper seal), and Lyons (injection zone).

The geologic model was then used as an input into Computer Modeling Group's (CMG's) GEM 2022.10 (GEM) simulator, which is one of the most accurate and technically sound reservoir simulation software packages for conventional, unconventional, and secondary recovery. GEM uses equation-of-state (EOS) algorithms, along with some of the most advanced computational methods, to evaluate compositional, chemical, and geochemical processes and characteristics to produce highly accurate and reliable simulation models for carbon sequestration. GEM was used to accurately simulate the movement of supercritical CO_2 and the increase in reservoir pressure due to injection operations.

3.4.3 Structural Framework

The structure model was built from formation tops as determined from log analysis and seismic interpretation. A three-dimensional (3D) model was constructed in Petrel from interpreted geologic horizons and mapped regional faulting. Petrel employs simple kriging methods, with the well logs as control points, to distribute property values across the modeled formations. The primary distributed properties were permeability and porosity estimates.

The geocellular model consists of 500-foot by 500-foot hexahedral grid cells. The model covers an area of 102 miles by 57 miles. Surfaces for the four primary zones of interest—Chugwater, Goose Egg, Lyons, and Satanka—were interpreted from well logs and seismic data (**Figure 5**). An average cell thickness of 4.52 feet was used to characterize the Lyons Formation.

Additional layering for the model was defined through isopach maps and well tops, resulting in vertical cells of varying thickness ranging from 2 to 40 feet. The isopach maps honored significant features observed from seismic data including facies changes. Because no faults were observed in the area of interest, the model contains no fault planes.

Petrophysical analyses conducted on 47 wells within the model boundary were used to determine porosity and permeability for each stratigraphic zone. Using the values derived from log analysis, properties in the geocellular static model were assigned by taking the continuous range of the property and upscaling the value to match the final grid cell resolution using the arithmetic average over each cell. Property distribution in the Lyons Formation consisted of applying a kriging algorithm from upscaled logs, guided by an experimental spherical variogram, with major and minor range of 100,000 feet and a vertical range of 50 feet for each zone. Property distribution consisted of applying the kriging algorithm from upscaled porosity logs, guided by variograms for each zone as seen in **Figure 6**.

3.4.4 Initial Conditions

The model is a pseudo-infinite acting reservoir that is 100 percent brine filled. Based on 2D seismic interpretation and log information collected at Juniper M-1, the sands within the Lyons Formation have an average gross thickness of 55 feet. Based on pressure gauges in Juniper M-1, it was determined that the reservoir has a pressure gradient of 0.34 pound per square inch per foot (psi/ft). A reservoir temperature gradient of 2.07°F per 100 feet with a mean surface temperature of 60°F was used. Average salinity of the brine fluid in the reservoir was measured at Juniper M-1 with a value of approximately 230,000 milligrams per liter (mg/L).

3.4.5 Permeability and Porosity

Permeability was distributed along corresponding porosity values. Air permeability was correlated to ambient porosity. The correlation of porosity to permeability is defined by the best-fit trend line of the measured data taken from Razor 26J-2633L (API #051233749500), Marathon-Avalo 1-32

(API #05123106700) and Juniper M-1 (API #490212954800) as shown on **Figure 7**. An equation was created with a best-fit trend line to calculate permeability based on the distributed porosity. These values were then converted into brine permeability based on the Swanson K_{air}/K_{brine} relationship (Swanson 1981). In the study, if the brine permeability was greater than the air permeability, the authors chose to use the air permeability to provide a more conservative estimate in the model.

Permeability and porosity values were distributed across the model. Observed values of porosity calculated from offset well logs can be in excess of 30 percent, yielding permeabilities of 1,029 millidarcies (mD). To constrain these anomalously high values of permeability, a cutoff of 1,029 mD was applied to the model to remove any extremities that could be derived from the permeability-porosity relationship.

3.4.6 Fracture Gradient

Fracture gradients were calculated for the Lyons Formation because the core sample acquired from the Juniper M-1 stratigraphic well was not conducive to plugging. A value of 0.57 psi/ft was calculated and used as the fracture gradient of the Lyons Formation. The maximum injection pressure gradient was calculated as 90 percent of the fracture gradient, resulting in a maximum injection pressure gradient of 0.51 psi/ft.

3.4.7 CO_2 Phase

There are numerous advantages to storing CO_2 under supercritical conditions. Supercritical fluids have significantly higher density that allows for a greater mass of molecules to be stored in the same space. CO_2 also has a low viscosity which lowers the pressure required to store it. For this project, CO_2 will be injected in a supercritical state and, based on the pressure and temperature of the Lyons Formation, will remain as a supercritical fluid throughout the life of the project.

3.4.8 Injection

High Plains is permitted to construct and operate six injection wells designed to sequester 1.5 MMT/yr per well for the EWS Hub. **Table 3** summarizes planned injection for each EWS Hub project.

3.4.9 Boundary Conditions

The initial conditions for the simulation model are assumed to be in a pseudo-infinite acting reservoir fully saturated with brine water. From well log and seismic analysis, the Lyons Formation sandstone was determined to pinch out to the northwest and to the southeast of the area of interest. Therefore, the northwest and southeast edges have been established as no-flow boundaries for modeling purposes. Conversely, the northeast and southwest edges of the model have volume modifiers in place, allowing them to act as open boundaries. To simulate a pseudo-infinite acting boundary and pinch-out of the Lyons Formation sandstone, the red grid blocks at the east and west edges of the model are adjusted with a volume multiplier equal to 739 times the volume of the blue grid blocks in the interior of the model. The volume multiplier simulates 70 miles of additional pore volume from the model edge.

3.4.10 Modeling Results

Once all variables were input, the simulation model was run with the primary objective to maximize storage capacity and minimize the lateral extent of CO_2 plume. The objectives were achieved by optimizing injection patterns and well placement, as well as performing sensitivity analyses. The maximum extent of the plume is assumed to be the point where the concentration of supercritical-phase CO_2 reaches below 2 percent saturation.

The Lyons Formation sands were upscaled into eight distinct 7-foot layers that were all simultaneously injected with supercritical CO_2. The top of the Lyons Formation is bound by an upper shale (Chugwater) that is a physical trap preventing the upward migration of CO_2. Supercritical CO_2 is more buoyant than water; thus, the CO_2 migrates to the upper 7-foot layer of the modeled Lyons Formation. The maximum extent of the plume was measured from this uppermost layer.

Figure 8 shows modeling results of the predicted CO_2 plume radius over time. As indicated by negligible change after 2065 (10 years after the end of injection), the plumes are considered stabilized by that time.

The increase in pressure experienced from injection operations was also modeled. **Figure 9** represents the pressure buildup at the end of injection. In the model, the reservoir experiences a maximum pressure buildup of 1,100 psi. This buildup does not exceed 90 percent of the fracture pressure at that location, allowing for safe injection of supercritical CO_2.

Table 3. Injection Details

Plume	Total Sequestered Volume (MMT)	Injection Begins (Year)	Injection Ends (Year)	Injection Total (Years)
Juniper	13*	2025	2043	18
Old Barberry	2	2025	2026	1.5
Barberry	31	2025	2050	25
Spirea	10	2025	2040	15
Azalea	45	2025	2055	30
Cypress	15	2025	2040	15

*Anticipated volumes after permit modification approval to incorporate Juniper into the EWS Hub

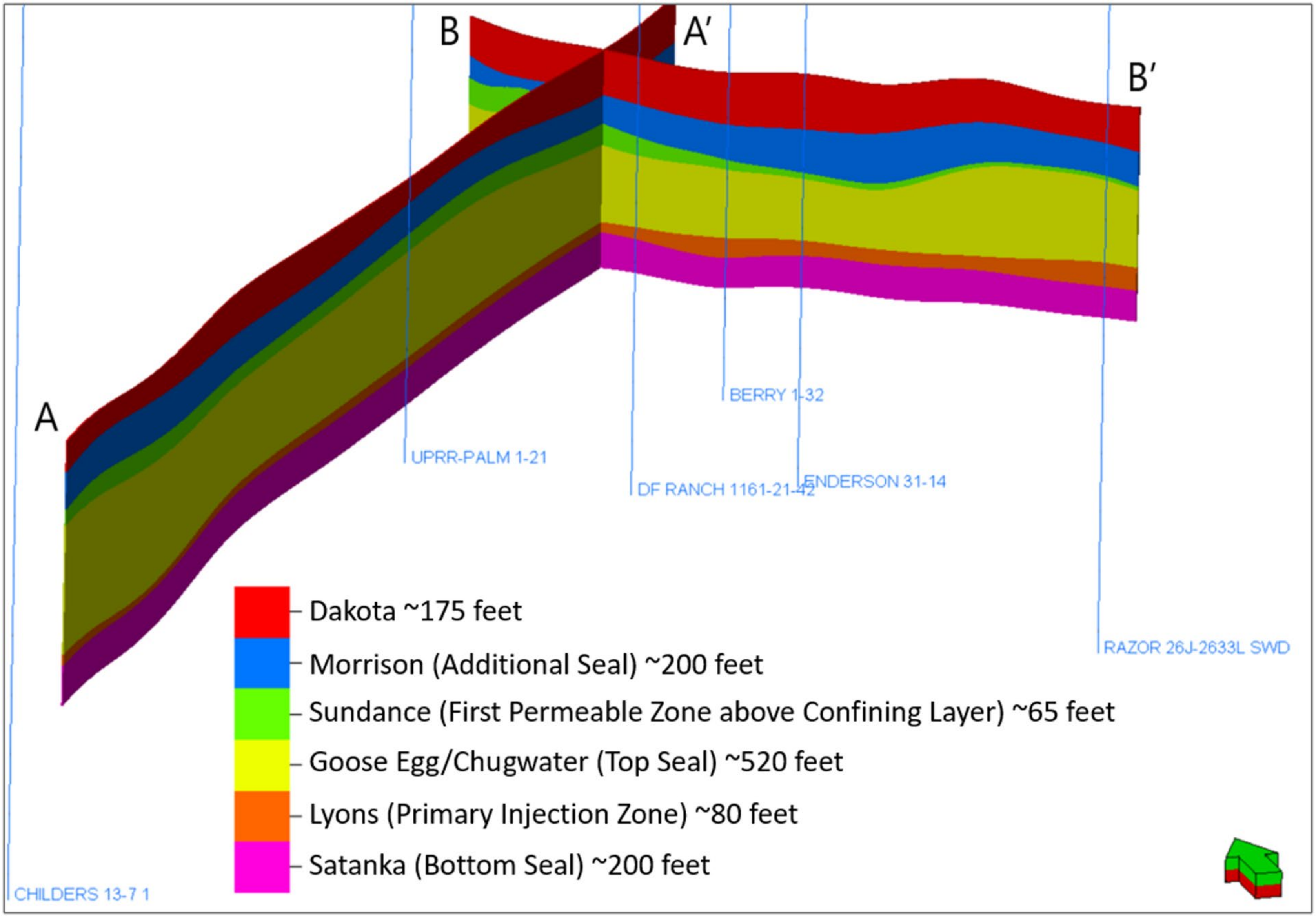

Figure 5. Model Layers.

