



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
AIR AND RADIATION

June 30, 2021

Mr. Carl Thunem
Perdure Petroleum, LLC
Farnsworth, Texas 79033

Re: Monitoring, Reporting and Verification (MRV) Plan for Farnsworth Unit

Dear Mr. Thunem:

The United States Environmental Protection Agency (EPA) has reviewed the Monitoring, Reporting and Verification (MRV) Plan submitted for the Farnsworth Unit as required by 40 CFR Part 98, Subpart RR of the Greenhouse Gas Reporting Program. The EPA is approving the MRV Plan submitted by Perdure Petroleum LLC for the Farnsworth Unit as the final MRV plan. The MRV Plan Approval Number is 1009999-1. This decision is effective July 5, 2021 and appealable to the EPA's Environmental Appeals Board under 40 CFR Part 78.

If you have any questions regarding this determination, please write to ghgreporting@epa.gov and a member of the Greenhouse Gas Reporting Program will respond.

Sincerely,

A handwritten signature in black ink, appearing to read "Julius Banks".

Julius Banks, Chief
Greenhouse Gas Reporting Branch

Technical Review of Subpart RR MRV Plan for Farnsworth Unit

June 2021

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Appendix A: Final MRV Plan

Appendix B: Submissions and Responses to Requests for Additional Information

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 Perdure Petroleum, LLC (Perdure) for the carbon dioxide (CO₂) - enhanced oil recovery (EOR) project in the Farnsworth Unit (FWU).

1 Overview of Project

Perdure indicates in the MRV plan that it operates a CO₂-EOR project in the FWU located in Ochiltree County, Texas. This MRV plan was developed in accordance with 40 CFR §98.440-449 (Subpart RR) to provide for the monitoring, reporting and verification of the quantity of CO₂ sequestered at the FWU during a Specified Period of injection. Perdure submitted its MRV plan related to EOR operations within the FWU. The field was discovered in 1955 and unitized in 1963 by operators for the purpose of waterflooding. Perdure has operated the FWU since 2017.

The MRV plan states that there are 61 abandoned wells, 32 injection wells, 58 production wells, and 2 monitoring wells within the FWU field area. Of these 153 wells, 17 are active injection wells and 32 are active production wells. The Oil and Gas Division of the Texas Railroad Commission (TRRC) regulates oil and gas activity in Texas. All wells in the FWU (including production, injection, and monitoring wells) are permitted by TRRC through Texas Administrative Code (TAC) Title 16 Chapter 3. TRRC has primacy to implement the Underground Injection Control (UIC) Class II program in the state for injection wells. The MRV plan indicates that the TRRC has issued UIC Class II enhanced recovery permits for all the injection wells included under the plan.

The MRV plan states that the FWU is located on the northwest shelf of the Anadarko basin, and is one of the oil fields in the area that produces from a sequence of alternating sandstones and mudstones deposited during the late-Pennsylvanian Morrowan period. CO₂ injection and oil production at the FWU are limited to the uppermost Morrow sandstone, referred to in the MRV plan as the Morrow B formation, which is overlain by the Atokan Thirteen Finger limestone. The reservoir is approximately 60 feet thick and lies at a depth of roughly 7,600 - 7,700 feet. The Morrowan and Attokan intervals were deposited approximately 315 - 300 million years ago.

The primary caprocks of the Morrow B formation are the upper Morrow shales and the Thirteen Finger limestone. The plan states that the shale and limestone rocks comprise a primary seal package that is approximately 180 - 200 feet thick and is overlain by thousands of feet of Atokan and younger limestones and shales. Contacts between the Morrow sandstone and the Morrow shale are described as sharp and irregular. The shale generally fines upwards in a series of thin beds that alternate between fine sands and muds, with sand content decreasing upwards through the section. The entire Thirteen Finger interval is 130 feet thick, with approximately 40% of the thickness comprised of mudstone, 4% coal, and 46% is limestone. Refer to Figure 2.2-2 in the MRV plan for a geologic column that contains more detailed information on the stratigraphy of the FWU.

The plan indicates that the FWU does not contain any significant geologic faults or fractures that intersect the CO₂ storage complex. The unit was located on the basin shelf in an area that was not

greatly affected by tectonic activity during the Pennsylvanian period. Further, the presence of accumulated oil reserves in the reservoir indicates that no significant pathways exist for the escape of hydrocarbons outside of the reservoir of interest. Mercury injection capillary pressure analyses were conducted on the confining systems among other geomechanical tests, which showed that the Morrow shale and Thirteen Finger limestone can support CO₂ column heights of 1,000 - 10,000 feet, which is, at a minimum, an order of magnitude greater than the thickness of the Morrow sandstone injection horizon.

The project is planning to inject CO₂ volumes of 24 million standard cubic feet per day (MMCFD) through roughly 17 active injection wells. Purchased CO₂ is expected to make up 12 MMCFD, while recycled CO₂ will make up the remaining 12 MMCFD. This ratio of purchased to recycled CO₂ is expected to remain constant until 2033, at which point CO₂ purchases will either decline or cease. A total of 25.65 million stock tank barrels (MMstb) of cumulative oil has been produced at the end of secondary recovery from the west half of FWU, which represents nearly 40% of oil originally in place (OOIP). The MRV plan states that at the end of August 2020, simulation results showed that a total of 4.8 MMstb of oil have been produced from the west half of FWU since CO₂ - water alternating gas (WAG) operations commenced in December of 2010.

Figure 2.3-1 of the MRV plan depicts a simplified flow diagram of the facilities and equipment within the FWU. Perdure purchases CO₂ that is transferred via pipeline from an ethanol plant located in Liberal, Kansas. A custody transfer meter is located in the compression facility owned and operated by Perdure. Once CO₂ enters the FWU there are three main processes involved in EOR operations: CO₂ distribution and injection, produced fluids handling, and produced gas processing. Purchased CO₂ is combined with recycled CO₂ from the FWU central tank battery and sent through to the main CO₂ distribution system to various WAG injectors. The three injection manifolds distribute the CO₂ to the field. The injection manifolds have valves to switch from CO₂ to water for when the wells switch from injecting CO₂ to injecting water, or vice versa. Over time, the WAG cycle will likely be adjusted to maximize oil recovery and minimize CO₂ utilization. Produced fluids are tested by 1) separating and metering oil, gas, and water, and 2) separating gas from liquid and sending the two phases to the central tank battery for final separation. All fluid phases are transferred to the central tank battery to separate oil, gas, and water by using a series of vessels and storage tanks.

The MRV plan states that a computer assisted history matching effort was undertaken for the current and forecasted volumes of CO₂ injection into the FWU. Perdure ran several prediction cases based on different injection scenarios to maximize the potential of the projected flood. Per Perdure's current plan, five existing water injection wells will be converted to WAG injection wells and are included in the CO₂ prediction model. The model was performed for a 12-year period with bottomhole pressure and oil rate target constraints. Significant amounts of CO₂ were modelled to be recycled back into the injection stream. Compressor capacity is expected to be expanded to compensate for high recycle volumes in the future. The model forecasts that CO₂ is contained in the reservoir within the boundaries of FWU.

The description of the project is determined to be acceptable and provides the necessary information to comply with 40 CFR 98.448(a)(6).

2 Evaluation of the 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 maximum monitoring area (MMA) and active monitoring area (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 CO₂ plume until the CO₂ 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 CO₂ 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 CO₂ plume at the end of year t + 5.” See 40 CFR 98.449.

Perdure has defined the MMA as the boundary of the FWU plus an additional one-half mile buffer zone and the AMA as the boundary of the FWU itself. While the operations are currently only focused on the western portion of the FWU, these determinations for the AMA and MMA allow for operational expansion into the eastern portion of the FWU throughout the next 12 years, or the anticipated life of the project. The MRV plan states that the minimum buffer of one-half mile was implemented for the MMA and that the site characterization of the FWU did not reveal any leakage pathways that would allow free-phase CO₂ to migrate laterally.

The MRV plan states there will be a subsidiary purpose of establishing the long-term containment of CO₂ in the FWU during the Specified Period. Figure 3.1-2 in the plan depicts a reservoir simulation of the extent of the CO₂ plume over 22 years into the Morrow B formation. The plan also indicates that injected CO₂ is expected to remain contained in FWU for the modeled 5-year post-injection monitoring period considered as part of their reservoir modeling assumptions.

The MMA, as it is defined in the MRV plan, is consistent with subpart RR requirements because the defined MMA accounts for the expected free phase CO₂ plume, based on modeling results, and incorporates the additional 0.5-mile or greater buffer area. The rationale used to delineate the MMA, as described in Perdure’s MRV plan, accounts for the existing operational and subsurface conditions at the site along with any potential changes in future operations. Therefore, the designation of the AMA as the FWU and the designation of the MMA as the FWU, plus the required one-half mile buffer, is an acceptable approach.

The delineations of the MMA and AMA were determined to be acceptable and in compliance with 40 CFR 98.448(a)(1). The MMA and AMA described in the MRV plan are clearly and explicitly 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 CO₂ in the MMA and the likelihood, magnitude, and timing of surface leakage of CO₂ through these pathways pursuant to 40 CFR 98.448(a)(2). Perdure identified the following as potential leakage pathways in their MRV plan that required consideration:

- Existing well bores;
- Faults and fractures;
- Natural and induced seismic activity;
- Previous operations;
- Pipeline and surface equipment;
- Lateral migration outside the FWU;
- Drilling through the CO₂ area; and
- Diffuse leakage through the seal.

3.1 Leakage through Existing Well Bores

The MRV plan asserts that adherence to rule 46 of the TRRC, which governs fluid injection into productive reservoirs, and mechanical integrity testing (MIT) requirements under the Texas UIC program ensure that active injection wells will be operated in a manner that is protective of subsurface and surface resources and the environment. MIT is described as a way to demonstrate that injection wells do not act as pathways for leakage into underground sources of drinking water and to the surface environment. Given their stated compliance with state UIC requirements, Perdure concluded that leakage of CO₂ to the surface through injection wells is unlikely.

The Southwest Regional Partnership on Carbon Sequestration (SWP) has repurposed an old WAG injection well for monitoring reservoir pressure and temperature, borehole temperature, and microseismicity. Downhole pressure and temperature gauges were permanently installed into the repurposed well to monitor real time pressure and temperature in the reservoir. Distributed temperature sensing (DTS) was used to monitor real time temperature along the wellbore for leakage detection. Passive and active microseismic activities within the FWU were monitored using a geophone array. Surface-level microseismic activities were measured using twenty surface seismometer stations. Surface seismic data was integrated with data from the borehole geophone array to enhance event detection and location. Perdure operators may continue to observe and collect data from the monitoring well after SWP concludes their research efforts, but it is stated that such efforts will not be an ongoing part of the FWU MRV plan. Perdure suggested there is minimal risk of groundwater contamination from CO₂ leakage from wells based on peer-reviewed studies specifically related to the FWU. Two peer-reviewed studies (Xiao et al., 2016, Xiao et al., 2017) evaluated leakage through seal units and leakage of CO₂ into overlying underground sources of drinking water or into the atmosphere through wellbores. An additional study (Ting et al., 2017) evaluated the geomechanical impacts of CO₂-

fluid interaction on cements typically used in regional wellbore completions and the surrounding caprock.

The MRV plan provides an acceptable characterization of the likelihood of CO₂ leakage that could be expected through existing well bores.

3.2 Leakage through Faults and Fractures

According to section 4.3 of the MRV plan, the main concern of CO₂ migration at the FWU is via seal bypass systems along fracture networks. The presence of hydrocarbons in the reservoir is one of the primary arguments against present day up-fault transmissibility of CO₂. If a pathway existed, the MRV plan asserts that hydrocarbons would have migrated out of the reservoir prior to current day conditions. An additional argument presented in the MRV plan against the possibility of leakage through faults and fractures is addressed in the results of an extensive field and regional analysis of core, 2D, and 3D seismic data. 3D reflection seismic data of the FWU was acquired in 2013 and reprocessed in 2017 to obtain a better image resolution. In-depth analyses of the reprocessed data provided Perdure with confidence that there are no significant faults or fractures in the field area. A detailed isopach was created from an interpretation of 346 well logs and used to crosscheck the seismic interpretation.

According to the MRV plan, the reprocessed seismic data shows an increase in the intensity of the reflectors in the central and western part of the field, which are interpreted as facies changes between carbonate or sandstone shelf deposits that transition laterally to shales. The plan indicates that while such facies changes or channels could allow for preferential flow paths, they are discontinuous and irregular features that do not constitute a pathway to the surface. In addition to the 3D interpretations, no faults were observed in any of the 70 miles of 2D seismic line data surveyed in the region.

Perdure noted that small fractures existed in some, but not most, of the reservoir cores that were examined. The plan indicated that most fractures were induced by drilling activities. Any additional fractures were stated to be unlikely to provide migration pathways unless significant changes in reservoir pressure occurs and damages the reservoir. In the case of leakage along faults, Perdure's anticipated response plan is to shut in injector wells near the faults.

The MRV plan provides an acceptable characterization of the likelihood of CO₂ leakage that could be expected through faults and fractures.

3.3 Leakage through Natural and Induced Seismicity

The MRV plan states that while past earthquake data cannot predict future earthquakes, the small number of events near the FWU after initiating waterflood operations in 1969 implies that the area is not seismically sensitive to injection. In addition, the plan states that there is no existing documentation that any distant earthquake events caused a disruption in injectivity or damage to any of the wellbores in the FWU. Furthermore, the plan states that Perdure did not find any direct evidence of tectonic faults within the FWU, as is discussed in section 3.2 of this document. Section 4.6 of the MRV plan concludes

that there is no direct evidence that natural seismic activity poses a significant risk for loss of CO₂ to the surface in the FWU.

Leakage through induced fractures is anticipated to be avoided by complying with the rules for keeping injection pressures below fracture parting pressure (FPP). The FPP is the pressure at which the induced stress from the injection of fluids causes brittle fractures, which results in discontinuous and non-recoverable deformation to the formation. As discussed, Perdure did not identify any significant faults or fractures in the field area from the results of the 2D and 3D seismic data. Leakage through natural and induced seismic activity is continuously monitored through any deviations of pressure of WAG wells or through pressure monitoring of new wells as they are being drilled. Perdure anticipates that, in the unlikely event of a leakage pathway created via seismicity, they will shut in any injection wells near any seismic events that may occur during the project.

The MRV plan provides an acceptable characterization of the likelihood of CO₂ leakage that could be expected through natural and induced seismicity.

3.4 Leakage as a Result of Previous Operations

The MRV plan indicates that any loss of seal in abandoned wells will be continuously monitored via pressures in WAG wells and high pressures that are found in new wells as they are drilled. The MRV plan states that Perdure has identified 61 abandoned wells in the FWU. In the event of a leakage event, the anticipated response plan is to re-enter and re-seal the abandoned well(s). Section 4.2.1 of the MRV plan described how all wells within the FWU have been plugged and abandoned under the regulations of the TRRC, and that leakage of CO₂ to the surface through those wells is unlikely.

The MRV plan provides an acceptable characterization of the likelihood of CO₂ leakage that could be expected as a result of previous operations.

3.5 Leakage from Pipeline and Surface Equipment

The MRV plan states that ongoing field surveillance of pipelines, wellheads, and other surface equipment is conducted by personnel who are instructed on how to detect surface leaks and other equipment failures in order to minimize release events. The TAC rules for the TRRC Oil and Gas Division require the reporting and quantification of leaks. Together the actions taken by personnel and the TAC rules serve to minimize leakage of greenhouse gases from surface equipment. The plan also indicates that operations and maintenance procedures currently follow and will continue to follow appropriate industry standards. If leakage is detected from pipeline or surface equipment, Perdure plans to quantify the volume of CO₂ released by following the requirements of subpart W of the GHGRP. Routine field inspections of surface equipment provide a monitoring method that allows workover crews to respond within days to address the leakage issue.

Additionally, the plan states that FWU production has trace amounts of hydrogen sulfide (H₂S), which is toxic. There are approximately 8-10 workers on the ground in the FWU at any given time, and all field

and contractor personnel are required to wear H₂S detectors at all times. The primary purpose of the H₂S detectors is to protect workers from the risk of harmful exposure to H₂S. The detection limit of the H₂S detectors is quantified for readings in the range of 0-100 parts per million (ppm) and will sound an alarm above 10 ppm. The secondary purpose of H₂S detectors is to provide an indication of emissions of gas from a pipeline or surface equipment that might go unnoticed through other observations or measurements including detection of possible CO₂ emissions from surface equipment at the FWU. CO₂ volumes cannot be calculated based on the detector reading or alarm; H₂S leakage can only be detected and located at the FWU. Once identified, a further response will be initiated, and CO₂ volumes will be quantified in accordance with the requirements under subpart W and subpart RR.

The MRV plan provides an acceptable characterization of the likelihood of CO₂ leakage that could be expected from pipeline and other surface equipment.

3.6 Leakage from Lateral Migration

Section 4.3.1 of the MRV plan notes that the presence of oil found trapped in the reservoir provides evidence that if significant escape pathways existed, oil would have drained from the reservoir prior to the current day. Section 4.4 of the MRV plan describes the Morrow strata as a deltaic sequence that prograded toward the southeast, which resulted in the deposition of shales with lenticular, discontinuous coarse sandstones separated with very fine sandstone, minor conglomerates, and shale. Because CO₂ is lighter than the water that remains in the reservoir, the CO₂ will migrate to the top of each lenticular structure as it becomes filled. The plan states that producing wells will drain the water and keep the CO₂ within each discontinuous sandstone.