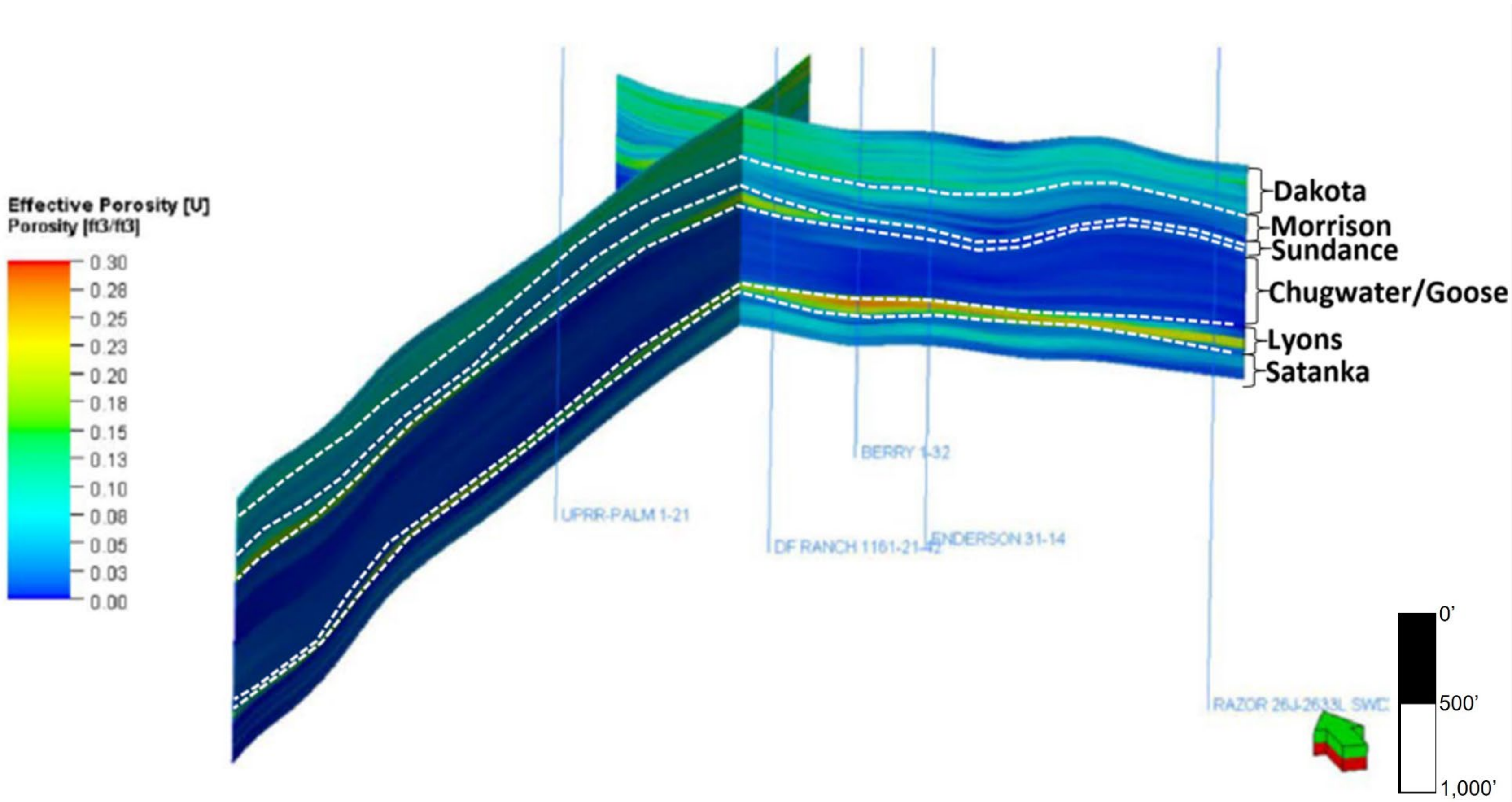

Figure 6. Distribution of Porosity Using Simple Kriging Methodology.

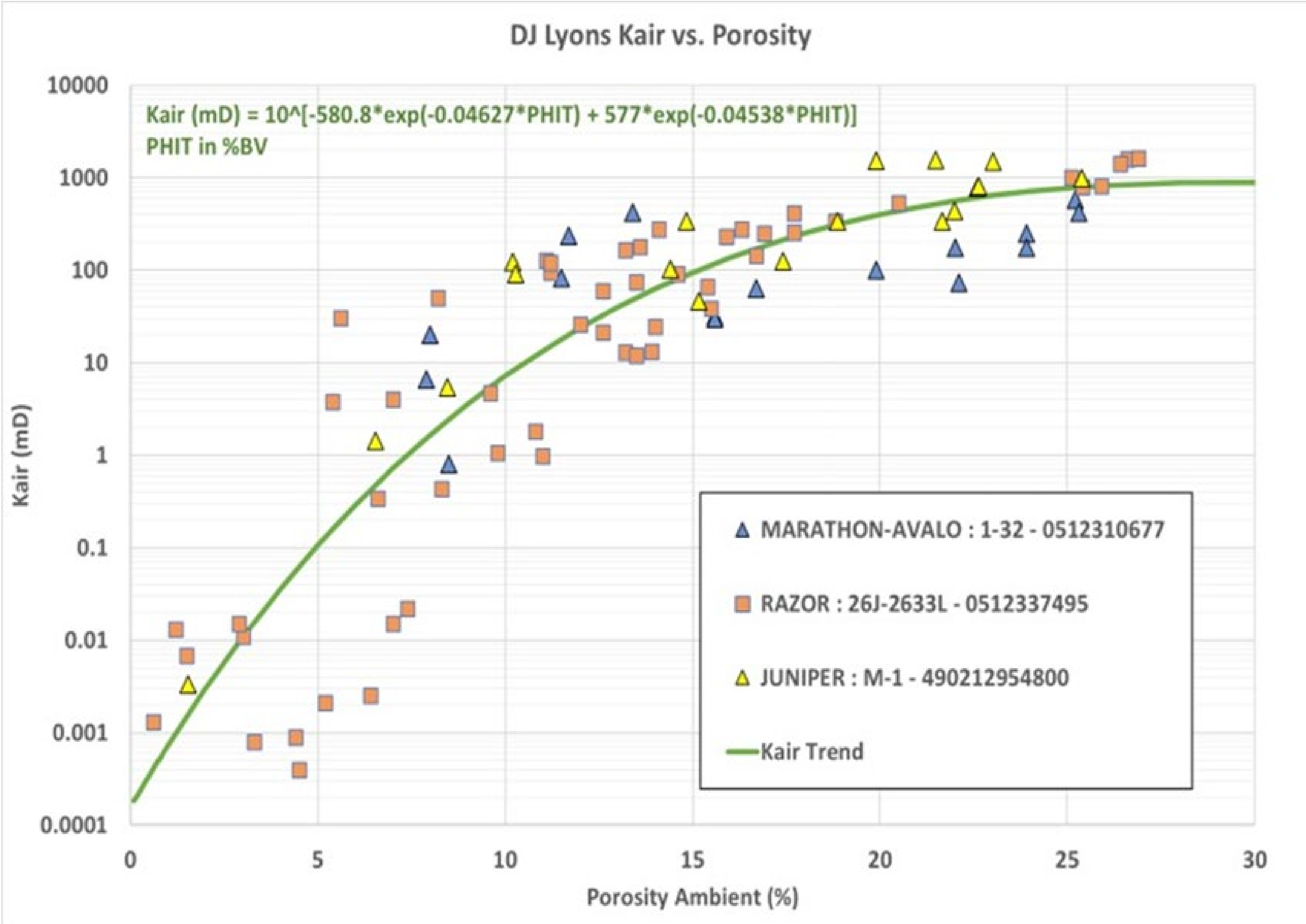

Figure 7. Porosity and Permeability Relationship.