Any possible overflow beyond spill points will be continuously monitored through pressures in WAG wells and any high pressures found in new wells as they are drilled. Perdure indicates that a response plan to lateral migration of fluids is to conduct fluid management activities along lease lines. Modelling simulations in section 3.1.1 of the MRV plan also lead to the assertion that there is a high concentration of CO₂ in the injection area, which reiterates the containment of fluids within the injection zone and area. Section 4.4 of the plan states that the likelihood of CO₂ leakage from lateral migration outside of the AMA is very low by primarily describing the geology of the formation in the FWU.

The MRV plan provides an acceptable characterization of the likelihood of CO₂ leakage that could be expected from lateral migration.

3.7 Leakage from Drilling Operations

The MRV plan states that any new wells will be constructed in accordance with the relevant rules for the TRRC, which is expected to protect subsurface and surface resources and the environment. These rules govern well siting, construction, operation, and closure for all wells in oilfields. The plan notes that new well construction is also based on existing best practices that were established during the drilling of existing wells, which is stated to significantly limit any potential leakage from well pathways considering that existing wells followed TRRC rules. In addition, the plan notes that it is very unlikely that anyone will

ever drill through the AMA reservoir in the future because the area of the FWU plus one mile past the unit boundary contains over 100 wells that were drilled deeper than the Morrow formation. None of these wells were productive in the reservoirs deeper than the Morrow according to section 4.2.5. Any unplanned wells drilled through the Morrow formation will be prevented through weekly field inspections and compliance with TRRC permitting for planned wells.

In the event of loss of bottom-hole pressure control, the MRV plan notes that weekly inspections and the presence of field personnel will help monitor any blowout events. In the case of such an event, the plan states that operators will maintain well kill procedures.

The MRV plan provides an acceptable characterization of the likelihood of CO₂ leakage that could be expected from drilling operations.

3.8 Leakage through the Formation Seal

The FWU is a structure that formed a natural trap for oil that has migrated from source rocks over millions of years. Perdure asserts that the limestone formations are mechanically strong but susceptible to brittle deformation, while the shale layers are weaker but sufficiently ductile to prevent extensive fracture propagation. The MRV plan states that the Morrow shale and Thirteen Finger limestone provide an effective combination of strength and elasticity in the form of a seal. A variety of analytical methods were used for caprock (confining system) analysis. Petrologic examination included standard thin section petrography and backscattered electron microscopy. Petrophysical analytical methods included retort analysis, pulse-decay permeability measurement, pressure decay permeability analysis for tight rocks, and mercury injection porosimetry. Geomechanical analysis of the confining system involved a standard series of mechanical tests: Brazil tension, unconfined compression, triaxial compression, and multi-stress compression.

The analyses led Perdure to conclude that the mudstone lithologies in the Morrow shale and Thirteen Finger limestone can support CO₂ column heights of roughly 1,000 to 10,000 feet, which was characterized as an effective seal for CO₂ storage in the Morrow B injection horizon. According to the MRV plan, in the unlikely event that leakage occurred through the formation seal, Perdure has laid out strategies for leak detection and quantification in sections 4.7 and 4.8, respectively.

The MRV plan provides an acceptable characterization of the likelihood of CO₂ leakage that could be expected through the formation seal.

4 Strategy for Detection and Quantifying Surface Leakage of CO₂ and for Establishing Expected Baselines for Monitoring

40 CFR 98.448(a)(3) requires that an MRV Plan contain a strategy for detecting and quantifying any surface leakage of CO₂, and 40 CFR 98.448(a)(4) requires that an MRV Plan include a strategy for establishing the expected baselines for monitoring CO₂ surface leakage. Section 5 of the MRV plan

details Perdure’s strategy for determining baselines for CO₂ monitoring and sections 4.7 and 4.8 detail strategies for the detection of, response to, and quantification of CO₂ leakage. Perdure’s approach for detecting and quantifying surface leakage of CO₂ includes monitoring of injection wells, well maintenance, monitoring of surface infrastructure, and field inspections (visual inspections and H₂S detection by personnel and in-field monitoring equipment). Perdure’s approach to these activities are summarized in Table 1 of the MRV plan, which is reproduced below.

Potential Leakage Risk	Monitoring Methods and Frequency	Anticipated Response Plan
Tubing Leak	Monitor changes in annulus pressure; MIT for injectors	Workover crews respond within days
Casing Leak	Weekly field inspection; MIT for injectors; extra attention to high-risk wells	Workover crews respond within days
Wellhead Leak	Weekly field inspection	Workover crews respond within days
Loss of Bottom-hole pressure control	Blowout during well operations (weekly inspection but field personnel present daily)	Maintain well kill procedures
Unplanned wells drilled through Morrow	Weekly field inspection to prevent unapproved drilling; compliance with TRRC permitting for planned wells.	Assure compliance with TRRC regulations
Loss of seal in abandoned wells	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Re-enter and reseal abandoned wells
Pumps, valves, etc.	Weekly field inspection	Workover crews respond within days
Leakage along faults	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Shut in injectors near faults
Overfill beyond spill points	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Fluid management along lease lines
Leakage through induced fractures	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Comply with rules for keeping pressures below parting pressure
Leakage due to seismic event	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Shut in injectors near seismic event

Perdure plans to determine the most appropriate methods for quantifying the volume of leaked CO₂ on a case-by-case basis and will report it as required by subpart RR. The plan states in section 4.8 that any volume of CO₂ detected leaking to surface will be quantified using acceptable emission factors such as those found in 40 CFR Part 98 subpart W or engineering estimates of leak amounts based on measurements in the subsurface, field experience, and other factors such as the frequency of inspection. The plan also states that leaks will be documented, evaluated, and addressed in a timely manner.

Perdure uses industry standard approved methods for measuring the flow rate of CO₂ through field equipment. These data are recorded and summed into a recorded 24-hour flow rate. CO₂ is transported via a United States Department of Transportation (DOT)-regulated pipeline to the FWU. A flow meter located in the field measures temperature, line pressure, and differential pressure across the meter. A similar type of flow meter takes daily measurements of gas that is produced and recycled from onsite wells. Each injection well pad has a totalizer meter to measure injected volumes every 24 hours. This data is collected daily by the field personnel and input into the data warehouse to be allocated for the pattern injection. The MRV plan indicates that the flow meters, as described above, will be used to determine the total volume of CO₂ injected for the mass balance equations necessary to determine annual and cumulative volumes of the stored CO₂.

Fluid composition will be determined quarterly to be consistent with subpart RR specifications in section 98.447(a). The MRV plan states that all meter and composition data are documented and will retain records in accordance with 40 CFR 98.3 (g) and 40 CFR 98.447.

4.1 Determination of Baselines for Monitoring CO₂ Surface Leakage

Ongoing operational monitoring and research projects at the FWU have provided data for establishing baselines of surface CO₂ leakage and emissions from the Morrow B sandstone and from surface equipment. The site characterization, modeling, and monitoring, verification and accounting work conducted by the SWP provides the basis for the established CO₂ baselines. Ground water monitoring activities conducted since 2013 indicate no leakage of CO₂ has occurred from formations or wells into the Ogallala aquifer. These data were collected at the 14 ground water monitoring wells in the area. Perdure is not likely to continue ground water monitoring efforts, as SWP studies suggest that there is minimal risk of ground water contamination from CO₂ leakage at depth. The SWP has also conducted regular soil flux surveys to determine CO₂ leakage in the western half of the FWU since 2013. CO₂ soil flux variations have only been attributed to seasonal changes and crop growth and rotation. The plan also indicates that atmospheric CO₂ concentration values from the Moody, Texas station can be used for baseline CO₂ values in the FWU area. The SWP soil flux collar network has identified no CO₂ leakage at the FWU from any sources since monitoring activities began. The plan states that any significant and consistent variance from this baseline will be investigated to determine the source of the CO₂. If the CO₂ source is determined to be leakage from the FWU then appropriate steps will be taken to measure and report the volumes, mitigate any leaks, and make any adjustments to the MRV plan that are required.

4.2 Wellbore Leakage

As described in section 4.2.4 of the MRV plan, the SWP has conducted monitoring of the Morrow B injection horizon and overlying seal formations in the area adjacent to the new WAG injection well (#13-10A). This repurposed well has served to monitor reservoir pressure and temperature, borehole temperature, and microseismicity. This real time monitoring is not expected to continue as an ongoing part of the MRV plan. However, results from monitoring activities described in section 5 of the MRV plan support Perdure's conclusion that leakage of CO₂ to the surface through injection wells is unlikely.

The plan states that the rules under the TRRC require that all wells be equipped with a Bradenhead gauge to measure the pressure between casing strings and follow procedures to report and address any instances where pressure on the Bradenhead is detected. Mechanical integrity testing of wells under the state UIC program is noted as important for demonstrating that wells do not act as conduits for leakage into the injection and production zone. The MRV plan notes that UIC regulations provide that an injection well has mechanical integrity if there is no significant leak in the casing, tubing, or packer; and there is no significant fluid movement into an underground source of drinking water through vertical channels adjacent to the injection well bore. In the case of leakage, Perdure anticipates that injectors can be shut in and workover crews can respond to the issue within days.

Perdure indicates in the MRV plan that they follow the rules and regulations of the TRRC, which governs well location, construction, operation, maintenance, and closure for all wells in permitted areas. Wells must adhere to specified casing, cementing, drilling well control, and completion requirements designed to prevent fluids from moving from the strata they are encountered into strata with oil and gas, or into subsurface, and surface waters.

4.3 Injection and Production Zone Leakage

In addition to the methods used to detect and measure surface leakage of CO₂ from wellbores, Perdure has determined a strategy for establishing several baselines to monitor CO₂ leakage via soil and ground water tests. Since beginning the tests in 2013, the plan states that there is no indication of CO₂ leakage from the Morrow B formation. Perdure indicates that any volume of CO₂ detected leaking to the surface will be quantified using acceptable emission factors such as those found in 40 CFR Part 98 Subpart W, engineering estimates of leak amounts based on measurements in the subsurface, Perdure's field experience, and/or other factors such as the frequency of inspection. Leaks are expected to be documented, recorded and retained in the electronic environmental documentation and reporting system. Any repairs requiring a work order will be documented in the electronic equipment maintenance system.

4.4 CO₂ and H₂S Detection

The MRV plan's discussion of produced fluids handling incorporates H₂S detection methods because production contains trace amounts of H₂S. All field and contractor personnel are always required to wear H₂S detectors. The detection limit of the H₂S detectors is quantified for readings in the range of 0-100 ppm and will sound an alarm above 10 ppm. Perdure considers the secondary purpose for H₂S detectors to be an indicator of gas emissions from a pipeline or surface equipment that might go unnoticed by other observations or measurements. While gas volumes cannot be calculated based on the H₂S detector alarm, any volume of CO₂ detected leaking to surface will be quantified using acceptable emission factors such as those found in 40 CFR Part 98 Subpart W or engineering estimates of leak amounts based on measurements in the subsurface, Perdure's field experience, and other factors.

4.5 Equipment Leaks and Vented Emissions of CO₂

The plan states that Perdure evaluates and estimates leaks from equipment, the CO₂ content of produced oil and vented CO₂, as required under 40 CFR Part 98 subpart W. Missing data estimation procedures will be used for any values associated with CO₂ emissions from equipment leaks and vented emissions of CO₂ from surface equipment at the facility that are reported in this subpart, as specified in subpart W of 40 CFR Part 98. Section 9 of the MRV plan indicates that records will be retained for information used to calculate the CO₂ emitted from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead, as well as between the production wellhead and the flow meter used to measure production quantity.

The strategy for detecting and quantifying surface leakage of CO₂ and for establishing expected baselines for monitoring is determined to comply with 40 CFR 98.448(a)(3) and 40 CFR 98.448(a)(4). The strategies described in the MRV plan are clearly and explicitly delineated and are consistent with subpart RR requirements.

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

5.1 Calculation of Mass of CO₂ Received

Perdure proposes to use equation RR-2 per 40 CFR 98.443(a)(2) to calculate the amount of CO₂ received. The equation is:

$$CO_{2T,r} = \sum_{p=1}^4 (Q_{r,p} - S_{r,p}) * D * C_{CO_{2p},r}$$

Where:

$CO_{2T,r}$ = Net annual mass of CO₂ received through flow meter r (metric tons).

$Q_{r,p}$ = Quarterly volumetric flow through a receiving flow meter r in quarter p at standard conditions (standard cubic meters).

$S_{r,p}$ = Quarterly volumetric flow through a receiving flow meter r that is redelivered to another facility without being injected into your well in quarter p (standard cubic meters).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

$C_{CO_{2p},r}$ = Quarterly CO₂ concentration measurement in flow for flow meter r in quarter p (vol. percent CO₂, expressed as a decimal fraction).

p = Quarter of the year.

r = Receiving flow meter.

Perdure provides an acceptable approach to calculating each of these variables in section 6.1 of the MRV Plan.

5.2 Calculation of Total Annual Mass of CO₂ Injected

Section 6.2 of the MRV plan states that the mass of CO₂ injected into the subsurface at the FWU will be calculated using equation RR-5. Perdure indicates in the plan that two totalizer meters will be used to determine the total volume injected.

Perdure provides an acceptable approach for calculating the total annual mass injected under the subpart RR requirements.

5.3 Calculation of Total Annual Mass of CO₂ Produced

Perdure plans to use Equation RR-8 from 40 CFR 98.443 to calculate the total mass of CO₂ produced from all production wells and Equation RR-9 to calculate CO₂ produced from all production wells in addition to the mass of CO₂ entrained in oil in the reporting year. The MRV plan states that Perdure will calculate the mass of CO₂ produced at the FWU using measurements from each gas-liquid separator in accordance with the procedure specified in equation RR-9.

The MRV plan indicates in equation RR-9 that the mass of CO₂ entrained in oil in the reporting year will be calculated under the assumption that the total CO₂ measured at the separators represents a percentage of the total CO₂ produced.

Perdure's proposed approach for calculating the total annual mass produced is acceptable for the subpart RR requirements.

5.4 Calculation of Total Annual Mass of CO₂ Emitted by Surface Leakage

For reporting of the total annual CO₂ mass sequestered under subpart RR, potential surface leaks must be accounted for in the mass balance equation. Pursuant to 40 CFR 98.448(a)(2), an MRV Plan must describe the likelihood, magnitude, and timing of surface leakage of CO₂ through potential pathways. Subpart RR also requires that the MRV plan identify a strategy for establishing a baseline for monitoring CO₂ surface leakage, pursuant to 40 CFR 98.448(a)(4).

Equation RR-10 will be used to calculate and report the mass of CO₂ emitted by surface leakage. The plan states that the emissions factor listed in Table W-1A of Subpart W shall be used to estimate all streams of gases, including the recycled CO₂ stream. Perdure states in the MRV plan that any volume of CO₂ detected leaking to the surface will be quantified using acceptable emission factors such as those found in 40 CFR Part 98 Subpart W or engineering estimates of leak amounts based on measurements in

the subsurface, Perdure’s field experience, and other factors such as the frequency of inspection. The plan’s approach, using techniques from subpart W of the GHGRP, is acceptable for estimating potential emissions from surface leakage given the likelihood, magnitude and timing of surface leakage as described in the MRV plan.

5.5 Calculation of Mass of CO₂ Sequestered

Perdure will use equation RR-11 to calculate the mass of CO₂ sequestered in subsurface geologic formations in the reporting year at the FWU. Perdure also provided equation RR-12 as a potentially relevant method of calculating the mass of CO₂ sequestered. However, the plan notes that equation RR-12 does not apply to Perdure’s current operations at the FWU. Perdure proposes an acceptable approach for calculating mass of CO₂ sequestered.

6 Summary of Findings

The subpart RR MRV plan for the Farnsworth Unit facility meets the requirements of 40 CFR 98.238. The regulatory provisions of 40 CFR 98.238(a), which specifies the requirements for MRV plans, are summarized below along with a summary of relevant provisions in the FWU MRV Plan.

Subpart RR MRV Plan Requirement	FWU MRV Plan
40 CFR 98.448(a)(1): Delineation of the maximum monitoring area (MMA) and the active monitoring areas (AMA).	Section 3 of the MRV Plan describes the MMA and AMA. The MMA is delineated as equal to the boundary of the FWU, plus an all-around buffer zone of at least one-half mile and the AMA is defined as the boundary of the FWU. The MMA and AMA delineations consider site characterization and reservoir modeling along with prior operating experience.
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 4 of the MRV Plan identifies and evaluates potential surface leakage pathways. The MRV Plan identifies the following potential pathways: leakage from surface equipment; leakage from wells; leakage from fractures, faults and bedding plane partings; lateral fluid movement; leakage through confining/seal system; and natural and induced seismic activity. The MRV Plan analyzes the likelihood, magnitude, and timing of surface leakage through these pathways. Perdure determined that these leakage pathways are not likely at the FWU facility and it is very unlikely that potential leakage conduits would result in significant loss of CO ₂ to the atmosphere.

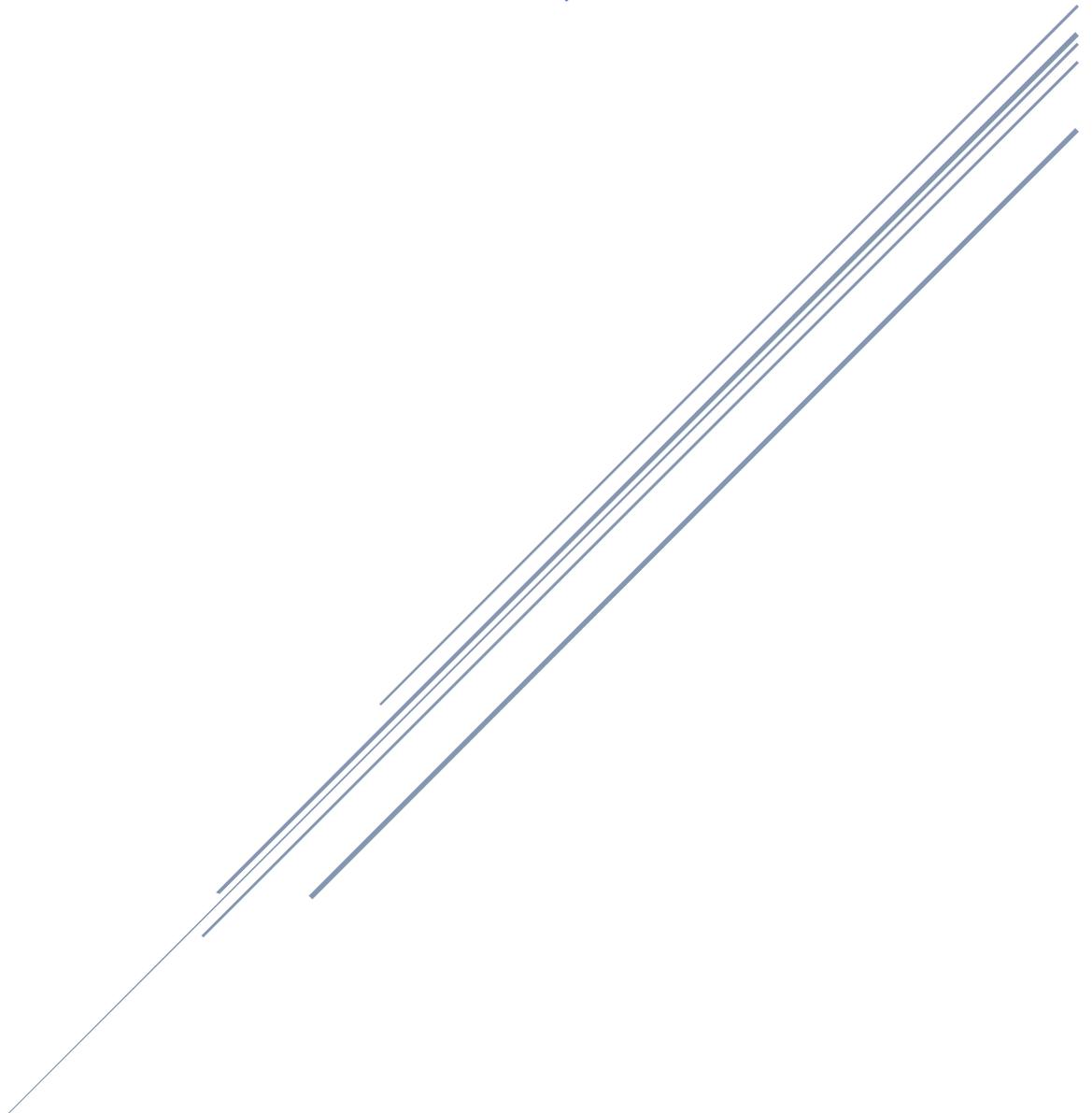
<p>40 CFR 98.448(a)(3): A strategy for detecting and quantifying any surface leakage of CO₂.</p>	<p>Section 4.7 of the MRV Plan describes a strategy for how the facility would detect CO₂ leakage to the surface, such as monitoring of existing wells, field inspections and pressure monitoring. Sections 4.8 and 6 of the MRV Plan describe a strategy for how surface leakage would be quantified.</p>
<p>40 CFR 98.448(a)(4): A strategy for establishing the expected baselines for monitoring CO₂ surface leakage.</p>	<p>Section 5 of the MRV Plan describes the strategy for establishing baselines against which monitoring results will be compared to assess potential surface leakage.</p>
<p>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.</p>	<p>Section 6 of the MRV Plan describes Perdure's approach to determining the amount of CO₂ sequestered using the subpart RR mass balance equation, including as related to calculation of total annual mass emitted as equipment leakage.</p>
<p>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.</p>	<p>Appendix 1 in the MRV Plan provides well identification numbers for each injection well. The MRV Plan specifies that all EOR injection wells in the FWU MRV plan have been issued UIC Class II enhanced recovery permits.</p>
<p>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.</p>	<p>The MRV Plan states that the Farnsworth CO₂ Flood facility will begin implementation of this MRV plan starting on January 1, 2022.</p>

Appendix A: Final MRV Plan

Farnsworth Unit, Texas (FWU)

MONITORING, REPORTING, AND VERIFICATION PLAN

Perdure Petroleum, LLC



May, 2021

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Introduction

Perdure Petroleum, LLC (Perdure) operates the Farnsworth Unit (FWU) located in Ochiltree County, Texas for the primary purpose of enhanced oil recovery (EOR) using carbon dioxide (CO₂) with a subsidiary or ancillary purpose of geologic sequestration of CO₂ in a subsurface geologic formation. The discovery date of the field was October 26, 1955 and the FWU was unitized December 6, 1963 by Union Oil Company of California for the purpose of waterflooding with fresh water sourced from the Ogallala formation. The field structure is a lenticular bedding sand trending northwest to southeast with the average top of sand at 7990 feet, true vertical depth. Perdure has been operating the FWU since 2017. Perdure acquired the FWU from Chaparral Energy LLC, which initiated the CO₂-EOR project in December 2010. Perdure intends to continue CO₂-EOR operations until the end of the economic life of the CO₂-EOR program using various Class II injection wells as defined by Underground Injection Control (UIC) regulations and permitted under Texas Railroad Commission Statewide Rule 46. In this document, the term “gas” usually means a mixture of hydrocarbon light end components and the CO₂ component that can be produced as part of the EOR process.

Perdure has chosen to submit this Monitoring, Reporting, and Verification (MRV) plan to EPA for approval according to 40 CFR 98.440 (c)(1), Subpart RR of the Greenhouse Gas Reporting Program (GHGRP) for the purpose of qualifying for the tax credit in section 45Q of the federal Internal Revenue Code.

This MRV Plan contains ten sections:

Section 1 contains facility information.

Section 2 contains the project description including: a detailed description of the injection operation including the duration and volume of CO₂ to be injected; a detailed description of the geology and hydrogeology of the FWU located on the northwest shelf of the Anadarko basin and a detailed characterization of the injection reservoir and modeling techniques employed.

Section 3 contains the delineation of the maximum monitoring area (MMA) and the active monitoring area (AMA), both defined in 40 CFR 98.449, and as required by 40 CFR 98.448(a)(1), Subpart RR of the GHGRP.

Section 4 identifies the potential surface leakage pathways for CO₂ in the MMA and evaluates the likelihood, magnitude, and timing, of surface leakage of CO₂ through these pathways as required by 40 CFR 98.448(a)(2), Subpart RR of the GHGRP. This section also describes the strategy for detecting, verifying, and quantifying any surface leakage of CO₂ as required by 40 CFR 98.448(a)(3), Subpart RR of the GHGRP. Finally, this section also demonstrates that the risk of CO₂ leakage through the identified pathways is minimal.

Section 5 describes the strategy for establishing the expected baselines for monitoring CO₂ surface leakage as required by 40 CFR 98.448(a)(4), Subpart RR of the GHGRP.

Section 6 provides a summary of the considerations used to calculate site-specific variables for the mass balance equation as required by 40 CFR 98.448(a)(5), Subpart RR of the GHGRP.

Section 7 provides the estimated schedule for implementation of this MRV Plan as required by 40 CFR 98.448(a)(7).

Section 8 describes the quality assurance and quality control procedures that will be implemented for each technology applied in the leak detection and quantification process. This section also includes a discussion of the procedures for estimating missing data as detailed in 40 CFR 98.445.

Section 9 describes the records to be retained according to the requirements of 40 CFR 98.3(g) of Subpart A of the GHGRP and 40 CFR 98.447 of Subpart RR of the GRGRP.

Section 10 includes Appendices supporting the narrative of the MRV Plan.

1 Facility Information

1.1 Reporter number

The Farnsworth Unit CO₂ Flood reports under Greenhouse Gas Reporting Program Identification number 544683.

1.2 UIC permit class

For injection wells that are the subject of this MRV plan, the Texas Railroad Commission (TRRC) has issued Underground Injection Control (UIC) Class II enhanced recovery permits under its State Rule 46 (see Appendix 2). All wells in the FWU, including both injection and production wells, are regulated by TRRC, which has primacy to implement the UIC Class II program.

1.3 UIC injection well identification numbers

A list of the injection wells in the FWU is provided in Appendix 1. The details of the injection process are provided in Section 2.3.

2 Project Description

2.1 Project characteristics

2.1.1 Estimated years of CO₂ injection

It is currently projected that Perdure will inject CO₂ for an additional 12 years.

2.1.2 Estimated volume of CO₂ injected over lifetime of project

The chart to the left in Figure 2.4-7 in Section 2.4 - Reservoir Characterization Modeling shows the forecasted simulated cumulative CO₂ injection volume of approximately 180 billion standard cubic feet (Bscf) or 9.5 million metric tonnes (MMMT) through October 2032. For the period September 2020 through October 2032, an additional 52.5 Bscf or 2.77 MMT will be stored in the FWU.

2.2 Environmental Setting of the MMA

2.2.1 Boundary of the MMA

Perdure has defined the boundary of the MMA as equivalent to the boundary of the FWU plus ½ mile beyond. A discussion of the methods used in delineating the MMA and the AMA are presented in Section 3.

2.2.2 Geology and hydrogeology

The geological discussions in Sections 2.2.2 and 4.3-4.4 are based on analysis of logs from over 140 wells, descriptions of cores from 8 wells including 3 recently cored that included sections from overlying seals as well as the shale underlying the main reservoirs, petrographic thin section descriptions and point counts as well as a variety of special analytical techniques including X-ray diffraction (XRD), which is the science of determining the atomic and molecular structure of rock crystals with an X-ray beam; scanning electron microscope (SEM) analysis; which uses a beam of electrons to define the surface of crystals; carbon isotope analysis to estimate the age of the sample; and a variety of mechanical tests. Two dimensional (2D) and three dimensional (3D) geophysical surveys were also used as part of this study. Details of recent geological investigations can be found in Gallagher (2014), Gragg (2016), Rasmussen et al (2019), Rose-Coss et al (2015), Trujillo (2018), Hobbs et al (2019), and Gragg et al (2018).

2.2.2.1 Tectonic Setting and Stratigraphy

The FWU is located on the northwest shelf of the Anadarko basin (Figure 2.2-1) and is one of many oil fields in the area that produce from a sequence of alternating sandstones and mudstones deposited during the late-Pennsylvanian Morrowan period. Oil production and CO₂ injection at FWU is restricted to the operationally-named Morrow B sandstone; the uppermost Morrow sandstone encountered below the Atokan Thirteen Finger limestone. The primary caprock intervals at FWU are comprised of the upper Morrow shale and the Thirteen Finger limestone (Figure 2.2-2). The Morrowan and Atokan intervals were deposited approximately 315-300 million years ago. Overlying stratigraphy includes Late Pennsylvanian through the middle Permian shales and limestones, with lesser amounts of dolomite, sandstone and evaporites.

The reservoir is approximately 60 feet thick through the field and lies at a depth of approximately 7600-7700 feet. The primary seal rocks of the Morrow shale and the Thirteen Finger Limestone comprise a package of approximately 180-200 feet thick in the field and are overlain by thousands of feet of Atokan and younger limestones and shales.

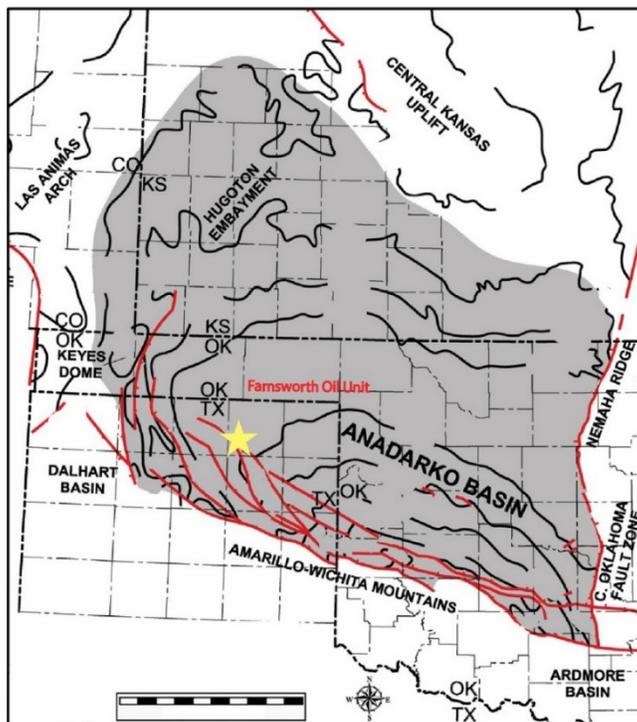


Figure 2.2-1- Location of the Farnsworth Unit (FWU) on the Northwest Shelf of the Anadarko Basin in West Texas. Red lines are approximate locations of faults that have been documented in the region.

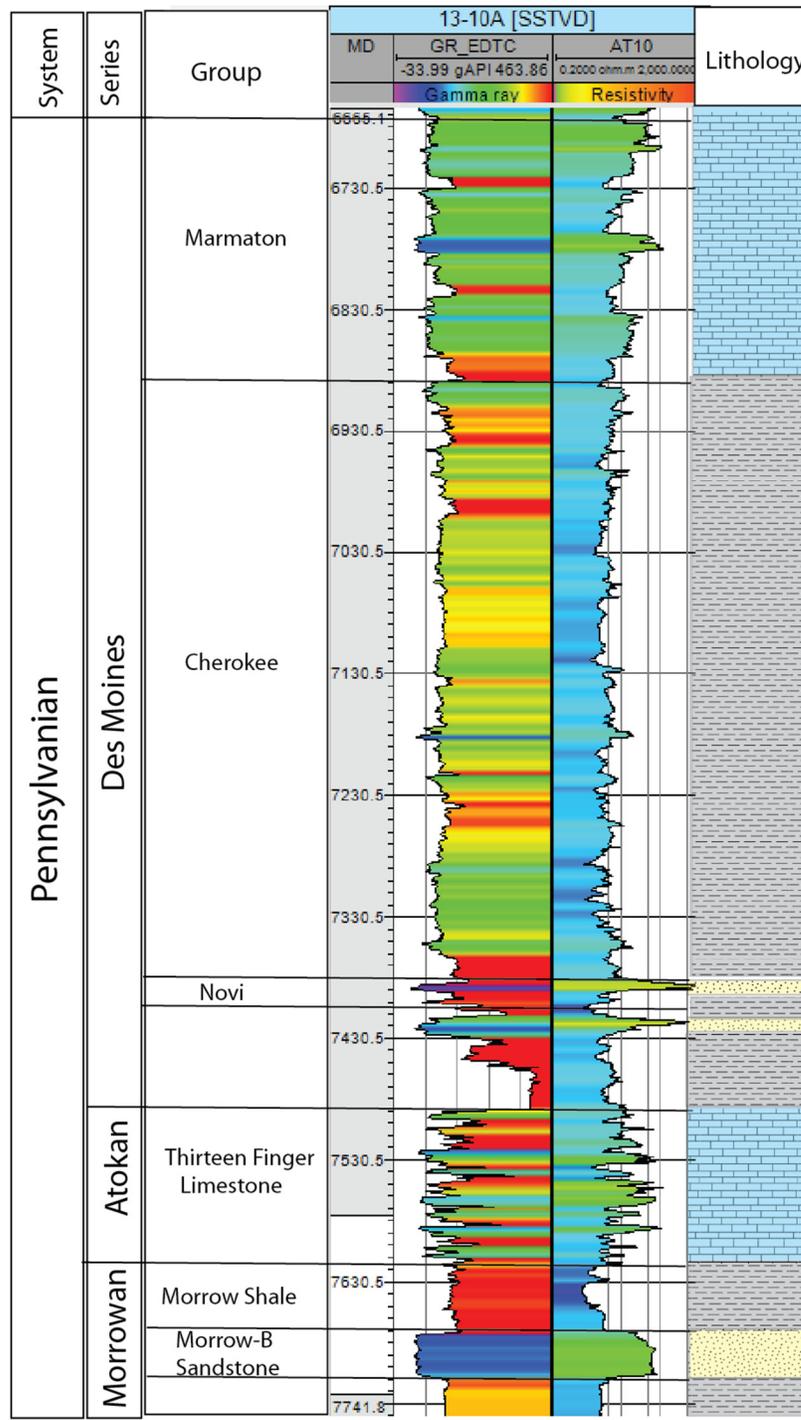


Figure 2.2-2- Stratigraphic section of the FWU.

Tectonic Setting

From FWU's location on the western edge of the basin, the Anadarko Basin plunges to the southeast where it reaches depths of over 40,000 feet (12,192 meters) adjacent to the Amarillo-Wichita Uplift (Perry, 1989). Maximum rates of subsidence occurred during

Morrowan to Atokan times (Evans, 1979; Perry, 1989; Higley, 2014). Positive features that might have influenced deposition within the region include the Ancestral Rockies to the north, the Central Kansas uplift to the northeast, and the Wichita-Amarillo uplift to the south (Evans, 1979; Munson, 1989). Of note is the fact that during Pennsylvanian time the FWU was located on the basin shelf in an area that was not affected greatly by tectonic deformation. Although faults have been reported previously in the northwest Anadarko Basin, we found no direct evidence for tectonic faults within the FWU (see Section 4).