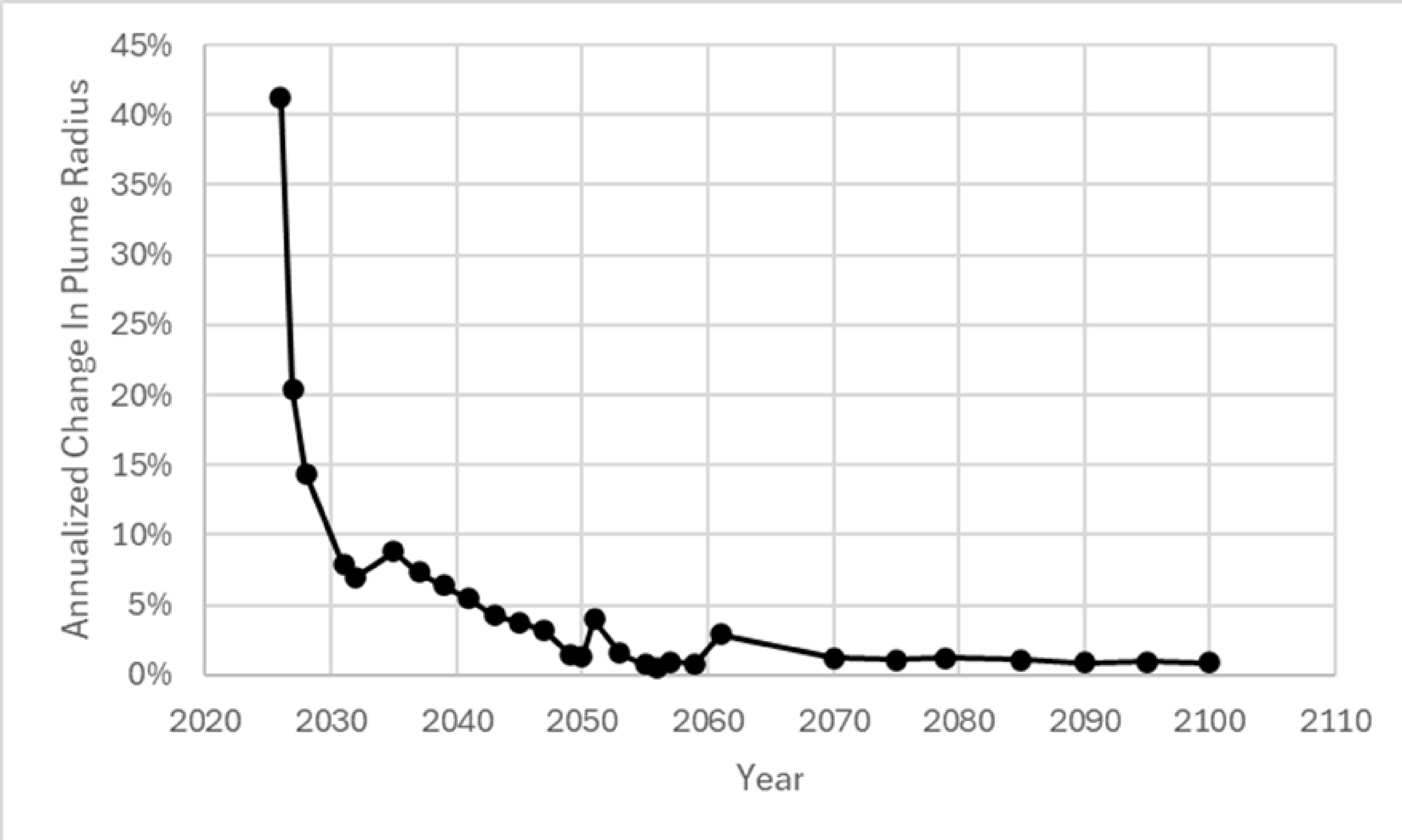

Figure 8. Modeled Change in Plume Radius, EWS Hub. Annualized percent change in plume radius from the first year of injection through the end of post-injection site care (site closure), combined plume. Uses the plume area with saturation greater than 2 percent and assumes that the area is a circle.

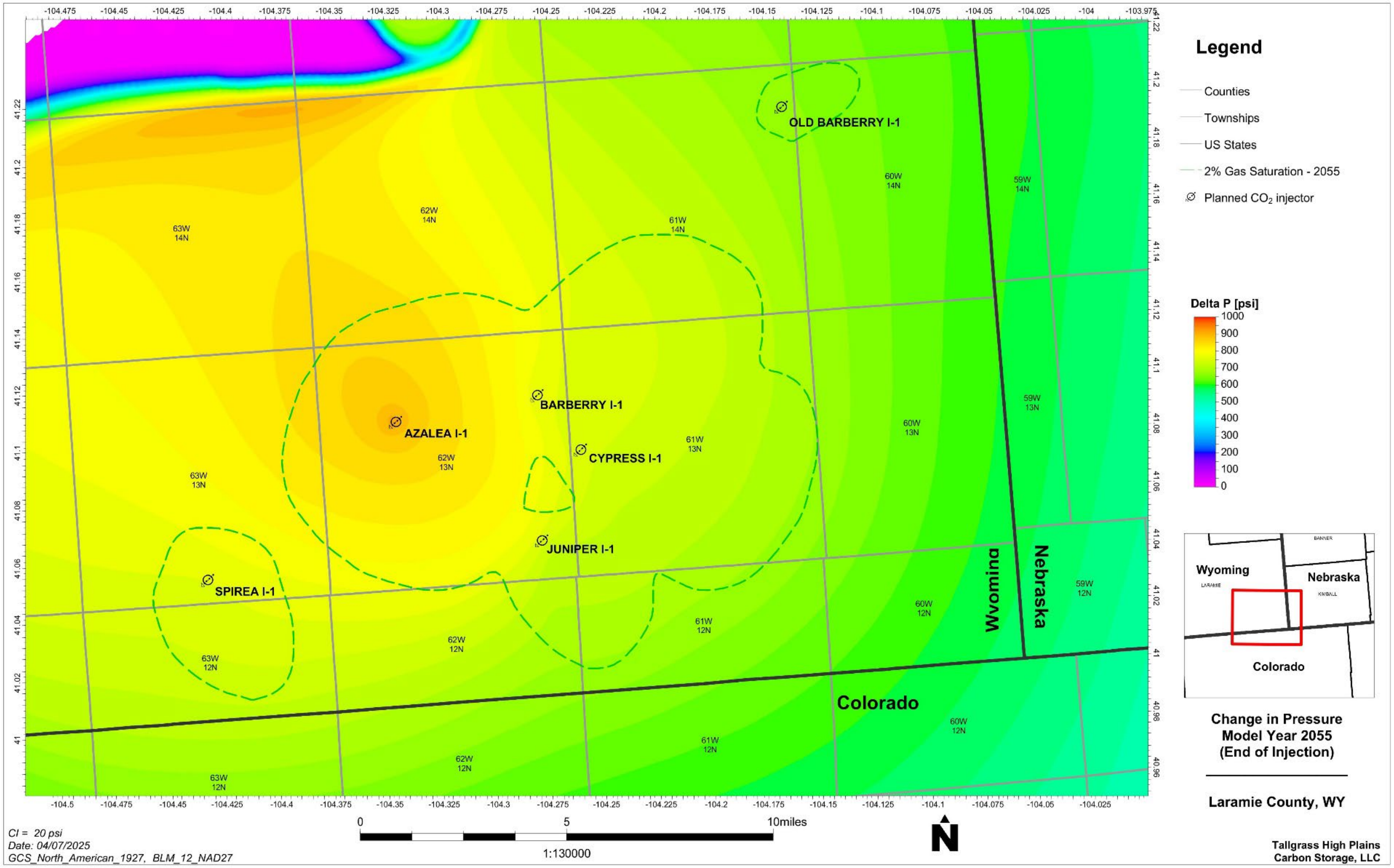

Figure 9. Change in Pressure, Model Year 2055 (End of Injection). Represents the pressure buildup seen within the reservoir after thirty years of injection, year 2025 to 2055.

4. Delineation of the Monitoring Areas

Reservoir simulation modeling (Section 3.4) was used to define the MMA and the active monitoring area (AMA), as described in Sections 4.1 and 4.2. In determining the monitoring areas, the extent of the separate-phase CO_2 plume is equal to the point where the concentration of supercritical-phase CO_2 reaches below 2 percent saturation.

The monitoring time frame will be the same as the post-injection site care (PISC) time frame in the Class VI permit. At the conclusion of the PISC period, a request for discontinuation of Subpart RR reporting will be submitted including a demonstration that current monitoring and modeling show that the cumulative mass of CO_2 reported as sequestered is not expected to migrate in the future or encounter leakage pathways.

4.1 Maximum Monitoring Area

As defined in Subpart RR, the MMA is equal to or greater than the area expected to contain the free-phase CO_2 plume until the CO_2 plume has stabilized plus an all-around buffer zone of at least 0.5 mile. **Figure 10** shows the MMA as defined by the final extent of the stabilized CO_2 plume (50 years after the end of injection) plus a 0.5-mile buffer.

4.2 Active Monitoring Area

The AMA boundary was established by superimposing two areas (40 CFR § 98.449):

- *Area #1:* The area projected to contain the free-phase CO_2 plume at the end of year *t*, plus an all-around buffer zone of 0.5 mile or greater if known leakage pathways extend laterally more than 0.5 mile.
- *Area #2:* The area projected to contain the free-phase CO_2 plume at the end of year $t + 5$.

The AMA boundary was determined for the time period ("*t*") corresponding to 50 years after the end of injection. Area #1 was taken as the plume area plus an all-around buffer zone of 0.5 mile. Area #2 is smaller or equal in all directions; therefore, the final AMA was defined as Area #1 (**Figure 10**).

High Plains has established one AMA boundary for 50 years after injection ends and does not anticipate any expansion of the monitoring area under 40 CFR § 98.448 under the currently planned project operating conditions. Given the definitions used to define the MMA and AMA, the AMA is functionally equivalent to the MMA. Instituting monitoring throughout the entire MMA boundary provides maximum operational flexibility.