Stratigraphy

Reservoir

Upper Morrowan sandstones in the Anadarko Basin margins have long been recognized as fluvial deposits (Swanson, 1979; Sonnenberg, 1985; Munson, 1989; Krystinik and Blakeney, 1990; Bowen et al., 1990; Al-Shaieb et al., 1995; Mckay and Noah, 1996; Puckette et al., 1996; Bowen and Weimer, 2003, 2004; Devries 2005; Puckette et al., 2008; Gallagher, 2014). At FWU, the Morrow B is a relatively coarse-grained subarkosic sandstone. The upper Morrowan facies in FWU, with sequences of basal conglomerate, coarse-grained sandstone, and fine-grained sandstone appear to be typical of incised valley deposits, as described by Wheeler et al. (1990), Krystinik and Blakeney (1990), Bowen et al. (1990), Blakeney et al. (1990), Sonnenberg et al. (1990) and Puckette et al. (2008). Typical reservoir porosity ranges from almost 0-25% with an average of ~15%, and permeability from 1-780 millidarcies (mD) with an average of ~35 mD (Rose-Coss, 2017)

Primary Seals

The Morrow B sandstones at FWU are encased above and below by shales. Contacts with shale both below and above the sandstone are sharp and irregular. The Morrow shale generally fines upwards in a series of thin beds (1-2 inches or 2.5-5 centimeters) that alternate between upper fine sands and fine to medium muds. Sand content decreases upwards through the section.

The Thirteen Finger limestone formation has two different lithofacies: diagenetic limestone (cementstone) and pyrite and fossil bearing fine to medium mudstone and coal. The two facies are intercalated with each other but tend to cluster in layers dominated more by one or the other. The number of limestone and mudstone beds varies from well to well; in one well 13-10A, 60-70 individual limestone beds were counted.

The entire Thirteen Finger interval is 130 feet (39.6 meters) thick, with approximately 40% of the thickness comprised of mudstone, 4% coal, and 46% is limestone. The cementstone is calcite rich, with some dolomite, and is completely diagenetic in origin and probably formed relatively soon following deposition. The organic-rich mudstone contains fibrous calcite "beef" fractures that are observed in the mudstone and coal lithology between cementstone "layers".

2.2.2.2 Hydrogeology

Information about Morrowan and Atokan formation water flow during oil operations has not been discovered in any oil or gas company published reports or academic research

studies in the Anadarko Basin. Groundwater flow rates in confined deep Anadarko layers at present are considered to be low to no flow (Nelson and Gianoutsos, 2014). Their arguments are based on (1) restricted recharge in the western basin, (2) density barriers to flow in the east, and (3) an overpressure pocket inhibiting flow in the deep basin. Jorgenson (1989) suggested flow could be west to east, driven by potential recharge to elevated units in the west and discharge at lower elevation outcrops in the east. The FWU CO₂ injection and production operations will not cause water to flow to outcrops of the Late Carboniferous (Pennsylvanian) time period that extend from Brownwood, Texas, to the Jacksboro/Bowie, Texas, area, which are hundreds of miles away (The Paleontology Portal).

The Carboniferous is a geologic period and system that cover 60 million years from the Devonian Period 358.9 million years ago, to the beginning of the Permian Period, 298.9 million years ago. As noted in the Section 2.2.2.1, the Morrowan and Atokan intervals of the FWU were deposited approximately 315-300 million years ago and are contained in the Carboniferous period.

2.3 Description of the Injection Process

Figure 2.3-1 depicts is a simplified flow diagram of the facilities and equipment within the boundaries of the FWU. CO₂ captured from the ethanol plant fermentation process is delivered via pipeline to the field for injection. The plant in Liberal KS is the only source of CO₂ to the field. The amount delivered is dependent on the production of CO₂ produced from the fermentation process. This amount will vary but should average 12 MMCFD. Once CO₂ enters the FWU there are three main processes involved in EOR operations. These processes are shown in Figure 2.3-1 and include:

1. CO₂ distribution and Injection. Purchased CO₂ is combined with recycled CO₂ from the FWU central tank battery and sent through the main CO₂ distribution system to various water alternating gas (WAG) injectors.
2. Produced Fluids Handling. Full well stream fluids are produced to the “all well test” site (AWT). The AWT site has two major purposes; 1) to individually test a well’s performance by separating and metering oil, gas and water, and 2) to separate all gas from liquid then send these two phases to the Central Tank Battery for final separation.
3. Produced Gas Processing. All phases from the AWTs are transferred to the central tank battery to separate the oil, gas and water using a series of vessels and storage tanks.

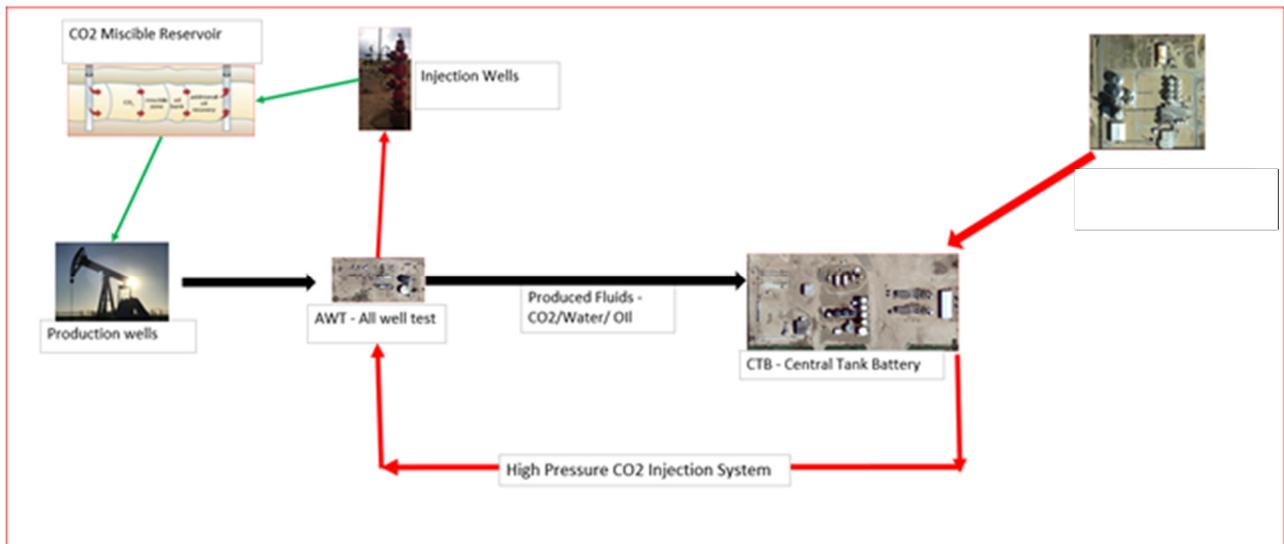


Figure 2.3-1 - Simplified flow diagram of the facilities and equipment within the boundaries of the Farnsworth Unit.

2.3.1 CO₂ Distribution and Injection

Perdure purchases CO₂ from Conestoga Energy Partners, the parent company of the Arkalon Ethanol plant located in Liberal Kansas. A custody transfer meter is located in the compression facility owned and operated by Perdure. The purchased CO₂ from the fermentation process is transported via a United States Department of Transportation (DOT) regulated pipeline to the FWU. A totalizer meter, for the purchased CO₂, is located in the field where instantaneous data is summed into a 24-hour flow rate which is recorded. A totalizer meter is a meter approved by American Gas Association (AGA) Report #3 to measure the flowrate of gases. The actual measurements taken are temperature, line pressure and differential pressure across the meter. Gas produced, recycled CO₂, from the wells is compressed and metered by a similar totalizer meter as the purchase CO₂ meter and is recorded daily.

Perdure currently has three active injection manifolds and approximately 17 active injection wells that the CO₂ is distributed through. When the MRV plan becomes active, the daily injection volume of the combined purchased CO₂ and recycled CO₂ will be approximately 24 MMCFD. Of this volume 12 MMCFD is purchased CO₂ and 12 MMCFD is recycled CO₂. This ratio of purchased CO₂ to recycled CO₂ is expected to change over time, with the percentage of recycled CO₂ increasing and purchased CO₂ decreasing. The current reservoir management plan projects that CO₂ purchases will remain constant at 12 MMCFD for 12 years and decline after 2033. (Per Reservoir Characterization and Modelling, the CO₂ purchases ceased at the end of 2033 which may or may not be true as ultimately production and the economic viability of the flood will dictate when purchased CO₂ is no longer required.) A reservoir management plan is an integrated process using various, surveillance techniques, economic evaluations, and accepted petroleum technical practices to efficiently operate enhanced oil recovery projects.

The three injection manifolds currently in the field distribute the CO₂ to the field. These manifolds have valves to switch to water when the time is called for. Depending on the

reservoir management plan the WAG cycle will be adjusted to maximize oil recovery and minimize CO₂ utilization in each injection pattern. At each injection well pad is a totalizer to measure the volumes injected every 24 hours. This data is collected daily by the field personnel and input into the data warehouse to be allocated for the pattern injection.

The two totalizer meters as described above will be used to determine the total volume injected used in section 7 for the mass balance equations necessary to determine annual and cumulative volumes of the stored CO₂.

2.3.2 Produced Fluids Handling

As injected CO₂ and water migrate through the reservoir, a mixture of oil, gas, and water (referred to as “produced fluids”) flows to the production wells. Gathering lines bring the produced fluids from each production well to the “all well test” (AWT) sites. Perdure has approximately 32 active production wells producing at any time. Each AWT has two separators. The first separator is used for testing individual wells to separate the gas, oil, and water produced from an individual well. This gas, oil and water is subsequently measured and recorded for the well. Each producing well is production tested every 30 to 60 days after the last production test, or after the well is returned to production. Depending on the reservoir management plan well testing can be more frequent to obtain data. The second separator is used to separate the gas from the oil/water mixture from the other wells producing into the AWT and the gas and liquids are displaced from the vessel in separate lines. Leaving the AWT sites are two lines transporting produced fluids. One for the liquid phase, a mixture of oil and water, and one for the gas phase.

When gas and liquid lines enter the CTB a series of vessels separate the oil, gas, and water to be accounted for and distributed for sales or reinjected. The liquid phase line has vessels to separate the oil from the water using density and residence time. The gas phase vessels collect any free liquids entrained with the gas. These free liquids are then combined back into the liquid phase line. All gas and water are reinjected, and the oil, which contains an estimated 2,930 ppm CO₂ (0.293%), is sold out of tanks. Annually, the oil from the stock tank is analyzed by a laboratory using ASTM crude oil analysis methods to determine the CO₂ content in the oil being sold.

After separation, the gas phase, which is approximately 89-93% CO₂, is mixed with reservoir volatile components, compressed, and distributed throughout the high-pressure distribution system using reciprocal compression and high-pressure horizontal pumps.

The water is transferred from the separation vessels to tanks for reinjection. After the water is conditioned, it is either reinjected at the WAG skids or disposed of into permitted disposal wells. Although Perdure is not required to determine or report the amount of dissolved CO₂ in the water, analyses have shown the water typically contains <690 ppm (0.069%) CO₂.

FWU production has trace amounts of hydrogen sulfide (H₂S), which is toxic. There are approximately 8-10 workers on the ground in the FWU at any given time, and all field and contractor personnel are always required to wear H₂S detectors. The primary purpose of the H₂S detectors is protecting people from the risk of being harmed. The detection limit of

the H₂S detectors is quantified for readings in the range of 0-100 ppm and will sound an alarm above 10 ppm. The secondary purpose H₂S detectors would be to provide an indication of emissions of gas from a pipeline or surface equipment, that might go unnoticed by other observations or measurements. No gas volumes can be calculated based on the detector reading or alarm; only a H₂S leakage is detected and located. Once identified, further a further response will be initiated and CO₂ volumes will be quantified as discussed in sections 4.5, 4.6, 5.4 and 8.1.5 of this MRV plan.

2.3.3 Produced Gas Handling

Produced gas separated at the central tank battery (CTB) is stripped by a series of vessels of entrained and free water. The water content has been recorded to be < 20 pounds mass per MMCF, thus dehydration is not necessary. The gas is then sent to a centralized compression system to be compressed and placed in the high-pressure distribution system. This compression turns the CO₂ into a variable density liquid, which is then transported out via high pressure lines to the AWTs where a manifold splits this dense CO₂ to the wells that are on CO₂ injection at that time.

2.3.4 Facilities Locations

The locations of the “all well test” sites (AWT) are positioned in the field to access both injection distribution and production gathering. The central tank battery (CTB) is where the final separation and injection equipment is maintained and operated. The water injection station is where the horizontal pumps are located to reinject the produced brine.

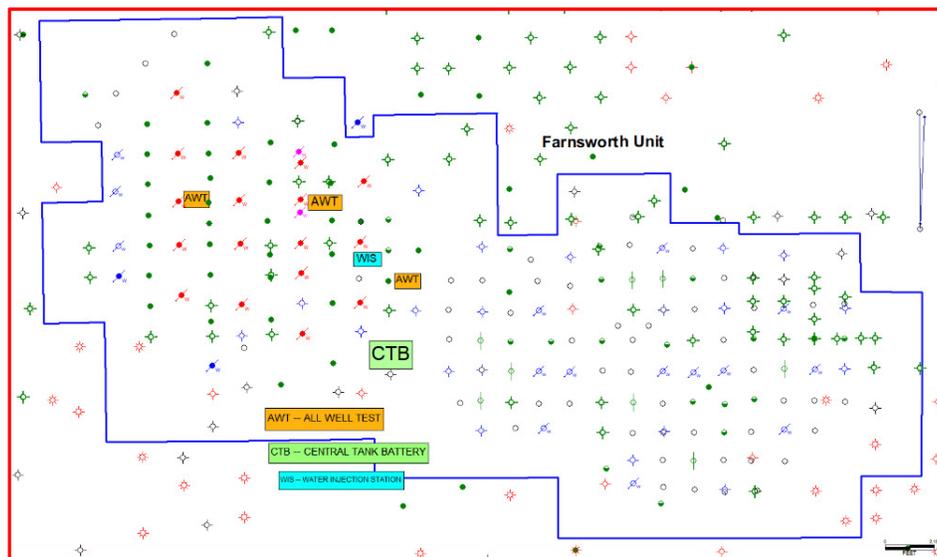


Figure 2.3-2 – Location of All Well Test (AWT) sites, Central Tank Battery (CTB) and Water Injection Station (WIS) in the FWU

2.3.5 Water Conditioning and Injection

Produced water collected at the central tank battery is collected in a series of vessels and tanks in a cascade system. This allows any entrained oil to further separate to the top of the tanks because of the density difference and is skimmed off and put back in the oil separation system. The clean water is then transferred to the water injection system where

it is boosted in pressure and sent out to the AWTs for distribution to all wells that are currently on water injection.

2.3.6 Well Operation and Permitting

The Texas Railroad Commission rules (Appendix 1) govern well location, construction, operation, maintenance, and closure for all wells in permitted units and wells. Perdure follows these rules and regulations to maintain safe and efficient operations. This includes complying with all current and updated information for mechanical integrity testing, well repairs for injection wells, drilling and completion permitting and reporting.

Briefly current rules require, among other provisions:

- That fluids be constrained in the strata in which they are encountered.
- That activities governed by the rule cannot result in the pollution of subsurface or surface water.
- That wells adhere to specified casing, cementing, drilling well control, and completion requirements designed to prevent fluids from moving from the strata they are encountered into strata with oil and gas, or into subsurface and surface waters.
- That wells file a completion report including basic electric log (e.g., a density, sonic, or resistivity (except dip meter) log run over the entire wellbore).
- That all wells be equipped with a Bradenhead gauge, measure the pressure between casing strings using the Bradenhead gauge, and follow procedures to report and address any instances where pressure on the Bradenhead is detected.
- And that all wells follow plugging procedures that require advance approval from the Director and allow consideration of the suitability of the cement based on the use of the well, the location and setting of plugs.

2.3.7 Number, Location and Depth of Injection Wells

Perdure's FWU injection wells are listed in Appendix 1. Injection is into the Upper Morrowan, a lenticular bedded sandstone trending northwest to southeast with the average top of sand at 7990 feet, true vertical depth. The Upper Morrowan is described in section 2.2.2.1 above.

2.4 Reservoir Characterization Modeling

2.4.1 Reservoir Model Description

The target reservoir Morrow B is a sandstone formation overlain by the Morrow shale and Thirteen Finger limestone, which serve as excellent seals for injected CO₂ (Ampomah et al., 2016a). The Morrow B sandstone reservoir is at a depth between 7550 feet and 7950 feet subsurface with an average dip of less than one degree (Figure 2.4-1). The productive limit of the FWU extends laterally to about 8300 acres. The maximum pay thickness is 54 feet with an average of 22 feet.

The FWU is approximately 4 mi by 7 mi and is usually divided into eastern and western portions because the two sides of this field have exhibited different reservoir behavior. The

eastern side was more prolific under primary production. However, the CO₂ –EOR study for FWU has concentrated on the west half of the field, which showed a better response to waterflood initiated in the 1960's and which is where the field operator is focusing their efforts (Ampomah et al., 2016b).

In the property modelling process, a hydraulic flow unit (HFU) methodology based on the Winland R35 method was used to describe and characterize heterogeneity within the Morrow B reservoir. The R35 parameter refers to the pore throat aperture radius when core samples are 35% saturated during a mercury injection porosimetry test. This captures pore throat size at which pore networks become interconnected and form continuous flow paths. Fifty-one (51) wells with core porosity and permeability measurements were used to define eight distinct porosity/permeability relationships (Figure 2.4-2). These eight relationships were based on depositional/diagenetic facies described from core and thin section analysis. The facies have differences, often subtle, that appear to greatly affect reservoir properties (Ross-Coss et al., 2016). There appears to be a strong relationship between the delineated hydraulic flow units and depositional and diagenetic trends that was not noted in early investigations into reservoir properties (Gallagher, 2014, Munson, 1989). After HFUs and porosity/permeability relationships were established, a Gaussian simulation method, cokriged with the facies model, was used to model porosity and net-to-gross ratio.