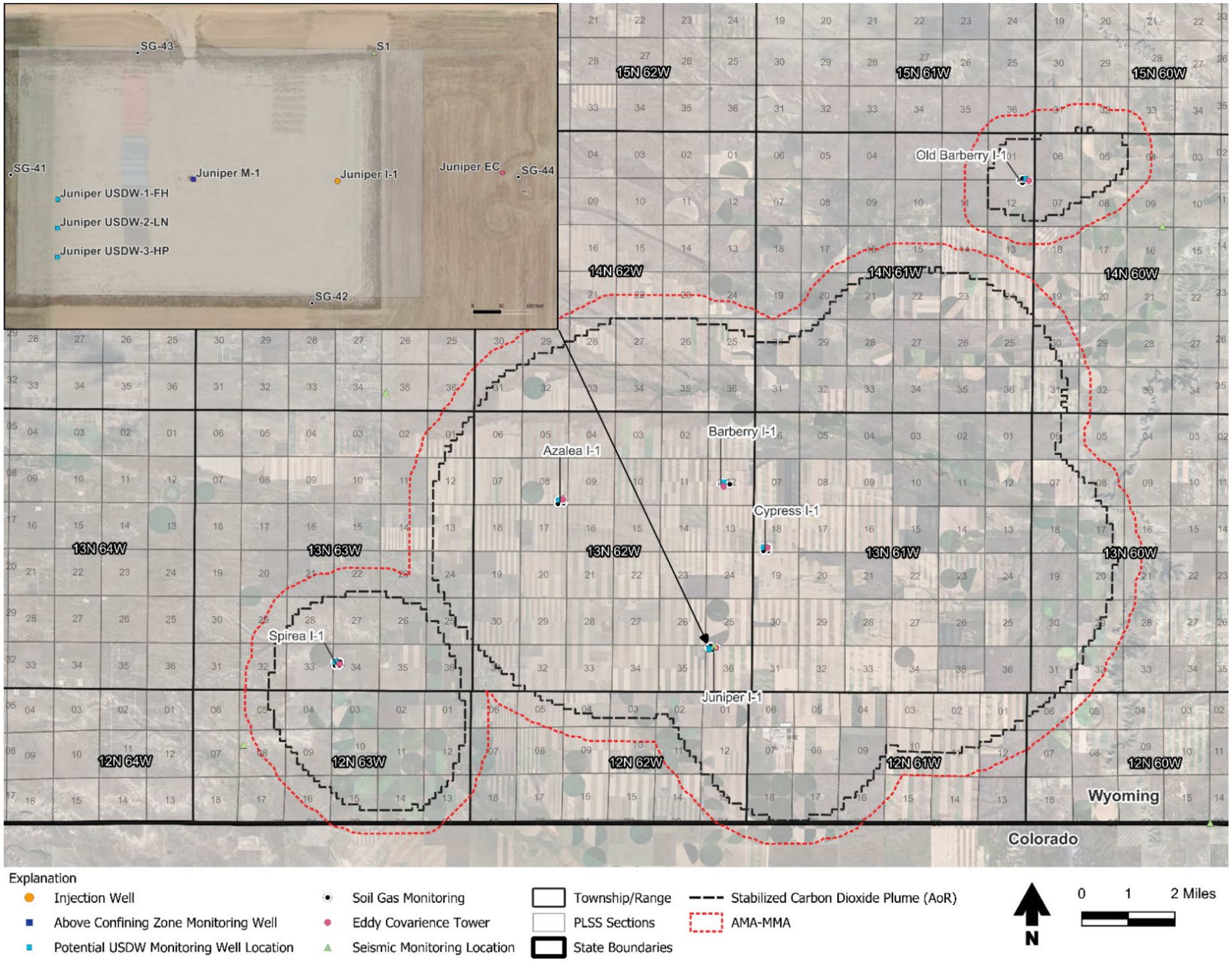

Figure 10. Project Location, Monitoring Locations, and AMA-MMA. Eddy covariance monitoring is discussed in Section 6.4.2 and soil gas monitoring is discussed in Section 6.5.2. Each project will include monitoring locations in orientation similar to that shown for Juniper inset.

5. Identification and Assessment of Potential Surface Leakage Pathways

This section assesses potential pathways for leakage of stored CO_2 to the surface. Monitoring protocols that will be in place for each potential pathway are discussed. Section 6 describes how High Plains will develop the inputs used in the Subpart RR mass-balance equation (Equation RR-12). Any incidents that result in CO_2 leakage through the wellbore and into the atmosphere will be quantified as described in Section 6.

5.1 Pipelines/Surface Equipment

The EWS Hub injector wellheads and the pipelines that transport CO_2 are potential pathways to allow CO_2 to leak to the surface. Leakage is most likely to be the result of aging and use of the surface components over time. The accumulation of wear and tear on the surface components, especially at the flanged connection points, is the most probable cause of the leakage. Another possible cause of leakage is the release of air through relief valves, which are designed to alleviate pipeline overpressure. Leakage can also occur when the surface components are damaged by an accident or natural disaster, causing CO_2 to be released. Therefore, High Plains infers that there is minor potential for leakage via this route.

There is a possibility of fugitive emissions from surface equipment in the event of equipment failure. CO_2 will occasionally need to be vented from surface equipment for operational maintenance. High Plains will monitor and report this CO_2 as part of its reporting requirements under 40 CFR § 98.446(f)(3).

Likelihood: Compliance with applicable pipeline and UIC regulations ensures that likelihood of leakage via this pathway is minor.

Timing*:* Surface component leakage is only a concern during the injection operation phase. Once the injection phase is complete, the surface components will no longer be able to store or transport CO_2, eliminating any potential risk of leakage.

Magnitude*:* Depending on the component's failure mode, the magnitude of the leak can vary greatly. For example, a rapid break or rupture could release large amounts of CO_2 into the atmosphere almost instantly, while a slowly deteriorating seal at a flanged connection could release only a small volume of CO_2 over several hours or days.

Should leakage be detected between the flow meter used to measure injection quantity and the injection wellhead, the mass of released CO_2 will be quantified following the requirements of EPA's GHGRP as referenced in 40 CFR § 98.444(d).

Monitoring*:* Routine field inspection and remote pipeline monitoring will be conducted to detect any potential leakage from pipelines and surface facilities. Continuous surface air monitoring (eddy covariance tower) and semiannual soil gas monitoring will also be in place to detect any surface leakage.

5.2 Wellbores

The project-related injection and monitoring wells will be monitored and maintained to prevent wellbore integrity issues. CO_2 migration could occur along an injection or monitoring well due to a degraded cement bond or corrosion of the casing and completion. Any well that penetrates the injection zone creates a possible migration pathway if the CO_2 plume reaches its position.

All of the injection and monitoring wells involved in the project will be permitted by the State of Wyoming in accordance with Chapter 24 of the WDEQ regulations. High Plains is required to demonstrate to WDEQ that Class VI wellbores do not pose a threat of leakage. Injection well tubing and casing pressures will be monitored continuously. Designs for each injection well are engineered to govern the rate and pressure of CO_2 injection. Pressure monitors on the injection wells are programmed to flag pressures that statistically deviate from design. Leakage on either the inside or outside of the injection wellbore would cause pressure inflections that would be detected through this approach. Injectors will also be monitored with mechanical integrity tests (MITs) and pressure tests to ensure internal and external integrity. If monitoring data lead to identification of a well integrity issue, High Plains will address the issue with corrective actions.

Likelihood*:* The probability that an existing or new well causes leakage to surface is minor. There are three abandoned wells within the CO_2 plume area that penetrate the injection zone (Cypress M-2 [API# 49-021-29598], Fritz 1 [API #49-021-05033], and UPRR Palm 1-21 [API #49-021-20254], and the injection and monitoring wells are designed, operated, and monitored according to WDEQ regulations. The monitoring program assesses the mechanical integrity of wells to ensure that well integrity is maintained.

Timing*:* Wellbore leakage risk from project wells will be highest during the injection phase. Risk will decrease after injection, most notably when the injection well is plugged. The wells will be plugged to WDEQ Class VI standards.

Magnitude*:* Leakage of CO_2 mass from project wellbores is considered to be negligible for the reasons previously described in this section (Section 5.2).

Monitoring*:* Wellbore monitoring will include MITs, injection well pressure and rate monitoring, annulus pressure monitoring, surface and near-surface (USDW) monitoring, and inspections. An annual temperature log via wireline or distributed temperature sensing (DTS) will be conducted in each injection well. Permanent installation of distributed temperature sensing (DTS)/distributed acoustic sensing (DAS) fiber behind casing has been executed or planned in all M-1 wells and will allow for future utility should these measurements be needed. Surface air (eddy covariance tower), soil gas, and USDW groundwater monitoring will also be instituted in the vicinity of each injection site.

5.3 Leakage through the Confining Zone

Leakage out of the Lyons Formation could result in elevated concentrations of indicator parameter(s) in groundwater sample(s) or other evidence of CO_2 leakage into shallow groundwater. Fluid leakage risk is low due to the significant thickness (>7,500 feet) of intervening geologic units above the sequestration zone.

High Plains conducted a seismic evaluation of 10 quality 2D lines within the region of the project area to confirm structural mapping and locate any potential faulting or fracturing within the area. The review also incorporated published public domain interpretations of surrounding 3D surveys for Silo Field, North Mustang Field, and Hereford Field. The 3D surveys were not licensed or purchased, as the surveys do not cover the project area. No faults that intersect the CO_2 plume were identified in the 2D seismic evaluation. Faulting was observed in Hereford Field, located 8 to 10 miles south of the EWS Hub project area, with a general orientation of east to west. These subsurface features have been evaluated and do not appear to intersect the modeled plume migration of any of the EWS Hub injection project locations. No transmissive fractures were identified based on a wireline image log of Juniper M-1 and Azalea I-1.

Diffusion of CO_2 through the upper confining zone (Goose Egg and Chugwater Formations) is not expected to result in significant loss from the storage reservoir given the low permeability (0.001 mD) and thickness (>480 feet) of these zones.

High Plains will operate the project to ensure containment of CO_2. Leakage will be avoided by ensuring injection well integrity through the following means:

- Conducting well maintenance and MITs
- Maintaining the injection pressure below 90 percent of the fracture gradient of the confining unit
- Assessing monitoring data to ensure competency of the confining layer
- Monitoring the Sundance Formation interval that overlies the confining unit to identify leakage before migration to shallower aquifers

Likelihood*:* Negligible for the reasons previously described in this section (Section 5.3).

Timing*:* Leakage risk will be similar via this pathway during the operation and post-injection project phases.

Magnitude*:* For reasons previously given in this section (Section 5.3), anticipated leakage magnitude is negligible.

Monitoring*:* Monitoring for leakage through the confining zone will include groundwater monitoring above the confining zone, annual DTS or temperature logs in all injection wells (Juniper I-1, Azalea I-1, Barberry I-1, Old Barberry I-1, Cypress I-1, and Spirea I-1) and M-1 monitoring wells (Juniper M-1, Azalea M-1, Barberry M-1, Old Barberry M-1, Cypress M-1, and Spirea M-1), surface air monitoring (eddy covariance tower), soil gas monitoring, and continuous injection well pressure monitoring.

5.4 Induced or Natural Seismic Event

In 2002, WSGS published a report on basic seismological characterization of Laramie County, Wyoming. The study analyzed historical seismicity, short- and long-term seismic probability, nearby faulting, and the Uniform Building Code to improve understating of potential risks of seismicity in Wyoming and their potential to incur damage. Findings from the study suggest that the 2,500-year probabilistic map of Wyoming should be referenced for Laramie County seismic analyses, as the map represents a conservative approach in the interest of public safety. The probabilistic acceleration map, shown in **Figure 11**, illustrates that the EWS Hub project area is located in one of the lowest-risk areas of Wyoming. Historical earthquake data were obtained from the USGS Earthquake Hazards database (USGS, 2022) for recorded earthquakes in the regional vicinity of the EWS Hub project area in the last 100 years. The search results, shown in **Figure 12**, identified no events within 40 miles of the EWS Hub project area.

Average depth of prior seismic hazard in the region based on reviewed historical seismicity has been approximately 3.7 miles, which is significantly deeper than the proposed injection zone.

***Likelihood**:* A probabilistic analysis indicates that the project is located in one of the lowest-risk areas of Wyoming for natural seismicity. Based on project operating conditions, it is highly unlikely that injection operations would ever induce a seismic event.

***Timing**:* Seismicity risk is negligible; however, pressures will be highest during the injection phase of the project. As a result, if induced seismicity were to occur it would likely correspond to the injection phase of the project.

***Magnitude**:* For reasons previously given in this section (Section 5.4), anticipated leakage magnitude is negligible.

***Monitoring**:* High Plains will monitor the USGS Intermountain West Seismic Network for seismic events.

5.5 Lateral Migration

It is highly improbable that injected CO_2 will migrate laterally outside the modeled plume area due to the buoyant properties of supercritical CO_2, the nature of the geologic structure, and the planned injection approach. As displayed in **Figure 3**, there is a structural dip in the injection zone (Lyons Formation) towards the west. This structural dip was accounted for in the computational modeling used to define the area of the stabilized CO_2 plume. Although CO_2 is predicted to migrate in the updip direction, it is slowed and eventually stopped by capillary trapping mechanisms within the predicted boundaries of the AMA-MMA (e.g., Zhao et al., 2014).

***Likelihood**:* Leakage via the lateral migration pathway is not anticipated.

***Timing**:* Although leakage via lateral migration is not anticipated, the risk is greatest when pressures are highest (generally at the end of the injection period).

Magnitude*:* Magnitude of any leakage is considered negligible, as leakage via lateral migration is not anticipated.

Monitoring*:* The CO_2 plume will be monitored indirectly through time-lapse 2D seismic, as listed in the Class VI permits. The 2D seismic will be used to detect any risk of lateral migration outside of the EWS Hub modeled plume area.

5.6 Drilling Through the CO_2 Area

It is possible that at some point in the future, drilling through the confining zone and into the Lyons Formation may occur.

Likelihood: The possibility of this activity creating a leakage pathway is extremely low because no oil and gas resources are identified and future well drilling would be regulated by WOGCC (oil and gas wells, Class II injection wells) or WDEQ (Class VI injection wells, all other UIC well classes), and will therefore be subject to requirements that fluids are contained in strata in which they are encountered.

Timing*:* Leakage via this pathway is not anticipated; however, leakage risk is greatest during future time periods if drilling through the confining zone and into the injection zone were to occur.

Magnitude*:* Leakage via this pathway is not anticipated to occur; therefore, magnitude of any leakage is considered negligible.

Monitoring: In the state of Wyoming, High Plains will receive a unitization order from the WOGCC for a unit area that encompasses the AoR (CO_2 Area), which will also be mapped in their records. If there is an application for a permit to drill a well (APD) proposed within a High Plains unit area that is proposed to penetrate the caprock, then High Plains will be notified by either or both the APD applicant and the WOGCC. High Plains will also assess potential drilling activity via the WOGCC online data explorer. In the unlikely event that third party drilling is conducted through the Lyons formation High Plains will coordinate with the operator regarding wellbore monitoring (Section 5.2) and if the site is accessible wellheads will be added to surface monitoring (Section 5.1).

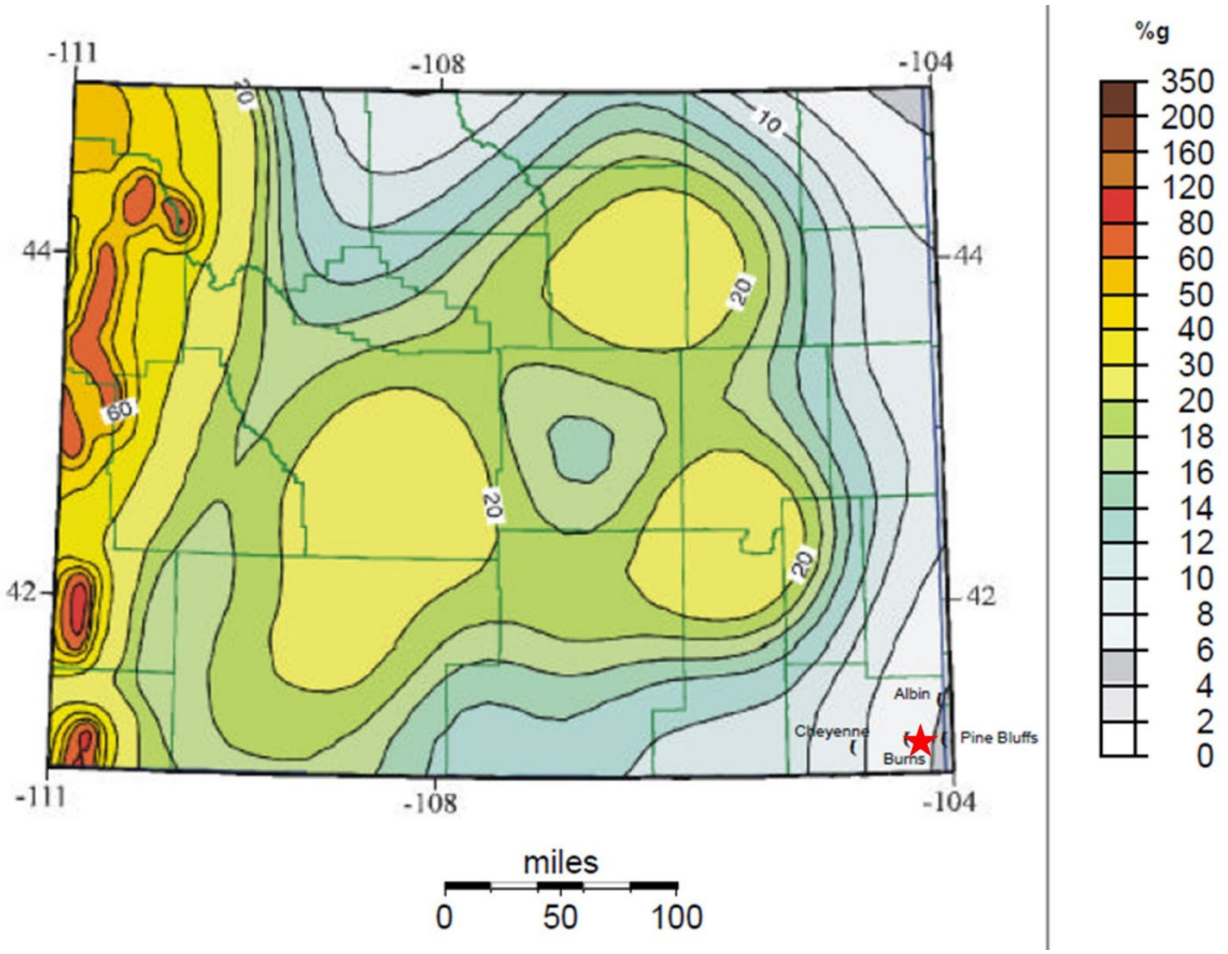

Figure 11. USGS 2,500-Year Probabilistic Acceleration Map of Wyoming. The contours represent a 2 percent probability of exceedance in 50 years. The red star is the approximate location of the EWS Hub project area (USGS, 2002).