The geocellular structural model has a grid cell distribution of 1573*962*23 with a grid dimension of 25 feet × 25 feet. and includes the reservoir formation and several of the overlying seal formations. This model was upscaled to a reasonable size to decrease computational time for simulation purposes. The upscaled model, which uses only the western half of FWU, has a grid size of 176×163× 8 for a total of 229,504 cells that are approximately 100 feet by 100 feet on the top view perspective.

Figure 2.4-3 shows porosity and permeability distribution for the western half of FWU used in this study. Reservoir porosity ranges from 9.2% to 24% with a mean of 14.6% and shows a normal population distribution. Permeability ranges from 0.01 mD to 181 mD with an average value of 58 mD. The permeability histogram shows a log-normal population distribution.

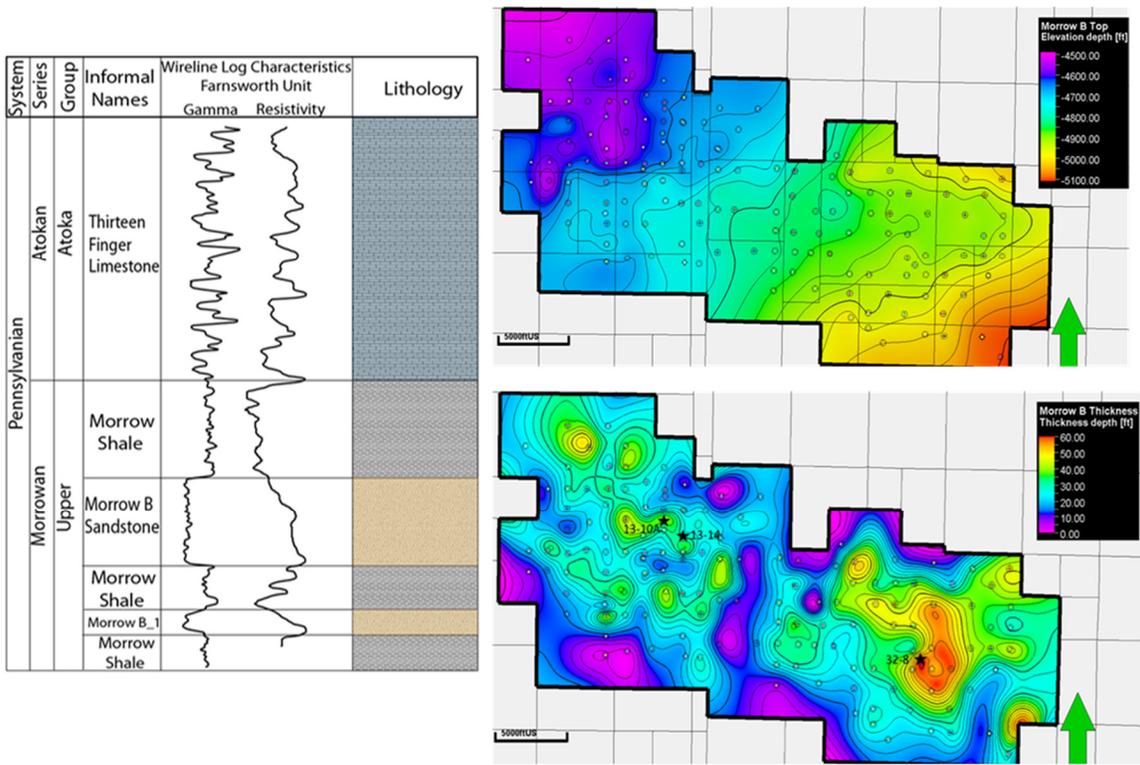


Figure 2.4-1- (Left) Type log of FWU caprock and reservoir. (Upper Right) Surface contour of Morrow B top. (Lower right) Thickness map of Morrow B sands (Gallagher 2014).

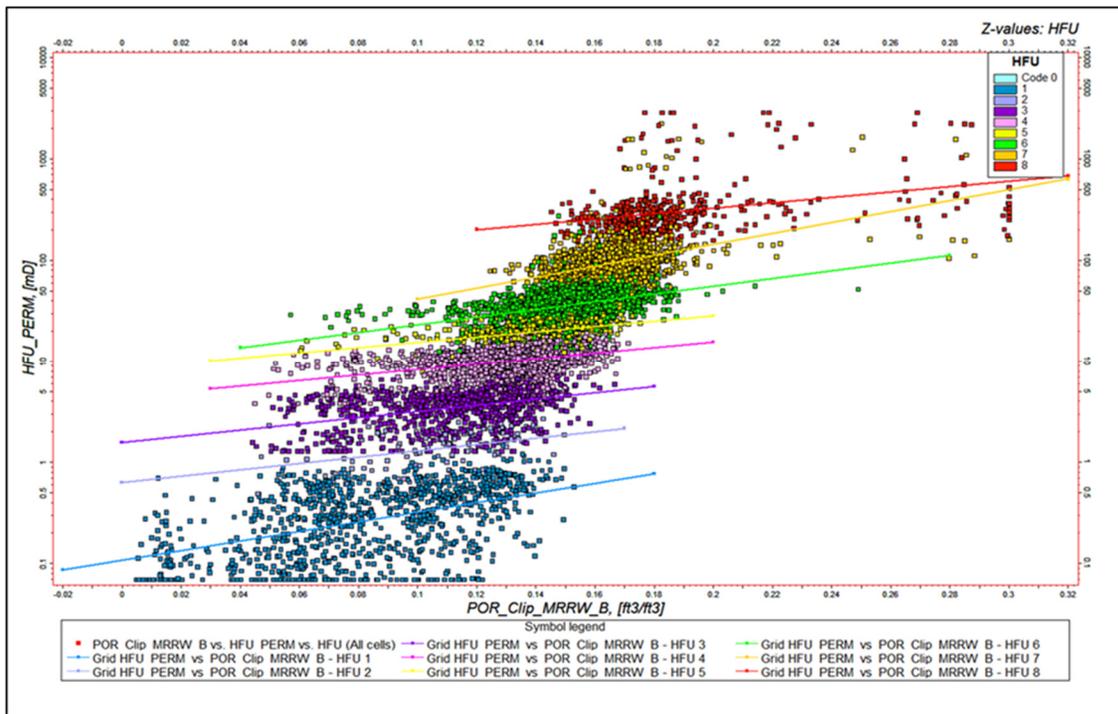


Figure 2.4-2 - Porosity versus permeability for the 51 cored wells, separated by pore throat size into hydraulic flow units.

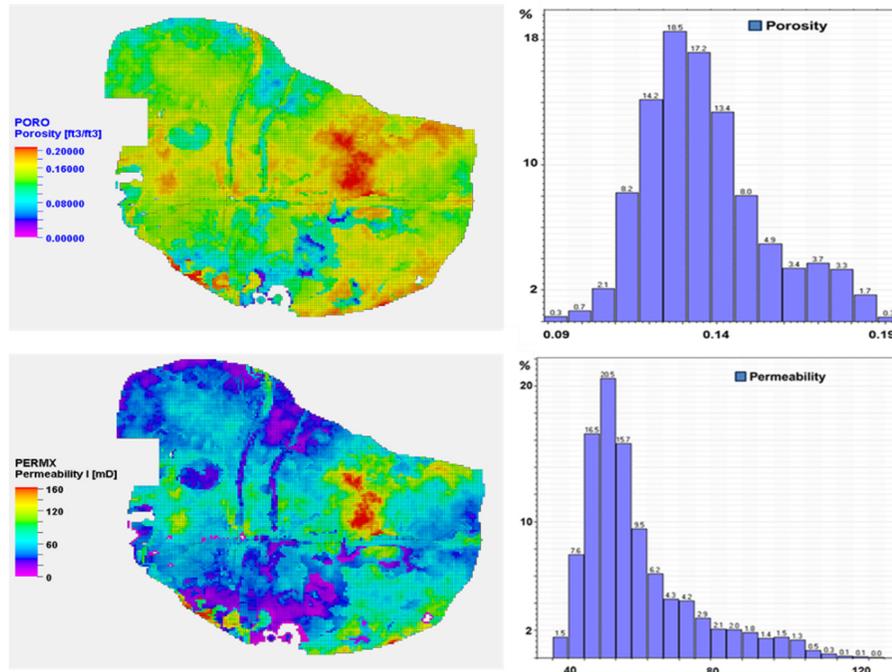


Figure 2.4-1- (Upper left) Porosity distribution using a Gaussian Simulation method for the west section of FWU used in the work. (Upper right) shows histogram illustrating a normal distribution of porosity with a mean of 14%. (Lower left) Permeability distribution constructed from porosity-permeability cross plots based on eight hydraulic flow units. (Lower right) Histogram illustrates a lognormal distribution of permeability.

2.4.2 Reservoir Fluid Modeling

The compositional fluid model was constructed from laboratory experiments tuned to an equation of state (Gunda et al., 2015). The process for the FWU involved comprehensive splitting and lumping of the C7+ fractions. The experimental data from PVT experiments including constant composition expansion (CCE), saturation pressure, differential liberation (DL), multi-stage separator tests and viscosity tests conducted on FWU fluid sample were used for the validation of the tuning process (Gunda et al., 2015). The mixing rules by Pedersen (Pedersen et al. 1989) were followed to split the C7+ fractions into two pseudocomponents using the average molecular weight, average specific gravity and the total mole percent. The isomers of C4 (butane) and C5 (pentane) were also lumped using the same methodology. A regression process was performed manually to achieve acceptable calibration to the laboratory data. The critical parameters for the two pseudocomponents were calculated based on Pedersen’s approach (Pedersen 2002) using Calsep’s PVTsim™ software package. The 3- parameter Peng Robinson equation of state (Peng and Robinson 1976) with Peneloux volume correction (Peneloux et al. 1982) was used to perform all the calculations. The viscosity modeled using the Lohrenz-Bray-Clark correlation (Lohrenz et al. 1964). After calibrating the fluid model to equation of state, a slim tube simulation experiment was conducted to obtain the minimum miscible pressure (MMP) for FWU. A one-dimensional 200 cell model was used for the experiment with a CO₂ injection rate of 1.2 pore volume. Figure 2.4-4 shows a plot of oil recovery vs. pressure illustrating the MMP of FWU computed from the simulation experiment. The MMP of 4009 psia realized from the simulation as compared to an MMP value 4200 psia derived from

laboratory experiments provided by the operator represents a less than 5% error (Gunda et al., 2015).

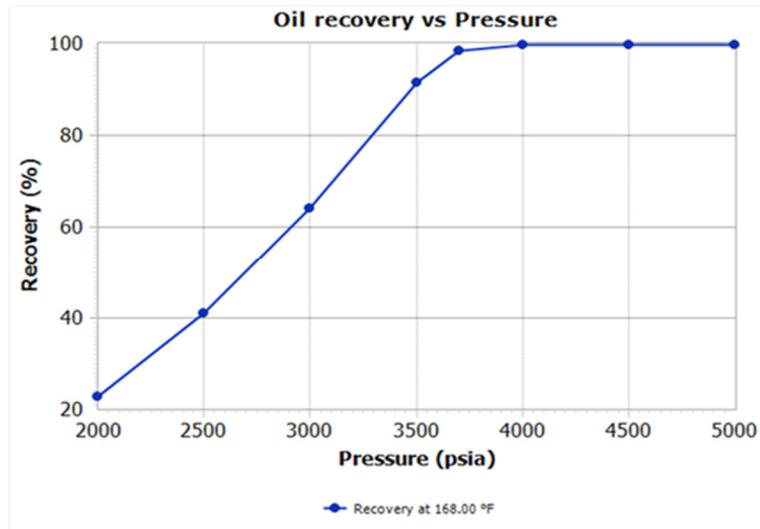


Figure 2.4-4. Oil recovery plot for 1D slim tube test

2.4.3 Assisted History Matching using Reduced Order Model

This section presents computer assisted history matching efforts for primary, secondary and tertiary recovery processes for FWU. Eclipse E300 (Schlumberger) was used throughout this study for all simulation runs. Most efforts were directed at matching secondary and tertiary processes by assigning higher weights in objective function formulation as compared to primary processes. Gas production field history was not available for primary recovery. The primary and secondary history processes lasted for 55 years until December 2010. The tertiary CO₂ flood was performed between December 2010 and August 2020. The parameters included in the objective function formulation were oil production, water production, water-cut, gas oil ratio (during waterflood), and injection rate. Pressure measurements including those made initially, prior to waterflood and at the end of waterflood were also used in the calibration process. Heath et al., (2015) conducted geomechanical analysis on FWU rock samples and determined a fracture pressure between 5400 to 5600 psia.

During primary recovery, there were a total of 60 production wells. As there were no recorded gas-oil or water-oil contacts, all grid blocks were assigned an initial oil saturation of 69% and 31% connate water saturation. With initial reservoir pressure of 2217.7 psia assigned to the datum depth of 4900 feet TVDSS, original average pressure in the model was 2150 psia. Oil originally in place (OOIP) for FWU west half in this model was about 71.4 MMstb with 23.8 MMscf of dissolved natural gas. During waterflood, there were 47 producer wells with 13 wells converted from producers to injector wells. An additional 6 water injector wells drilled during this period. The initial sensitivity analysis performed on primary and secondary recovery processes showed that well bottomhole pressure, oil-water contact (OWC), and bottomhole injection pressure were the most important parameters.

These uncertain variables were included in the history matching process to optimize the objective function at acceptable data uncertainty ranges.

From the history matching results it was deduced that OWC of an average value of 5000 feet TVDSS was appropriate to yield the best history match model. The bottomhole pressure had an optimum value of 4800 psia to improve history matching efforts. Sensitivity analysis showed global permeability was not particularly sensitive to the objective function. However, a few local permeabilities were furthered adjusted to improve the overall history matching. The overall RMS was about 10%, which was mostly contributed by gas-oil ratio match. This confirms some doubts the operator had on gas production history measurements during the primary and secondary recovery processes of the field. Figure 2.4-5 shows oil production and water cut profiles. Various waterflood patterns swept to residual oil saturation of about 27%, a successful flood. This is not unexpected given the relatively good mobility ratio of about 1.6 and high injection throughput of at least 1.7 displaceable pore volumes. From the simulation results, nearly 6 MMstb represents 10% of OOIP produced prior to the initiation of waterflood. A total of 25.65 MMstb of cumulative oil has been produced at the end of secondary from the west half of FWU, which represents nearly 40% of OOIP. During the tertiary history match, an initial simulation run showed a good calibration of compared to observed history until CO₂ breakthrough. Simulated gas production and CO₂ injection rates were unable to match measured volumes after the CO₂ breakthrough, which could be attributed to a potential change in wettability and interfacial tension. There is a possibility of the Morrow B transitioning into a mixed-wet wettability system. Corey parameters were adjusted to improve calibration of the CO₂ flood history match. An optimization approach was utilized to identify optimum values for Corey parameters. Figure 2.4-6 shows simulated results compared to historical oil production, gas production, CO₂ injection and water production profiles.

At the end of August 2020, according to simulation results, a total of 4.8 MMstb of oil has been produced from the west half of FWU since CO₂-WAG commenced (December 2010). About 93% of the purchased CO₂ remains as of August 2020.

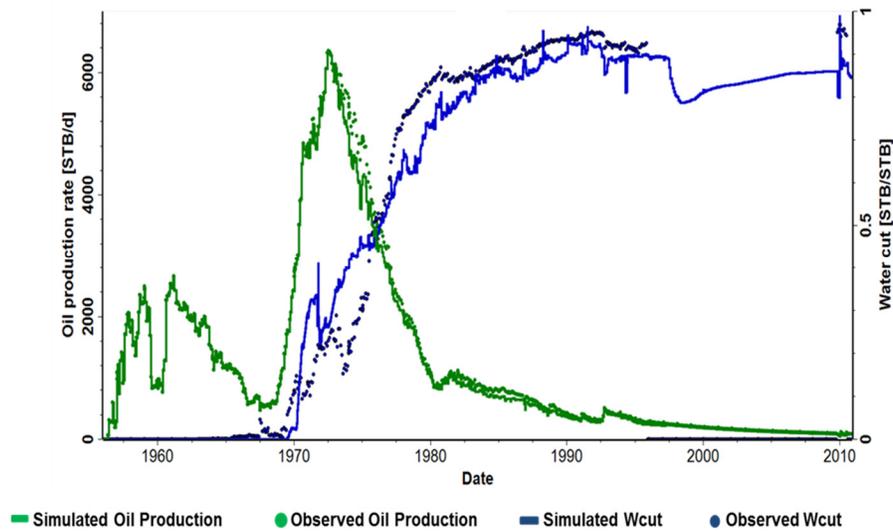


Figure 2.4-5- Calibration of simulated oil production rate and water cut vs. observed for primary and secondary history matching process.