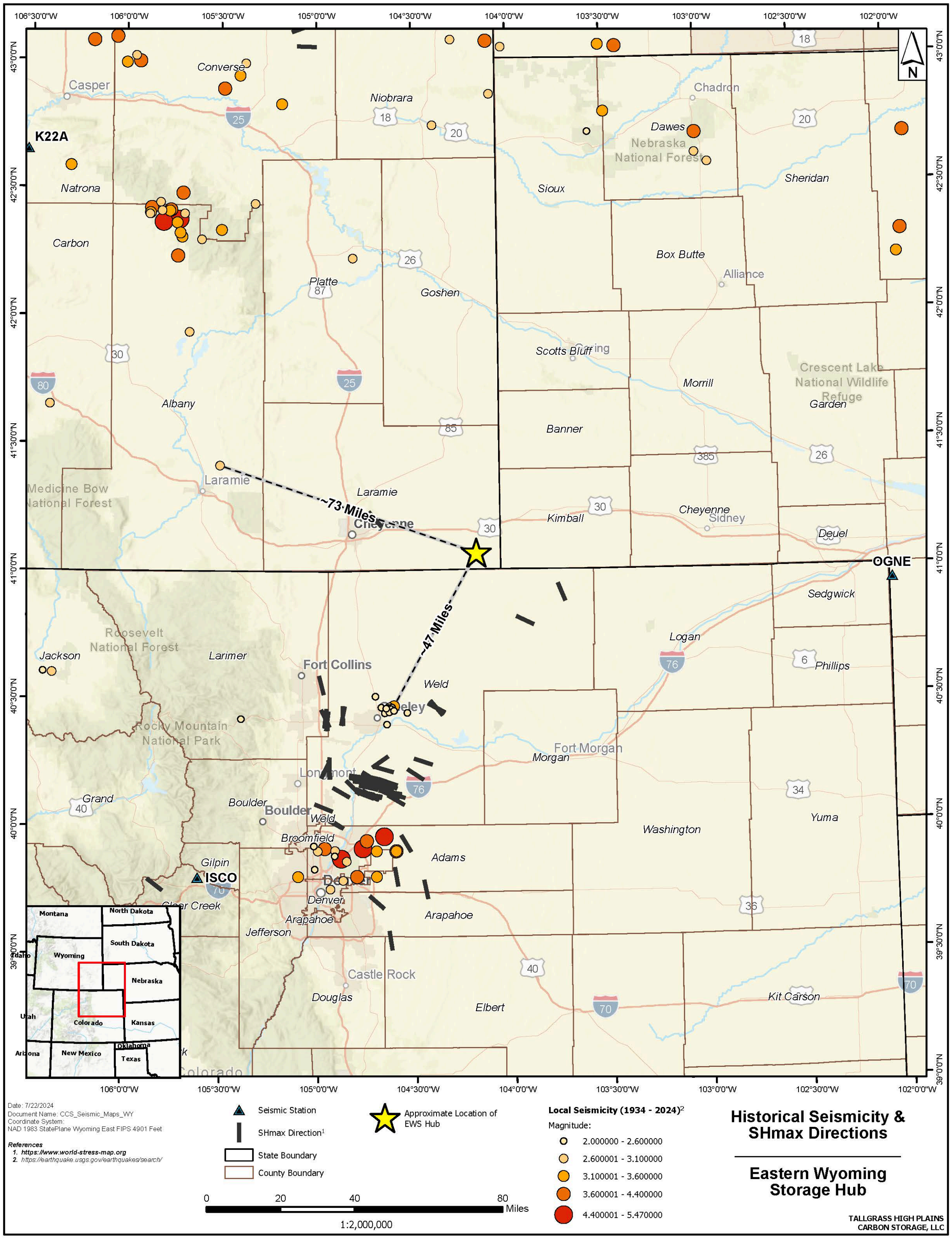

Figure 12. USGS-Reported Earthquakes Over the Past 100 Years. The yellow star is the approximate location of the EWS Hub Project Area.

6. Monitoring and Considerations for Calculating Site-Specific Variables

High Plains will establish a Central Control Center to ensure that personnel have access to the continuous data being acquired during operations. The Central Control Center will receive CO_2 metering data and continuous surface-air monitoring data (eddy covariance tower). **Figure 4a** identifies the meters that will be used to evaluate, monitor, and report on the injection project.

6.1 CO_2 Received

A custody-transfer meter will be used at the CO_2 source (pipeline) to continuously measure the mass and composition of CO_2 received at each EWS Hub injection site. Metering protocols will follow the prevailing industry standard(s).

6.2 CO_2 Injected into the Subsurface

Injected CO_2 associated with geologic sequestration will be calculated using flow meters monitoring the injection wells (Juniper I-1, Spirea I-1, Azalea I-1, Barberry I-1, Old Barberry I-1, and Cypress I-1).

6.3 CO_2 Produced, Entrained in Products, and Recycled

No CO_2 will be produced, entrained in products, or recycled.

6.4 CO_2 Emitted by Surface Leakage

As discussed in Section 5.1, standard GHGRP procedures as referenced at 40 CFR § 98.444(d) will be used to estimate surface leaks from equipment if leakage is detected between the flow meter used to measure injection quantity and the injection wellhead. In addition, an event-driven process will be used to assess, address, track, and, if applicable, quantify potential CO_2 leakage to the surface. Reporting will be completed in accordance with 40 CFR § 98.446(f)(3).

6.4.1 Injection Well Monitoring

Injection well pressure, temperature, and injection rate will be continuously monitored. If the measurements of injection pressure or rate exceed the specified set-points determined for any of the EWS Hub Injection wells, a data flag will automatically trigger, and field personnel will investigate and resolve the issue. These deviations will be reviewed by well management personnel to determine if CO_2 leakage may be occurring. Deviations are not necessarily indicators of leaks, but they indicate that injection rates and pressures are not conforming to the planned pattern of injection. In many cases, problems are straightforward to fix (e.g., recalibrating a meter), and there is no CO_2 leakage. If issues that are not readily resolved arise, a more detailed investigation and response will be initiated. To quantify leakage to the surface, an estimate of the relevant parameters (e.g., the rate, concentration, and duration of leakage) will be made to quantify the leakage mass. Depending on specific circumstances, these determinations may rely on engineering estimates. An example methodology that may be used for early detection and rate estimation of CO_2 wellbore leakage, based on temperature analysis, is outlined in Mao et al. (2017).

6.4.2 Broad Continuous Surface Air Monitoring

Broad aerial surface air monitoring will be conducted with permanently installed eddy covariance towers (**Figure 10**). The eddy covariance towers will consist of a solar-powered 3D sonic anemometer and open-path gas analyzer. The tower will be installed downwind of the prevailing wind direction from the injection well and injection zone monitoring well. Annual average prevailing wind direction in the vicinity is from the west (WRCC, 2022; Cheyenne AP KCYS station). All eddy covariance tower locations are chosen to be downwind (east) of the injection well and injection zone monitoring well and in a location with access for equipment installation and servicing.

Monitoring equipment will be installed at a height of approximately 4 to 5 meters (13 feet). In general, the upwind distance represented by the tower height can be determined by the 1:100 rule. In this case, with a 4-meter tower height, the majority of measured flux will come from an oval-shaped area from near the tower to 400 meters (1,312 feet) upwind (Burba, 2013).

Gas emission rate is calculated from air density, vertical wind speed, and dry CO_2 mole fraction. Air density fluctuation is assumed to be negligible (Burba, 2013). Wind speed will be measured with the sonic anemometer. CO_2 mole fraction will be measured with the gas analyzer. Eddy covariance tower instrumentation will be installed consistent with protocols listed in Burba (2013). The sonic anemometer will be a Campbell Scientific CSAT3 or equivalent. The CO_2 gas analyzer will be a LI-COR Biosciences LI-7500A or equivalent. The gas analyzer will be positioned at or slightly below the sonic anemometer level, with a separation distance less than 20 centimeters. Vibration will be minimized by the use of several guy wires attached at the middle of the tower.

Manual cleaning of the gas analyzer will be performed on an as-needed basis when anomalous readings or excessive zero-drift in the data is observed. Factory calibration is assumed to be stable for at least several years, and will be checked once every six months as a precaution.

Data processing will be conducted with the automated open-source package EddyPro (LI-COR Biosciences, 2021), and will be presented as hourly averaged CO_2 concentrations and gas emission rates. Detection of anomalous and increasing CO_2 concentrations will lead to eddy covariance tower equipment testing and further targeted surface air investigation (described in Sections 6.4.3 and 6.4.4). In the event of leakage detected by the eddy covariance tower, mass will be calculated based on the increased CO_2 subsurface flux rate.

6.4.3 Targeted Point Source Monitoring

Targeted monitoring of potential CO_2 point sources will be conducted at injection wellheads, as well as at pipelines/delivery systems within the MMA. Three artificial penetrations within the AoR penetrate the confining zone. Remedial work will be completed on Fritz 1 prior to injection. UPRR-Palm 21 contains adequate cement plugs across relevant formations and does not require corrective action. Cypress M-2 was drilled by High Plains and has since been plugged back to the surface.

Intermittent point-source monitoring will occur at a minimum of once per quarter at the injection wells and above confining zone monitoring wells, and once per year at other locations. Targeted point-source monitoring will also be triggered by indications of leakage from eddy covariance monitoring and/or other monitoring results. Point-source measurement will be conducted with a portable non-dispersive infrared (NDIR) CO_2 meter. CO_2 concentration, relative humidity, and temperature will be recorded at each location and collected with an attached USB Data Logger. measurement location will be recorded with a handheld global positioning system (GPS) unit, and corresponding wellhead or other infrastructure location will also be recorded. Leakage will be quantified based on leak flow rate and CO_2 gas concentration.

6.4.4 Inspection and Leak Detection

High Plains will perform inspection of wellheads, valves, and piping, including the following:

- Field inspections will be conducted on a routine basis by field personnel. Field personnel will be trained to identify visual indications of leaking CO_2 and other potential problems in the field.
- Injection well wellheads will be inspected on a quarterly basis, which will include the following and will be recorded on a well inspection data sheet:
  - ◇ Visual inspection for general condition of the wellhead system, including for external corrosion/coating damage and mechanical damage
  - ◇ Inspection of all bolts for needed replacement
  - ◇ Reenergizing wellhead seals as needed, reapplying screw and nut torque as needed, replacement of any needed fittings, packing, hand wheels, pins, or bearings
  - ◇ Visual inspection of all pipelines within 100 feet of the injection wells
  - ◇ Identification of faulty valves or gasket leaks
  - ◇ Verification of adequate fittings for wireline equipment and CO_2 injection
  - ◇ CO_2 gas analysis with a handheld meter at the wellhead and pipelines within 100 feet of the wellhead (pSense High Accuracy portable CO_2 meter or equivalent, with CO_2 measurement range of 0 to 9,999 ppm and accuracy of 30 ppm).
- Instrumentation will be installed on pipelines and facilities that allow the 24/7 operations staff to monitor the process and potentially spot leaks. High Plains will use a supervisory control and data acquisition (SCADA) software system to implement operational control decisions on a real-time basis throughout the project area to assure the safety of field operations and compliance with monitoring and reporting requirements in existing permits. Both manual and automatic shutdowns will be installed in the MMA to ensure that leaks are addressed in a timely manner. Potential leakage identified with dynamic modeling will be assessed in the field, including by visual inspection and gas analysis, as well as by soil gas analysis in the case of buried pipelines.
- Biannual testing of surface safety valve systems will be conducted to ensure their ability to hold anticipated pressure. Surface valve testing will be consistent with API Specification 6AV1. Annual testing of master valve and wellhead isolation valves will be conducted for proper function and verification of the valves' ability to isolate the well.