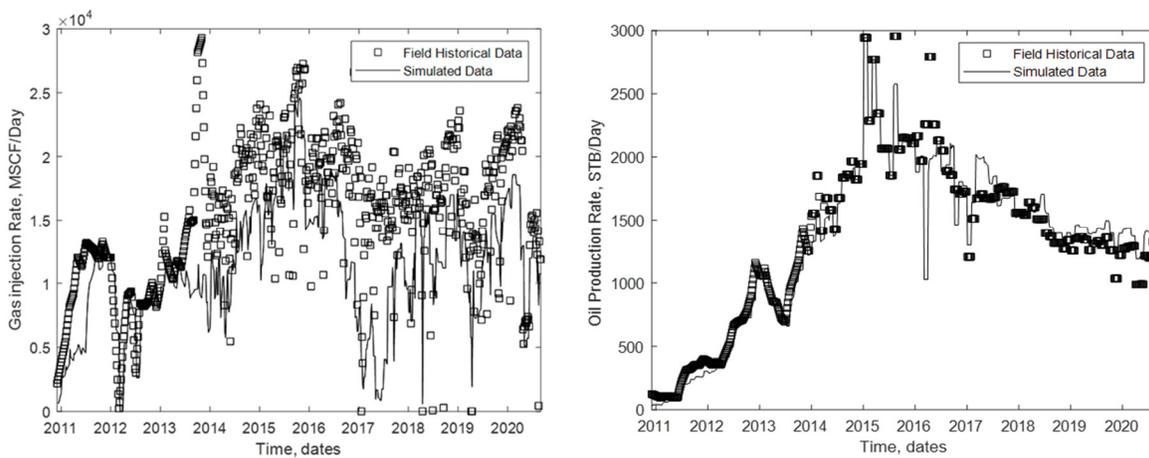


Figure 2.4-6- Calibration of simulated vs observed responses for tertiary recovery including CO₂ injection (left) and oil production rate (right).

2.4.4 CO₂ –EOR Performance Scenarios

Once an acceptable history match was reached, CO₂ flood performance could be predicted to optimize oil production and CO₂ storage. Several prediction cases based on different injection scenarios were run to maximize the potential of the projected flood. Per the current plan of the operator, five existing water injection wells will be converted to WAG injection wells and were included in the CO₂ prediction model. There is an anticipated constant CO₂ purchase of 12 MMscf/d and a flexible compressor capacity to recycle produced gas for reinjection purposes. A user-defined algorithm was developed in the numerical simulator to use purchased CO₂ in addition to produced gas (recycled) as a group injection rate target for the run scenarios. The model was performed for a 12-year period with bottomhole pressure and oil rate target constraints. Per §98.449 Definitions, the modelled area is projected to contain the free phase CO₂ plume at the end of year t + 5. The

injection profile shows the storage capacity of the Morrow B storage complex. Significant amount of produced CO₂ was recycled back into the injection stream (Figure 2.4-7). The compressor capacity will be expanded to compensate for high volume recycle volumes in the future.

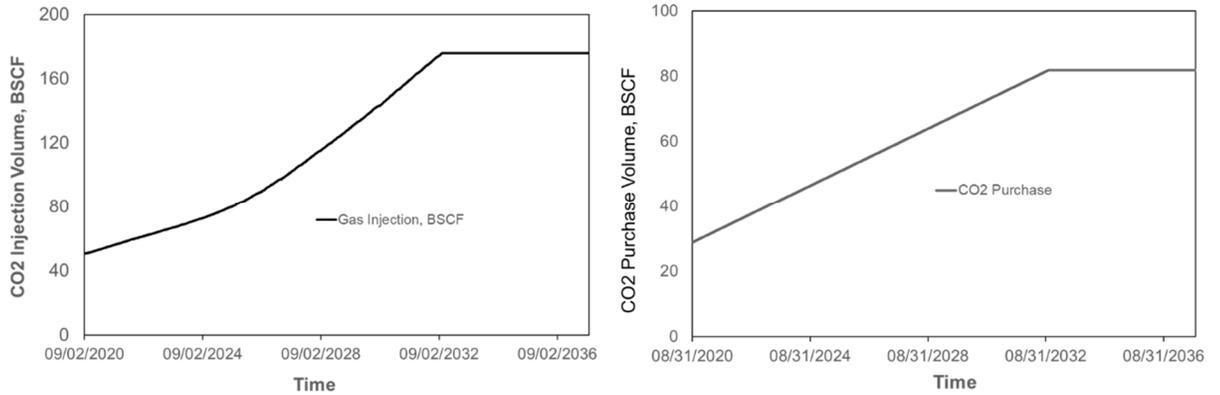


Figure 2.4-7 - Simulated Cumulative CO₂ injection Volume and CO₂ purchase volume for the Forecasting Scenario

3 Delineation of the monitoring areas

3.1 MMA

As defined in Subpart RR, the maximum monitoring area (MMA) is equal to or greater than the area expected to contain the free phase CO₂ plume until the CO₂ plume has stabilized plus an all-around buffer zone of at least one-half mile. The purchase volumes that are displayed in figure 2.4.7 and the mapped CO₂ composition results that are displayed in Section 3.1.1 indicate that all of the CO₂ will remain in modelled area is projected to contain the free phase CO₂ plume at the end of year t + 5; barring unforeseen future operational issues. Therefore, Perdure is defining the MMA as the boundary of the FWU plus an additional one-half mile buffer zone. This will allow for operational expansion throughout the FWU for the next 12 years, the anticipated life of the project.

3.1.1 Determination of free phase plume extent

Figure 3.1-1 shows the modeling simulation of the total CO₂ composition depicting the lateral extent of CO₂ in the injection zone. The injection area shows the significant high concentration of CO₂ which reiterates the containment within the injection zone and area. The simulation depicts the tertiary CO₂ flood that was performed between December 2010 and October 2032 with additional 5-year post-injection monitoring (Figure 3.1-2). The high green color shows almost zero CO₂ fraction which illustrates most of the CO₂ injected has not reach the model boundary even after a total of 22 years of potential CO₂ injection into the Morrow B formation.

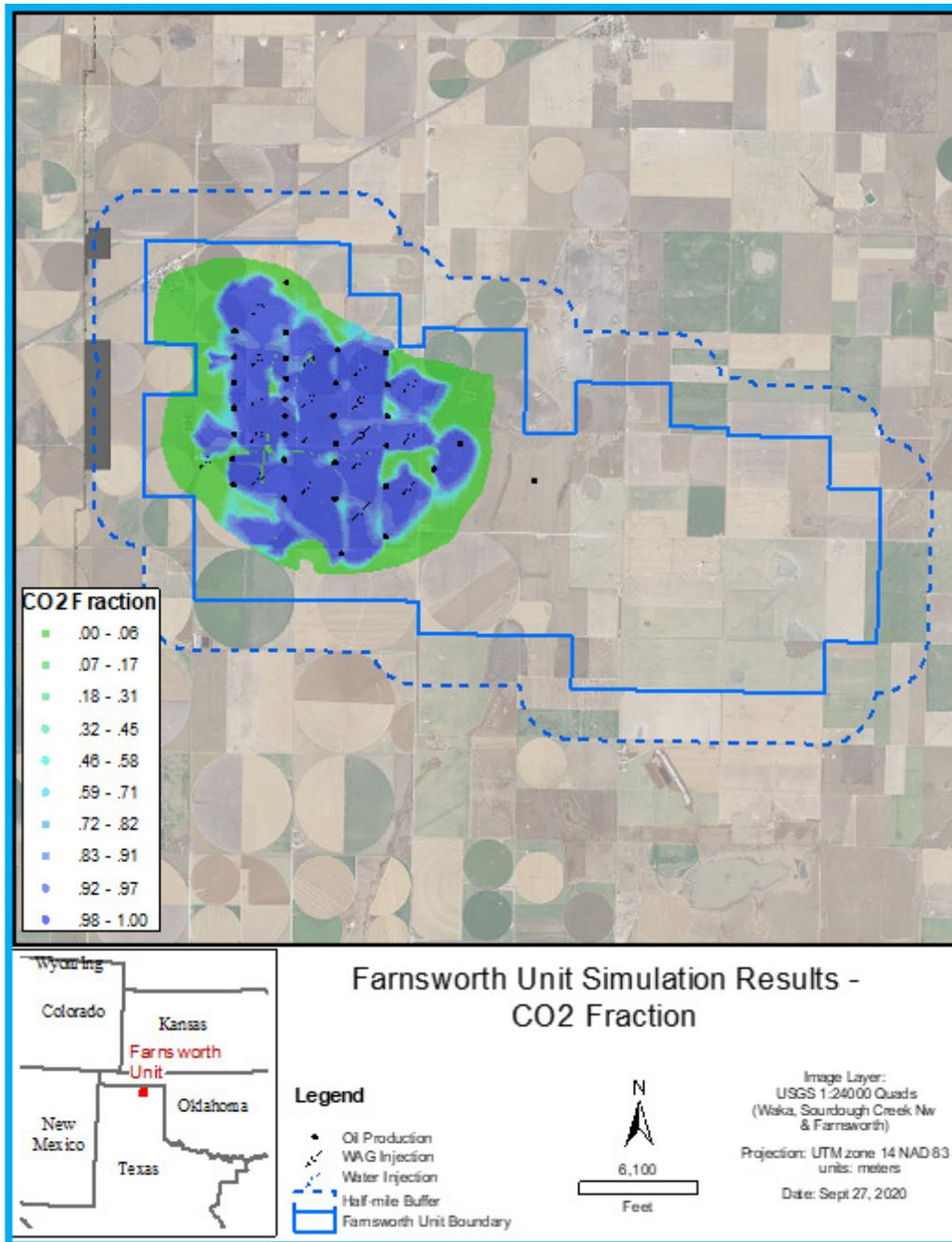


Figure 3.1-1: Model simulation of the tertiary CO₂ flood

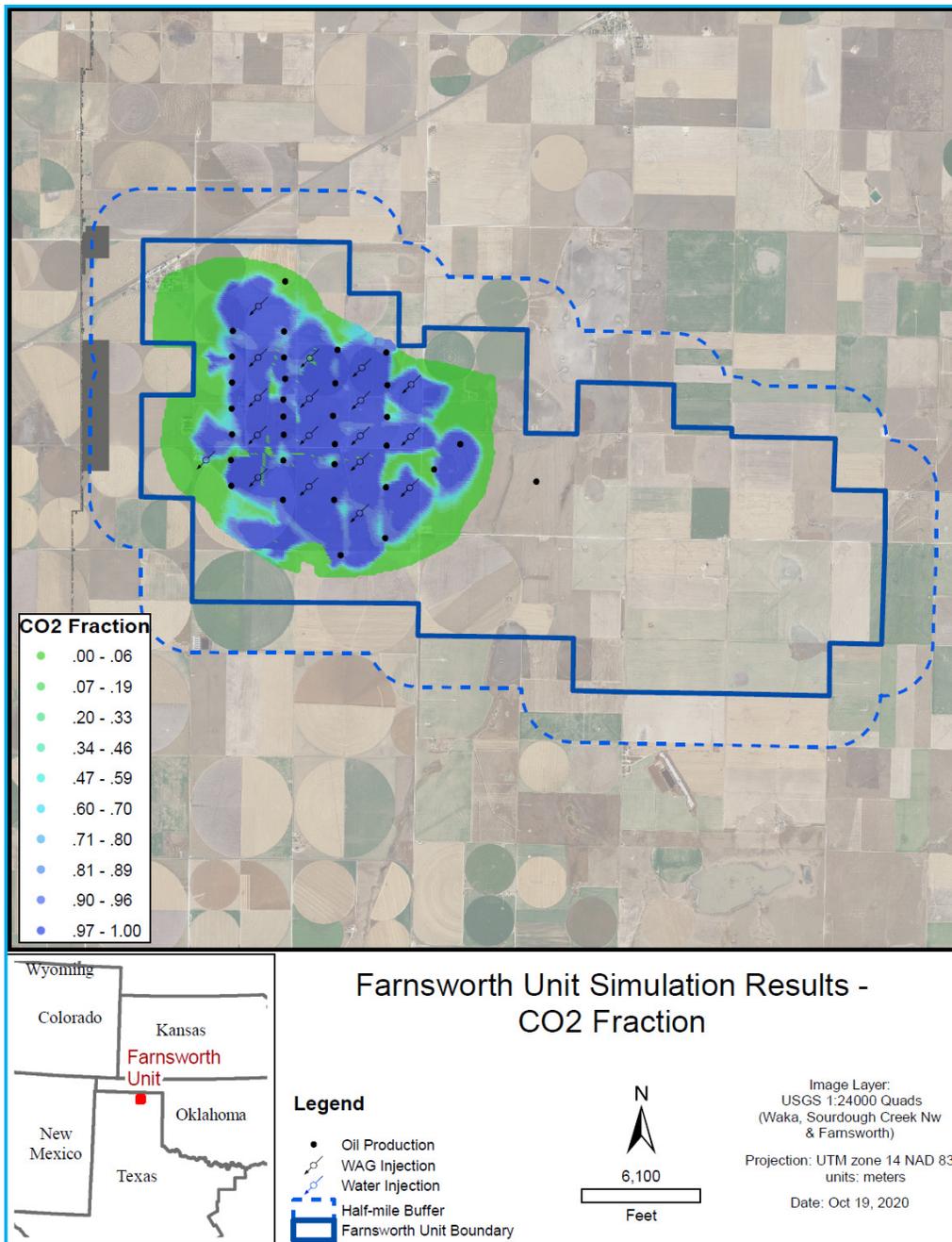


Figure 3.1-2 – CO₂ Plume Extent 5 years after Injection ceased.

3.1.2 Determination of buffer zone

Perdure intends to implement a buffer zone of one-half mile around the FWU, the minimum required by Subpart RR, because the site characterization of the FWU did not reveal any leakage pathways that would allow free-phase CO₂ to migrate laterally thereby warranting a buffer zone greater than one-half mile.

3.2 AMA

Currently, Perdure's operations are focused in the western portion of the FWU. However, it is anticipated as the project develops additional activity will occur in the eastern portion of the FWU; therefore, requiring active monitoring in that area. However, project development is driven by the market price of oil so Perdure is unable to provide a specific time in the future when the eastern portion of the FWU will be actively monitored. Therefore, for the purposes of this MRV plan, Perdure has chosen to include the entire FWU in the AMA.

4 Identification and Evaluation of Leakage Pathways

Since its discovery in 1955, its unitization in 1963, and the commencement of CO₂ EOR in 2010; the FWU has undergone extensive investigation and documentation as indicated in Section 2. From this body of work, Perdure has identified the following potential pathways of CO₂ leakage to the surface. This section will also address detection, verification, and quantification of leakage from each pathway.

4.1 Leakage from Surface Equipment

The surface equipment and pipelines utilize materials of construction and control processes that are standard in the oil and gas industry for CO₂ EOR projects. Ongoing field surveillance of pipelines, wellheads and other surface equipment via personnel instructed how to detect surface leaks and other equipment failure minimizes releases. In addition, requirements in the Texas Administrative Code (TAC) rules for the Texas Railroad Commission (TRRC) Oil and Gas Division to report and quantify leaks, both serve to minimize leakage of GHG from surface equipment. Operating and maintenance practices currently follow and will continue to follow demonstrated industry standards. As described in Section 6.4 below, should leakage from surface equipment occur it will be quantified according to the procedures in Subpart W of the GHGRP.

4.2 Leakage from Wells

Perdure has identified 61 abandoned wells, 32 injection wells (17 active), 58 production wells (32 active) and 2 monitoring wells within the MMA and assessed their potential for leakage of CO₂ to the surface as listed in Appendix 1.

4.2.1 Abandoned Wells

Figure 4.2-1 shows all wells plugged and abandoned in the FWU. Because the FWU was unitized in 1963, all plugging and abandonment activities of wells within the FWU have been conducted under the regulations of the TRRC for plugging wells. Perdure concludes that leakage of CO₂ to the surface through abandoned wells is unlikely. However, strategies for leak detection are in place that are discussed in Section 4.5 and the strategy to quantify the leak is discussed in Section 4.6.

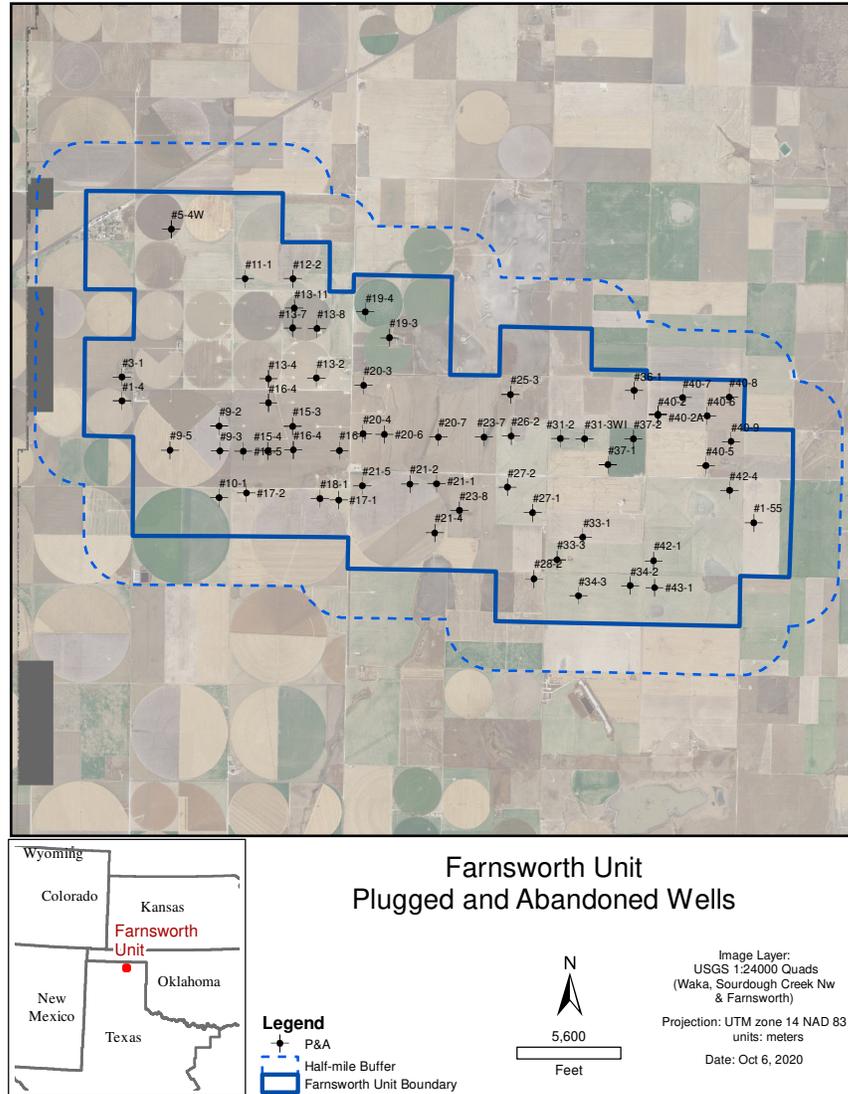


Figure 4.2-1: Plugged and Abandoned Wells in the FWU

4.2.2 Injection Wells

Mechanical integrity testing (MIT) is an essential requirement of the Underground Injection Control (UIC) program in demonstrating that injection wells themselves do not act as conduits for leakage into underground sources of drinking water (USDWs) and to the surface environment. Rule 46 and any special conditions pertaining to mechanical integrity testing the TRRC includes in the Class II permits issued to Perdure, ensure that active injection wells operate to be protective of subsurface and surface resources and the environment. Figure 4.2-2 and 4.2-3 shows the active and inactive, respectively, injection wells in the FWU. Perdure concludes that leakage of CO₂ to the surface through injection wells is unlikely.

4.2.3 Production Wells

Figure 4.2-2 4.2-3 shows the active and inactive, respectively, oil production wells in the FWU. However, as the project develops in the FWU additional production wells may be added and will be constructed according to the relevant rules of the TRRC. Additionally,

inactive wells may become active according to the rules of the TRRC. Perdure concludes that leakage of CO₂ to the surface through production wells is unlikely.

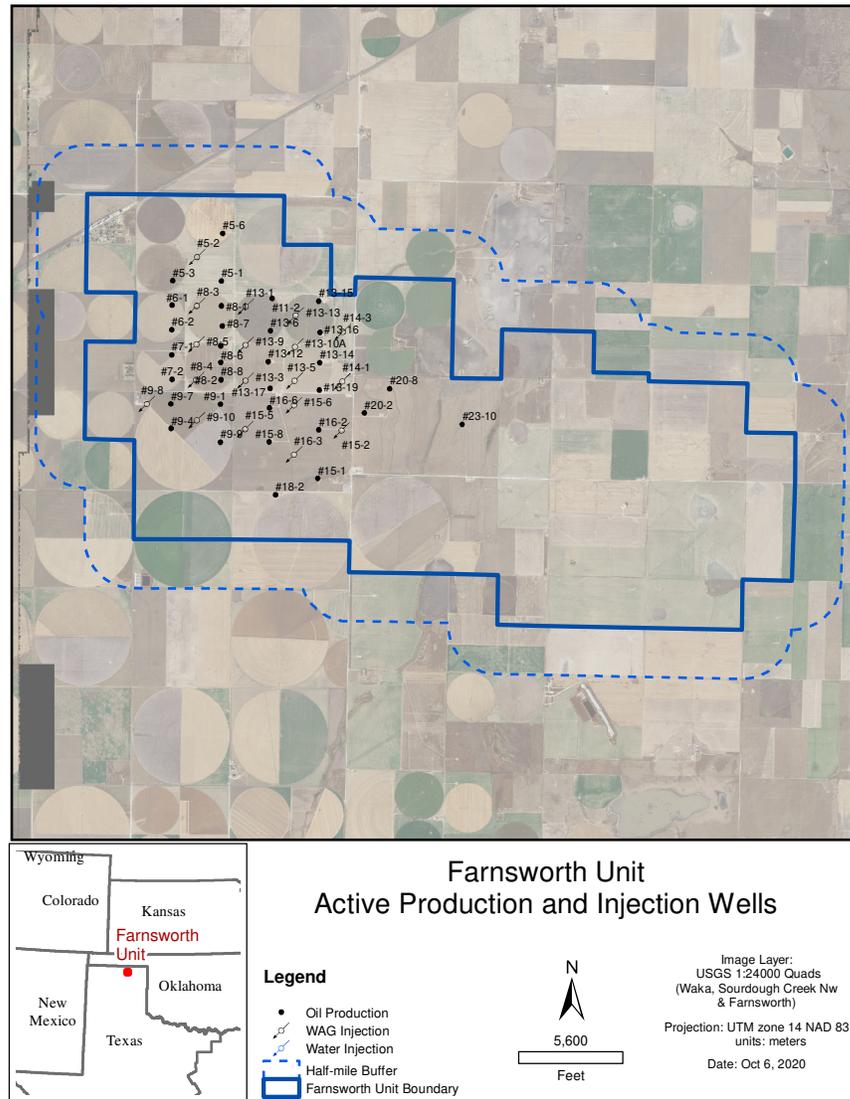


Figure 4.2-2: Active Production and Injection Wells in the FWU

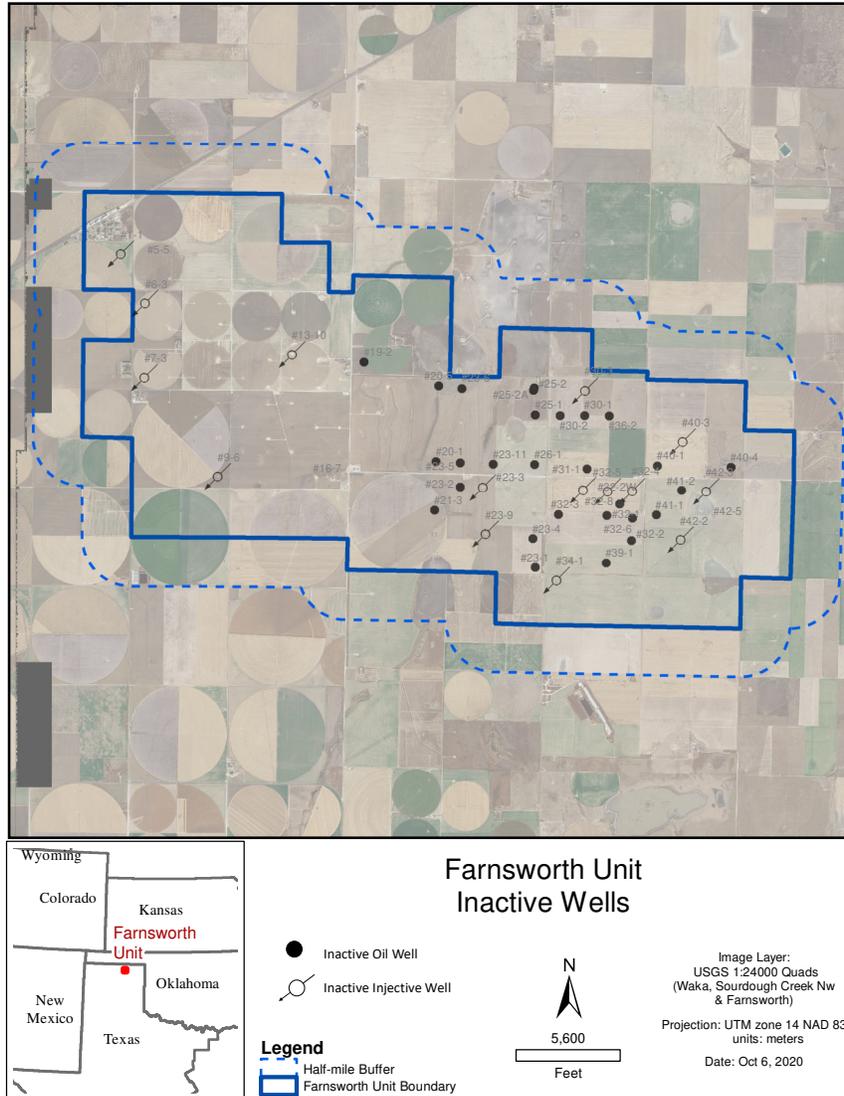


Figure 4.2-3: Inactive Production and Injection Wells in the FWU

4.2.4 Monitoring Well #13-10

The SWP has conducted monitoring of the Morrow B injection horizon and overlying seals in the area immediately adjacent to the new WAG injection well (#13-10A), through the use of a dedicated monitoring well (#13-10). This old WAG injection well (#13-10), drilled in 1971 to a total depth (TD) of 7770 feet, was repurposed for monitoring reservoir pressure and temperature, borehole temperature and microseismicity. To accomplish the task, the following equipment were permanently installed in the well:

- Downhole pressure and temperature gauges: Real time pressure and temperature monitoring of the reservoir
- Distributed Temperature Sensing (DTS): Real time monitoring of temperature along the wellbore for leakage detection.
- Sixteen level geophone array: Pseudo real time monitoring of passive and active (during injection and draw down cycles) microseismic activities within the FWU.

- Twenty surface seismometer stations: Monitor microseismic activities at the surface. Data is integrated with data from borehole geophone array to enhance event detection and location.

After the SWP has finished their Real time monitoring and their research efforts are completed Perdure may continue to observe and collect the data, but it will not be an ongoing part of the FWU MRV plan.

4.2.5 New Wells

As the project develops, new production wells and injection wells may be added to the FWU. All new wells will be constructed according to the relevant rules for the TRRC which ensure protection of subsurface and surface resources and the environment.

All wells in Texas oilfields, including both injection and production wells, are regulated by TRRC, which has primacy to implement the UIC Class II program in Texas, under TAC Title 16 Part 1 Chapter 3.

TRRC rules govern well siting, construction, operation, maintenance, and closure for all wells in oilfields. Briefly current rules require, among other provisions:

- That fluids be constrained in the strata in which they are encountered;
- That activities governed by the rule cannot result in the pollution of subsurface or surface water;
- That wells adhere to specified casing, cementing, drilling well control, and completion requirements designed to prevent fluids from moving from the strata they are encountered into strata with oil and gas, or into subsurface and surface water;
- That wells file a completion report including basic electric logs;
- That all wells be equipped with a Bradenhead gauge, measure the pressure between casing strings using the Bradenhead gauge, and follow procedures to report and address any instances where pressure on the Bradenhead is detected;
- And that all wells follow plugging procedures that require advance approval from the Director and allow consideration of the suitability of the cement based on the use of the well, the location and setting of plugs.

New well construction is based on existing best practices, established during the drilling of existing wells in FWU and follows TRRC rules, which significantly limits any potential leakage from well pathways. Additionally, the existing wells followed TRRC rules.

In public databases, the area of FWU plus one mile past the unit boundary contains over 100 wells that were drilled deeper than the Morrow formation and none of these wells were productive in reservoirs deeper than the Morrow. Therefore, it is very unlikely that anyone will ever drill through the AMA reservoir in the future. In the event a well is drilled within the AMA, the operator would be required to follow all TRRC rules and procedures in the drilling the well and the potential for leakage would be similar to any well that Perdure drills within the AMA. In addition, Perdure's visual inspection process during routine field operation will identify any unapproved drilling activity in the FWU.

4.3 Leakage from Fractures, Faults and Bedding Plane Partings

Primary seals at FWU have been demonstrated to be mechanically very competent (see Section 2.2.2), thus the main concern of CO₂ migration at FWU is via seal bypass systems along fracture networks. The following several lines of analysis have been used to assess this risk in the area.

4.3.1 Presence of Hydrocarbons

The first and foremost argument against present day up-fault transmissibility is the 120 MMB of oil that was found trapped in the reservoir at the time of discovery (Munson, 1988). If significant escape pathways existed, oil would have drained from the reservoir prior to the current day.

4.3.2 Structural Analysis

The second argument against up-fault leakage are the results of an extensive field and regional analysis of core, 2D and 3D seismic data. 3D Reflection seismic data of the FWU was acquired in 2013 and reprocessed in 2017 to obtain a better image resolution. In-depth analysis of the reprocessed data gives us confidence that there are no significant faults or fractures in the field area. The Morrow B is only 60 feet thick in the area; below the resolution of the seismic signal to pick an exact top and base. Horizons identified as the Kansas City top, Thirteen Finger base, and as a reflector in the proximity of the Morrow B reservoir unit were picked in the 3D seismic data. Two horizons below the Morrow B, tentatively identified as the top of the Hunton limestone and top of the Sylvan shale, were also used in the structural analysis. A detailed isopach map of the Morrow B created from interpretation of 346 well logs were also used to crosscheck the seismic interpretation.

Reprocessed data (Hobbs et al.) shows a series of seismic horizons that dip gently and thicken slightly to the southeast (Figure 4.3-1), consistent with the location of FWU on the western edge of the Anadarko basin dictating that sedimentary packages should thicken and dip towards the center of the basin. The most prominent feature of the seismic data is an increase in the intensity of the reflectors in the central and western part of the field (Figure 4.3-2). Based on the bifurcation of reflectors and on their lateral morphological changes they are interpreted as facies changes between carbonate or sandstone shelf deposits that transition laterally to shales. It is possible that such facies changes or channels could form preferential flow paths; however, these are relatively discontinuous, anastomosing, and irregular features that would not constitute a pathway to the surface. The structures visible in the seismic data can be interpreted as sedimentary/diagenetic features that include lateral facies changes, channel infills and karst collapse features.

In addition to the field-scale 3D seismic survey, over 70 mi of 2D seismic line in the region were used to constrain larger scale structural risk in the region. No faults were observed in any of the 2D lines.

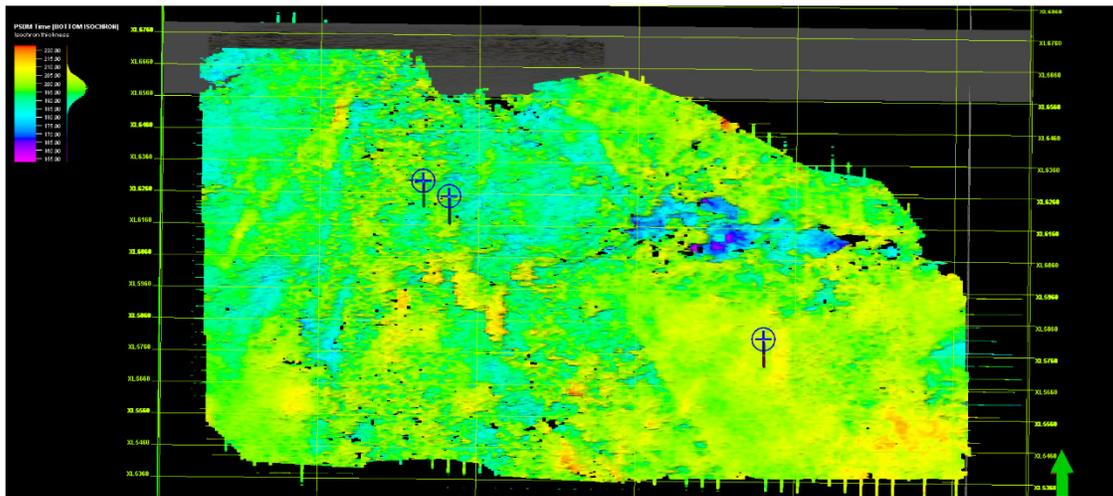
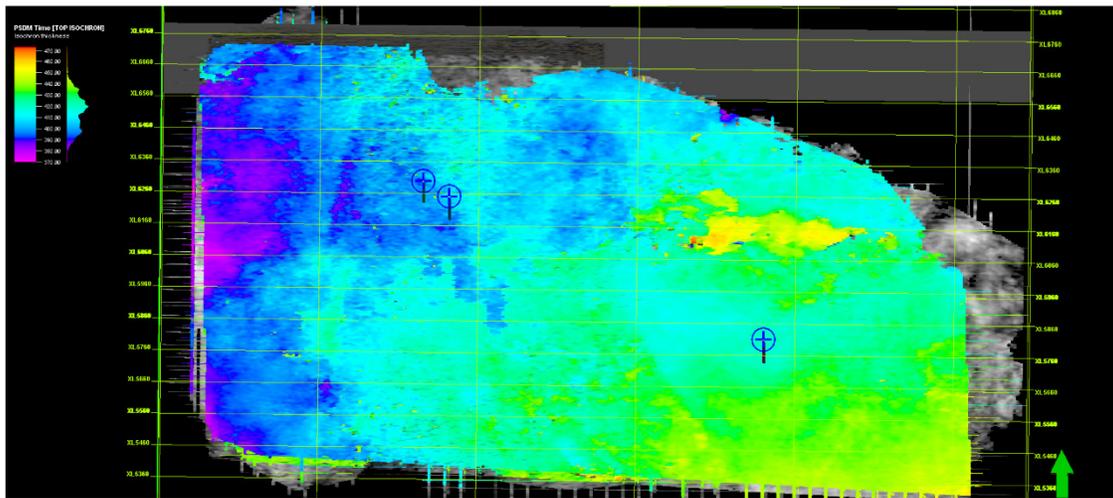
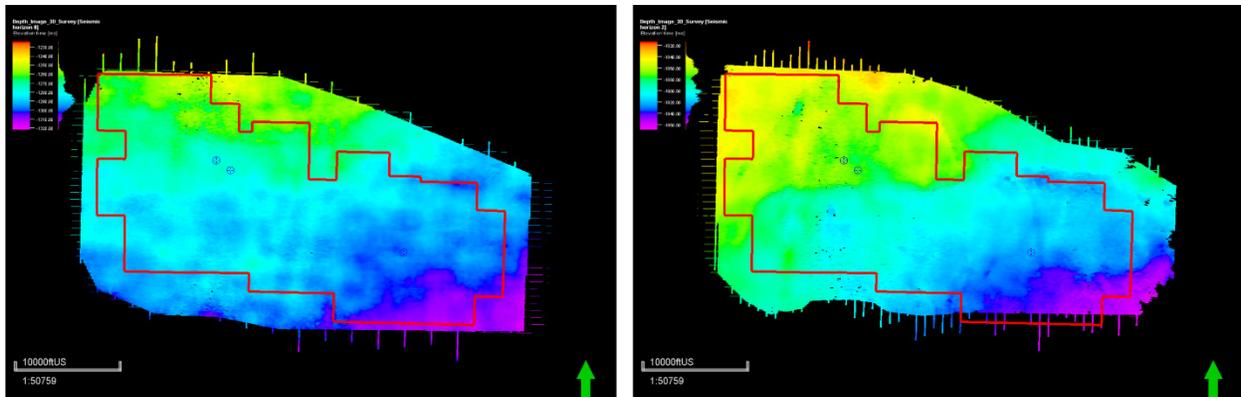


Figure 4.3-1 – a) depth (time) image of the Kansas City horizon (scale bar range – 1220-1320 milliseconds). b) depth (time) image of the Hunton base horizon (scale bar range – 1820-1960 milliseconds). c) Woodford base – Kansas City base isochron map (scale bar range – 470-370 milliseconds). d) Hunton base – Woodford base isochron map (scale bar range – 220-155 milliseconds).