Upon finding that a surface safety valve is inoperable, High Plains will immediately shut in the well and repair the valve within 90 days, or will determine an appropriate alternative time frame for testing a valve or addressing an inoperable surface or subsurface safety valve. Documentation of all inspections, tests, and results will be maintained by High Plains and will be available for EPA review during the active life of the project.

6.5 Monitoring for Potential Leakage from the Injection Zone

In addition to the surface-based monitoring previously described in Section 6.4, additional monitoring for potential leakage from the subsurface will include groundwater and soil gas monitoring. Annual permanent fiber optic sensing or annual temperature logging will occur in all EWS Hub injection wells.

6.5.1 Groundwater Monitoring

Monitoring wells to measure pressure, temperature, and fluid composition will be dedicated to geologic sequestration. These dedicated wells will monitor above the confining zones in the overlying USDWs.. Baseline analysis will be established for each of these wells. Any deviation from the baseline analysis will be assessed for potential indications of leakage. CO_2 leakage rates will be quantified based on measured increases in CO_2 concentration in formation fluids above the AoR.

Monitoring well locations are shown on **Figure 10** and are listed in **Appendix A**. Monitoring well details including chemistry monitoring parameters are listed in **Appendix B**. Monitoring well data collection procedures will be consistent with protocols listed in the Class VI permit application.

6.5.2 Soil Gas Monitoring

High Plains will perform soil gas monitoring including sampling of CO_2 and ratio of CO_2 to methane (CH_4) during the injection period. Soil gas composition monitoring will also be performed prior to injection to establish a baseline.

Soil gas monitoring will be performed with the portable flux accumulation chamber method, which offers the advantage of flexibility in sampling locations if leak detection survey monitoring is required, as well as real-time data collection. Baseline soil gas sampling locations are shown in **Figure 10**. If potential leakage is detected during the injection phase, soil gas monitoring locations will be determined based on the available data regarding the location of the potential leakage. In the case of potential leakage via an active well or buried pipeline, soil gas flux will be assessed within 10 feet of the wellbore/pipeline. For potential leakage indicated by broad aerial monitoring, soil gas measurements will be located within the area indicated by the atmospheric monitoring data.

Soil gas monitoring will be conducted with a portable self-powered flux accumulation chamber (LI-COR 8200-01S or equivalent) paired with a CO_2 and CH_4 gas analyzer (LI-7810 CH_4/CO_2/H_2O Trace Gas Analyzer or equivalent). The flux chamber computes real-time soil gas flux. Data will be digitally collected and integrated with GPS coordinates, soil moisture, and soil temperature (Stevens HydraProbe or equivalent). Soil gas flux will be measured at each location until steady-state flux is observed in the real-time observed data. Flux-accumulation chamber collars will be field deployed at each sampling location at least 24 hours prior to sample collection. Data will be processed and digitally stored with the SoilFluxPro software or equivalent. CO_2 flux and gas ratios will be compared to data collected during the baseline period to evaluate potential atmospheric leakage through the soil profile.

6.6 CO_2 Plume Tracking

The extent of the CO_2 plume will be monitored using 2D seismic surveys to understand CO_2 saturation changes through time. The existing seismic surveys, 2D and 3D, will establish a baseline view of the injection interval. One survey will be performed during the injection phase to confirm plume movement and direction. One survey will be performed to confirm plume stabilization after downhole pressure and temperature measurements indicate that the plume has stabilized. The results will be compared to those from the baseline surveys to determine the extent of the CO_2 plumes within the project area.

6.7 Seismicity Monitoring

High Plains will monitor the Intermountain West Seismic Network for seismic events. Historical seismicity within the area will be accounted for in the baseline assessment.

6.7.1 Baseline Analysis

Historical seismicity data from the Intermountain West Seismic Network will be reviewed to establish the baseline. These data will help establish historical natural seismic event depth, magnitude, and frequency to distinguish between naturally occurring seismicity and induced seismicity resulting from CO_2 injection.

6.7.2 Seismic Monitoring Analysis

Throughout the injection phase, monitoring for natural and induced seismic activity will be performed by monitoring data from the USGS Intermountain West Seismic Network.

6.8 Vented Emissions of CO_2 from Surface Equipment

Monitoring efforts will evaluate and estimate leaks from equipment and vented CO_2 as required under 40 CFR § 98.444(d).

7. Approach for Establishing the Expected Baselines

High Plains will use the Central Control Center to continuously monitor operating parameters and to identify any excursions from normal operating conditions that may indicate leakage of CO_2. The following bullets describe the High Plains strategy for collecting baseline information:

- *Visual Inspection:* High Plains field personnel conduct frequent periodic inspections of all surface equipment, providing opportunities to ensure facility and well integrity as described in Section 6.4.
- *Handheld CO_2 Monitors:* High Plains will perform leakage detection at wellheads, valves, and piping in the MMA as defined in Section 6.4.

- *Field Sampling:* Field sampling activities to monitor CO_2 at each EWS Hub injection well will include periodic well (groundwater and gas) and atmospheric sampling from the MMA around the injection wells. Pre-injection data will be collected for one year prior to injection to establish baselines.
- *Continuous Parameter Monitoring:* The Central Control Center will monitor injection rates, pressures, and composition on a continuous basis. High and low set points are programmed, and engineering and operations are alerted if a parameter is outside the allowable window. If a parameter is outside the allowable window, this will trigger further investigation to determine if the issue poses a leak threat.
- *Well Surveillance:* High Plains will adhere to the requirements of WDEQ governing the construction, operation, and closing of a Class VI well, including the requirement for testing and monitoring to ensure mechanical integrity. High Plains routine operation and maintenance procedures for all EWS Hub injection wells will ensure frequent periodic inspection of the wells and opportunities to detect leaks and implement corrective action.
- *Seismic Monitoring Stations:* High Plains will perform seismic monitoring as listed in Section 6.7, including pre-injection data collection from the USGS Intermountain West Seismic Network to establish baselines.

8. Considerations for Site-Specific Variables for the Mass Balance Equations

The following subsections describe how each element of the mass-balance equation (Equation RR-12) will be calculated.

8.1 Mass of CO_2 Received

High Plains will use Equation RR-1 as indicated in 40 CFR § 98.443 to calculate the mass of CO_2 received from the custody-transfer meter immediately downstream of the source (pipeline).

$$CO_{2T,r} = \sum_{p=1}^{4} (Q_{r,p} - S_{r,p}) * C_{CO_{2,p,r}} \quad \text{(Eq. RR-1)}$$

where $CO_{2T,r}$ = Net annual mass of CO_2 received through flow meter r (metric tons)

$Q_{r,p}$ = Quarterly mass flow through a receiving flow meter r in quarter p (metric tons)

$S_{r,p}$ = Quarterly mass flow through a receiving flow meter r that is redelivered to another facility without being injected into your well in quarter p (metric tons)

$C_{CO_{2,p,r}}$ = Quarterly CO_2 concentration measurement in flow for flow meter r in quarter p (wt. percent CO_2, expressed as a decimal fraction)

p = Quarter of the year

r = Receiving flow meter

Given the method by which High Plains will receive CO_2 and the requirements of 40 CFR § 98.444(a):

- All delivery to the EWS Hub Injection Facilities is used (or vented if needed), so quarterly flow redelivered, $S_{r,p}$, is zero (0), and will not be included in the equation.
- Quarterly CO_2 concentration will be taken from the gas measurement database.

High Plains will sum to total mass of CO_2 received using Equation RR-3 in 40 CFR § 98.443:

$$CO_2 = \sum_{r=1}^{R} CO_{2T,r} \text{ (Eq. RR-3)}$$

where CO_2 = Total net annual mass of CO_2 received (metric tons)

$CO_{2T,r}$ = Net annual mass of CO_2 received (metric tons) as calculated in Equation RR-1 for flow meter r

r = Receiving flow meter

8.2 Mass of CO_2 Injected into the Subsurface

Mass of CO_2 injected into the subsurface at each injection well will be calculated with Equation RR-4:

$$CO_{2,u} = \sum_{p=1}^{4} Q_{p,u} * C_{CO_{2,p,u}} \text{ (Eq. RR-4)}$$

where $CO_{2,u}$ = Annual CO_2 mass injected (metric tons) as measured by flow meter u

$Q_{p,u}$ = Quarterly mass flow rate measurement for flow meter u in quarter p (metric tons per quarter)

$C_{CO2,p,u}$ = Quarterly CO_2 concentration measurement in flow for flow meter u in quarter p (wt. percent CO_2, expressed as a decimal fraction)

p = Quarter of the year

u = Flow meter

Aggregated injection at all injection wells will be calculated with Equation RR-6:

$$CO_{2I} = \sum_{u=1}^{U} CO_{2,u} \text{ (Eq. RR-6)}$$

where CO_2 = Total annual CO_2 mass injected (metric tons) through all injection wells

$CO_{2,u}$ = Annual CO_2 mass injected (metric tons) as measured by flow meter u

u = Flow meter

8.3 Mass of CO_2 Emitted by Surface Leakage

High Plains will calculate and report the total annual mass of CO_2 emitted by surface leakage using an approach that is tailored to specific leakage events and relies on standard GHGRP procedures as listed at 40 CFR § 98.444(d). Operators will be prepared to address the potential for leakage in a variety of settings. Estimates of the amount of CO_2 leaked to the surface will depend on several site-specific factors, including measurements, engineering estimates, and emission factors, depending on the source and nature of the leakage.

The process for quantifying leakage will entail using industry standard engineering principles or emission factors. Some approaches for quantification of potential types of leaks that may occur are discussed in Section 6.4. In the event leakage to the surface occurs, the quantity and leakage amounts will be reported, and records will be retained that describe the methods used to estimate or measure the mass leaked as reported in the annual Subpart RR report.

Equation RR-10 in 40 CFR § 98.443 will be used to calculate and report the mass of CO_2 emitted by surface leakage:

$$CO_{2E} = \sum_{x=1}^{X} CO_{2,x} \text{ (Eq. RR-10)}$$

where CO_{2E} = Total annual CO_2 mass emitted by surface leakage (metric tons) in the reporting year

$CO_{2,x}$ = Annual CO_2 mass emitted (metric tons) at leakage pathway x in the reporting year

x = Leakage pathway

8.4 Mass of CO_2 Sequestered in Subsurface Geologic Formations

Equation RR-12 in 40 CFR § 98.443 will be used to calculate the mass of CO_2 sequestered in subsurface geologic formations in the reporting year as follows:

$$CO_2 = CO_{2I} - CO_{2E} - CO_{2FI} \text{ (Eq. RR-12)}$$

where CO_2 = Total annual CO_2 mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year

CO_{2I} = Total annual CO_2 mass injected (metric tons) in the well or group of wells covered by this source category in the reporting year

CO_{2E} = Total annual CO_2 mass emitted (metric tons) by surface leakage in the reporting year

CO_{2FI} = Total annual CO_2 mass emitted (metric tons) from equipment leaks and vented emissions of CO_2 from equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead, for which a calculation procedure is provided in Subpart W

Figure 4a illustrates that CO_2 supplied for geological storage will be metered between the CO_2 source and the injection meter.

8.5 Cumulative Mass of CO_2 Reported as Sequestered in Subsurface Geologic Formations

A sum of the total annual mass obtained using RR-12 in 40 CFR § 98.443 will be used to calculate the cumulative mass of CO_2 sequestered in subsurface geologic formations.

8.6 Data Reporting

High Plains will report all data per regulations listed in 40 CFR § 98.446, including the CO_2 facility source(s) to the pipeline per the following categories: (1) CO_2 production wells, (2) electric generating unit, (3) ethanol plant, (4) pulp and paper mill, (5) natural gas processing, (6) gasification operations, (7) other anthropogenic source, (8) discontinued enhanced oil and gas recovery project, or (9) unknown.

9. MRV Implementation Schedule

The final MRV plan will be implemented upon receiving approval from the EPA, and no later than the day after the day on which the plan becomes final, as described in 40 CFR § 98.448(c). After the injection wells are drilled, High Plains will reevaluate the MRV plan and, if any modifications are a material change per 40 CFR § 98.448(d)(1), High Plains will submit a revised MRV plan as required by 40 CFR § 98.448(d).

10. Quality Assurance and Quality Control

High Plains will meet the monitoring and quality assurance and quality control (QA/QC) requirements of 40 CFR § 98.444 of Subpart RR.

10.1 Greenhouse Gas Monitoring

As required by 40 CFR § 98.3(g)(5)(i), High Plains internal documentation regarding the collection of emissions data includes the following:

- Identification of positions of responsibility (i.e., job titles) for collection of the emissions data
- Explanation of the processes and methods used to collect the necessary data for the greenhouse gas (GHG) calculations
- Description of the procedures and methods that are used for quality assurance, maintenance, and repair of all continuous monitoring systems, flow meters, and other instrumentation used to provide data for the GHGs reported

10.2 Measurement of CO_2 Concentration

All measurements of CO_2 concentrations of any CO_2 quantity will be conducted according to an appropriate standard method published by a consensus-based standards organization or an industry standard practice. All measurements of CO_2 concentrations of CO_2 received will meet the requirements of 40 CFR § 98.444(a)(3).

10.3 Measurement of CO_2 Mass

Daily CO_2 received is recorded by totalizers on the mass flow meters on each of the pipelines listed in Section 8 using accepted flow calculations for CO_2. Daily CO_2 injected is recorded by totalizers on the mass flow meters using accepted flow calculations for CO_2.

High Plains does not produce CO_2 at the surface facility; therefore, no QA/QC procedures are necessary for produced CO_2 mass.

As required by 40 CFR § 98.444(d), High Plains will follow the monitoring and QA/QC requirements specified in the GHGRP for equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead.

As required by 40 CFR § 98.444(e), High Plains will ensure that:

- All flow meters are operated continuously except as necessary for maintenance and calibration.
- All flow meters used to measure quantities reported are calibrated according to the calibration and accuracy requirements in 40 CFR § 98.3(i), Subpart A of the GHGRP.
- All measurement devices are operated according to an appropriate standard method published by a consensus-based standards organization or an industry standard practice. Consensus-based standards organizations include, but are not limited to, the following:
  - ASTM International
  - American National Standards Institute (ANSI)
  - American Gas Association (AGA)
  - American Society of Mechanical Engineers (ASME)
  - API
  - North American Energy Standards Board (NAESB)
- All flow meter calibrations performed are National Institute of Standards and Technology (NIST) traceable.

10.4 QA/QC Procedures

High Plains will adhere to all QA/QC requirements in Subpart RR as required in the development of this MRV plan under Subpart RR. Any measurement devices used to acquire data will be operated and maintained according to the relevant industry standards.

10.5 Estimating Missing Data

High Plains will estimate any missing data according to the following procedures in 40 CFR § 98.445, Subpart RR of the GHGRP, as required:

- A quarterly flow rate of CO_2 received that is missing would be estimated using invoices, purchase statements, or a representative flow rate value from the nearest previous time period.
- A quarterly CO_2 concentration of a CO_2 stream received that is missing would be estimated using invoices, purchase statements, or a representative concentration value from the nearest previous time period.
- A quarterly quantity of CO_2 injected that is missing would be estimated using a representative quantity of CO_2 injected from the nearest previous period of time at a similar injection pressure.

- For any values associated with CO_2 emissions from equipment leaks and vented emissions of CO_2 from surface equipment at the facility that are reported in Subpart RR, standard GHGRP missing data estimation procedures specified in 40 CFR § 98.445(e) would be followed.

10.6 Revisions of the MRV Plan

High Plains will revise the MRV plan as needed for any of the following reasons:

- To reflect changes in monitoring instrumentation and quality assurance procedures
- To improve procedures for the maintenance and repair of monitoring systems to reduce the frequency of monitoring equipment downtime
- To address additional requirements as directed by U.S. EPA or the State of Wyoming

If any operational changes constitute a material change as described in 40 CFR § 98.448(d)(1), High Plains will submit a revised MRV plan addressing the material change.

11. Records Retention

High Plains will meet the recordkeeping requirements of paragraph 40 CFR 98.3(g), Subpart A of the GHGRP. As required by 40 CFR § 98.3(g) and 40 CFR § 98.447, High Plains will retain the following documents:

- A list of all units, operations, processes, and activities for which GHG emissions were calculated.
- The data used to calculate the GHG emissions for each unit, operation, process, and activity. These data include:
  - ◇ The GHG emissions calculations and methods used
  - ◇ Analytical results for the development of site-specific emissions factors, if applicable
  - ◇ The results of all required analyses
  - ◇ Any facility operating data or process information used for the GHG emission calculations
- The annual GHG reports.
- Missing data computations. For each missing data event, High Plains will retain a record of the cause of the event and the corrective actions taken to restore malfunctioning monitoring equipment.
- A copy of the most recent revision of this MRV plan.
- The results of all required certification and quality assurance tests of continuous monitoring systems, fuel flow meters, and other instrumentation used to provide data for the GHGs reported.
- Maintenance records for all continuous monitoring systems, flow meters, and other instrumentation used to provide data for the GHGs reported.

- Quarterly records of CO_2 received, including mass flow rate of contents of container at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- Quarterly records of injected CO_2 including mass flow at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- Annual records of information used to calculate the CO_2 emitted by surface leakage from leakage pathways.
- Annual records of information used to calculate the CO_2 emitted from equipment leaks and vented emissions of CO_2 from equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead.
- Any other records as specified for retention in this EPA-approved MRV plan.

References

Bethke, C.M. and M.K. Lee. 1994. Groundwater flow, late cementation, and petroleum accumulation in the Permian Lyons sandstone. *Denver Basin: AAPG Bulletin* 78(2): 221-241.

Burba, G. 2013. *Eddy covariance method for scientific, industrial, agricultural and regulatory applications: A field book on measuring ecosystem gas exchange and areal emission rates*. LI-Cor Biosciences.

Clayton, J.L. and P.J. Swetland. 1980. Petroleum Generation and Migration in Denver Basin. AAPG Bulletin (1980) 64 (10) p.1613-1633.

LI-COR Biosciences. 2021. Eddy covariance processing software (Version 7.0.8) [Software]. Available at <www.licor.com/EddyPro>.

Love J.D. and A.C. Christiansen. 1985. *Geologic map of Wyoming*. U.S. Geological Survey. Scale 1:500,000.

Lowry, M. and M. Crist. 1967. *Geology and ground-water resources of Laramie County, Wyoming*. U.S. Geological Survey Report.

Mao, Y., M Zeidouni, I. Duncan, 2017. Temperature analysis for early detection and rate estimation of CO_2 wellbore leakage, International Journal of Greenhouse Gas Control, Volume 67, 2017, https://doi.org/10.1016/j.ijggc.2017.09.021.

Sonnenberg, S.A. and R.J. Weimer. 1981. Tectonics, sedimentation, land petroleum potential, northern Denver basin, Colorado, Wyoming, and Nebraska. *Colorado School of Mines Quarterly* (76): 35–36.

Swanson, B.F. 1981. A simple correlation between permeabilities and mercury capillary pressures. *Journal of Petroleum Technology* 33(12): 2498–2504.

Taucher, P., T.T. Bartos, and K.G. Taboga. 2013. *Platte River Basin water plan update, level I (2009–2013), available groundwater determination*. WSGS Technical Memorandum 5.

U.S. Geological Survey (USGS). 2022. Earthquake Hazards Program. <https://earthquake.usgs.gov/>.

Western Regional Climate Center (WRCC). 2023. Prevailing wind direction. <https://wrcc.dri.edu/Climate/comp_table_show.php?stype=wind_dir_avg>. Accessed June 2023.

Zhao, B., C.W. MacMinn, and R. Juanes. 2014. Residual trapping, solubility trapping and capillary pinning complement each other to limit CO_2 migration in deep saline aquifers. Energy Procedia 63, p.3833-3839.