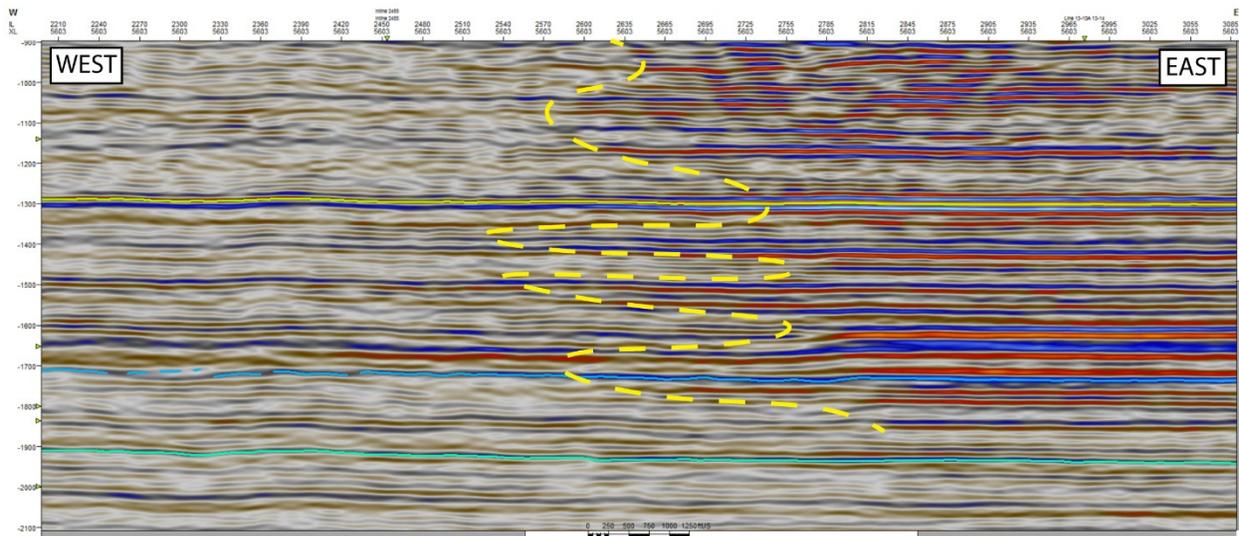
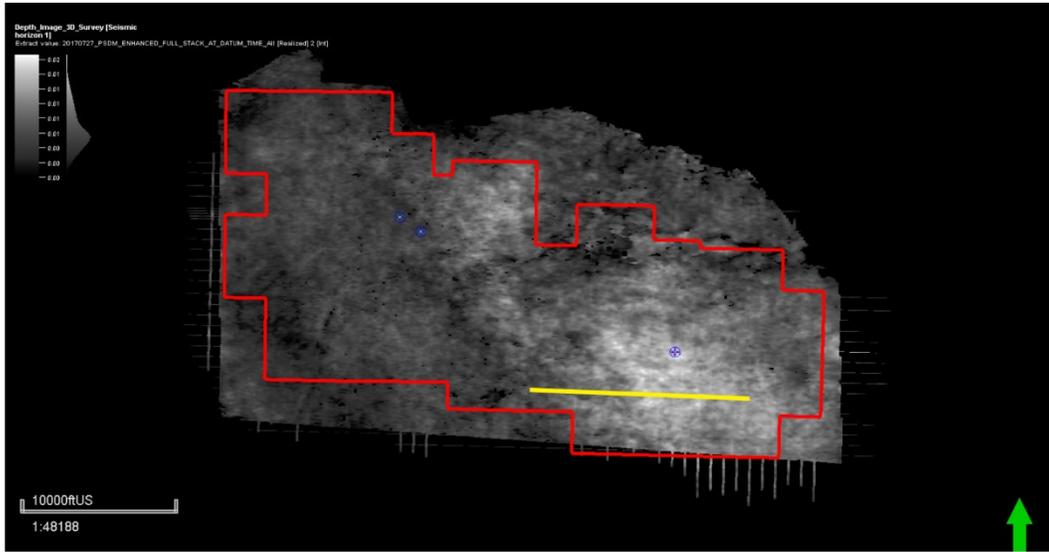


Figure 4.3-2 – a) amplitude intensity map of the base of the Woodford, yellow line shows location of the vertical seismic section. b) Lateral facies changes.

4.3.3 Fracture Analysis

Small aperture fractures were noted but not common in most of the reservoir cores we examined but most of these fractures appear to be drilling induced. Fractures in the Thirteen Finger limestone caprock were described using an industry-standard format for fracture class type, orientation, fracture dip, type of mineral fill, fracture porosity, fracture spacing, and intensity. Again, drilling induced fractures are most common. Natural mineral-filled fractures are quite rare, were formed during diagenesis at shallow depths, and are of Late Carboniferous age. Unless significantly damaged by large changes in reservoir pressure they are highly unlikely to provide migration pathways.

In the unlikely event CO₂ leakage occurs as a result of leakage through the faults and fractures it is unlikely that the leak would result in surface leakage. As with any CO₂ leakage, Perdure has strategies for leak detection in place that are discussed in Section 4.5 and the strategy to quantify the leak is discussed in Section 4.6.

4.4 Lateral Fluid Movement

Morrow strata in FWU was primarily a deltaic sequence that prograded toward the south east, resulting in deposition of mainly shales with lenticular, discontinuous coarse sandstones separated with very fine sandstone, minor conglomerates and shale. The likelihood of any extensive migration of fluid outside of the AMA is very low.

Since CO₂ is lighter than the water remaining in the reservoir it will migrate to the top of each lenticular structure as it is filled. The producing wells, which create low pressure points in the field, will drain the water and keep the CO₂ within each discontinuous sandstone.

4.5 Leakage Through Confining / Seal System

A variety of analytical methods were used for caprock (confining system) analysis. Petrologic examination included standard thin section petrography and backscattered electron microscopy. Petrophysical analytical methods include retort analysis, pulse-decay permeability measurement, pressure decay permeability analysis for tight rocks, and mercury injection porosimetry, which is also known as mercury injection capillary pressure (MICP). Geomechanical analysis involved a standard series of mechanical tests: Brazil tension, unconfined compression, triaxial compression, and multi-stress compression.

Results of the MICP analysis show that the mudstone lithologies in the Morrow Shale and Thirteen Finger Limestone can support CO₂ column heights of ~1,000 to 10,000 feet. At an order of magnitude over the thickness of the Morrow reservoir, this should prove an effective seal for CO₂ storage in the Morrow B injection horizon.

Failure analyses show that the Morrow B sands are weaker than overlying lithologies, so that any fracture initiation around the injection well would not be expected to propagate into the overlying sealing units. Mechanical properties of the overlying shale and limestones provide an interesting and effective combination of strength and elasticity. Limestone layers are strong but brittle, while the shale layers are weaker but sufficiently ductile to prevent extensive fracture propagation.

It is unlikely for hydrocarbon migration pathways that charged the Morrow reservoir to be potential CO₂ migration pathways via primary pore networks today. Any potential CO₂ migration would be most likely due to leakage from wellbores or bypass through fault and fracture networks, discussed in Sections 4.2 and 4.3.

In the unlikely event CO₂ leakage occurs as a result of leakage through the confining seal it is unlikely that the leak would result in surface leakage. As with any CO₂ leakage, Perdure has strategies for leak detection in place that are discussed in Section 4.5 and the strategy to quantify the leak is discussed in Section 4.6.

4.6 Natural and Induced Seismic Activity

Figure 4.6 shows the map of earthquakes with magnitudes measured at greater than 2.5 as defined by the United States Geological Survey (USGS). While past earthquake data cannot predict future earthquakes, the small number of events near FWU after the waterflood operations were initiated in 1969 implies the area is not seismically sensitive to injection. Also, no documentation exists that any of the distant earthquake events caused a disruption in injectivity or damage to any of the wellbores in FWU.

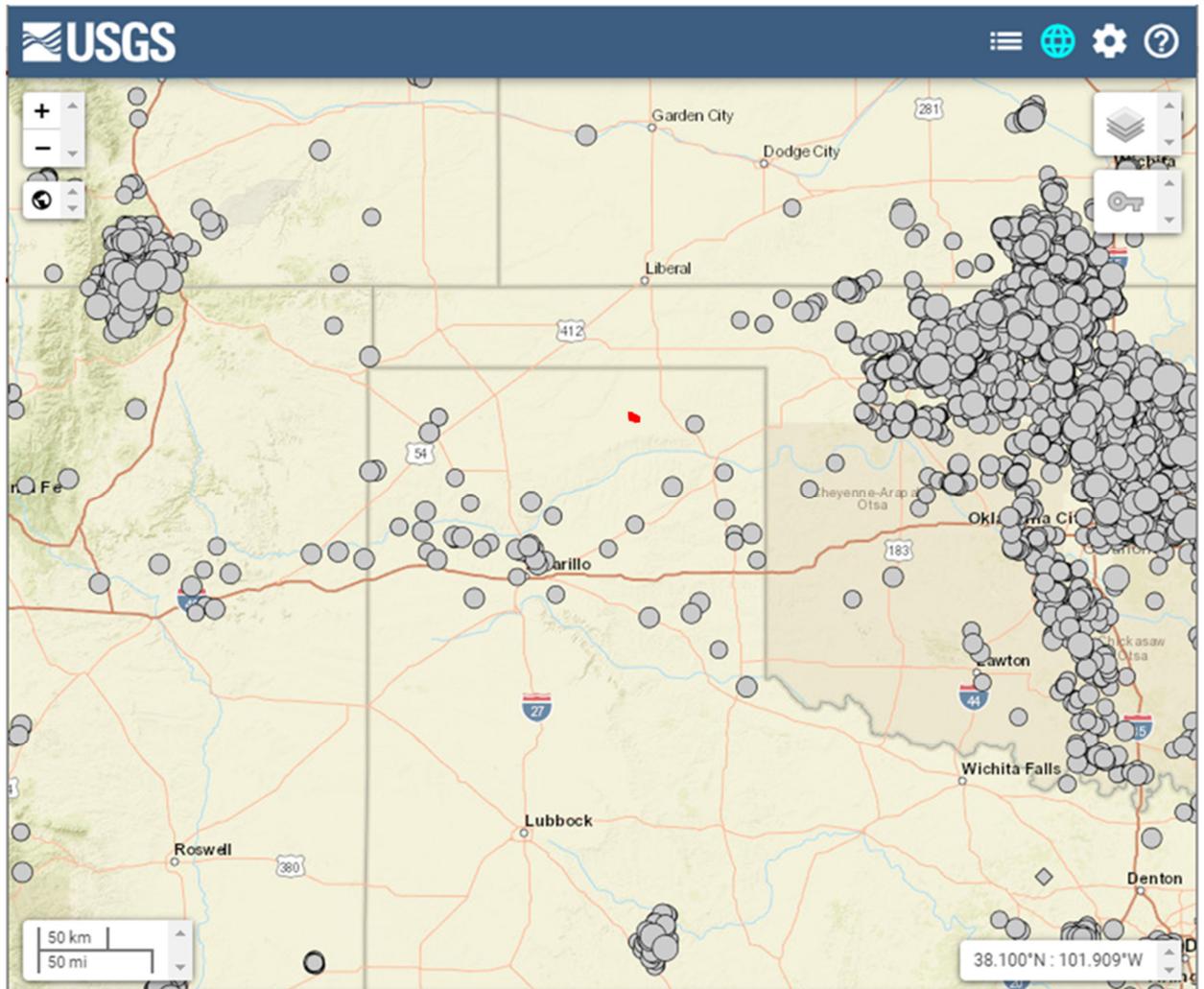


Figure 4.6: USGS earthquakes (>2.5 magnitude) for last 40 years with FWU highlighted red

There is no direct evidence that natural seismic activity poses a significant risk for loss of CO₂ to the surface in the FWU.

In the unlikely event that induced seismicity resulted in a pathway for material amounts of CO₂ to migrate from the injection zone, other reservoir fluid monitoring provisions (e.g., reservoir pressure, well pressure, and pattern monitoring) would lead to further investigation.

4.7 Strategy for Detection and Response of CO₂ Loss

As discussed above, the potential sources of leakage include fairly routine issues, such as problems with surface equipment (pumps, valves, etc.) or subsurface equipment (well bores), and unique events such as induced fractures. Table 1 summarizes some of these potential leakage scenarios, the monitoring activities designed to detect those leaks, Perdure’s standard response, and other applicable regulatory programs requiring similar reporting.

The potential CO₂ losses discussed in the table are identified by type. Once the type is reported to a response manager the correct resources and personnel can be mobilized to develop the optimal response procedure. The procedure will address and mitigate further CO₂ leakage.

Table 1 Response Plan for CO₂ Loss		
Known Potential Leakage Risks	Monitoring Methods and Frequency	Anticipated Response Plan
Tubing Leak	Monitor changes in annulus pressure; MIT for injectors	Workover crews respond within days
Casing Leak	Weekly field inspection; MIT for injectors; extra attention to high-risk wells	Workover crews respond within days
Wellhead Leak	Weekly field inspection	Workover crews respond within days
Loss of Bottom-hole pressure control	Blowout during well operations (weekly inspection but field personnel present daily)	Maintain well kill procedures
Unplanned wells drilled through Morrow	Weekly field inspection to prevent unapproved drilling; compliance with TRRC permitting for planned wells.	Assure compliance with TRRC regulations
Loss of seal in abandoned wells	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Re-enter and reseal abandoned wells
Pumps, valves, etc.	Weekly field inspection	Workover crews respond within days
Leakage along faults	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Shut in injectors near faults
Leakage laterally	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Fluid management along lease lines
Leakage through induced fractures	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Comply with rules for keeping pressures below parting pressure
Leakage due to seismic event	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Shut in injectors near seismic event

4.8 Strategy for Quantifying CO₂ Losses

Major CO₂ losses are typically event driven and require a process to assess, address, track, and if applicable quantify potential CO₂ leakage to the surface. Perdure will reconcile the Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.

Given the uncertainty concerning the nature and characteristics of leaks that will be encountered, it is not clear the method for quantifying the volume, or magnitude, of leaked CO₂ that would be most appropriate. In the event leakage occurs, Perdure will determine

the most appropriate method for quantifying the volume, or magnitude, leaked and will report the methodology used as required as part of the annual Subpart RR submission

Any volume, or magnitude, of CO₂ detected leaking to surface will be quantified using acceptable emission factors such as those found in 40 CFR Part 98 Subpart W or engineering estimates of leak amounts based on measurements in the subsurface, Perdure's field experience, and other factors such as the frequency of inspection. As indicated in Sections 6.4, leaks will be documented, and the records of leakage events will be retained in the electronic environmental documentation and reporting system. Repairs requiring a work order will be documented in the electronic equipment maintenance system.

Available studies of actual well leaks and natural analogs (e.g., naturally occurring CO₂ geysers) suggest that the amount released from routine leaks would be small as compared to the amount of CO₂ that would remain stored in the formation.

5 Strategy for Determining CO₂ Baselines for CO₂ Monitoring

Since conversion to a CO₂ EOR project in 2010, ongoing operational monitoring and several research projects at the FWU have provided data for establishing baselines of surface CO₂ leakage/emissions from the target injection zone for the CO₂, the Morrow B sandstone, and from surface equipment. The Site Characterization, Modeling, and Monitoring, Verification and Accounting (MVA) work conducted by the SWP provides the basis for established CO₂ baselines. Baseline groundwater monitoring conducted since 2013 indicates no leakage of CO₂ from underlying formations or wells into the local Ogallala aquifer. Soil flux monitoring also conducted since 2013 shows CO₂ flux ranging between 3 and 15 micromoles per second and square meter ($\mu\text{mol}/\text{m}^2/\text{sec}$) with variations generally attributed to seasonal changes and local crop growth patterns. Daily operational surface equipment inspection and periodic well surveillance monitoring are also conducted to ensure the integrity of infrastructure at the facility. Each of these is discussed in more detail below.

5.1 Site Characterization and Modeling

As described in Sections 2.2.2 and 2.4, the Morrow B sandstone is isolated both above and below by shale units of the Morrow. The primary seal consists of 180 – 200 ft of Morrow shale and Thirteen Finger Limestone which in turn is overlain by over a thousand feet of younger shale and limestone. These units provide a suitable seal to prevent the migration of CO₂ out of the injection reservoir. Additionally, no significant faults or fracture zones that cut across the seal units have been identified in the FWU, indicating that the most likely leakage pathway is from legacy wellbores that have been poorly completed/cemented.

Since 2013, several studies conducted by the SWP have evaluated the risk associated with leakage pathways through the seal units, including leakage of CO₂ to an overlying USDW or to the atmosphere through wellbores (Xiao et al, 2016, Xiao et al, 2017). The work of Ting et al (2017), in particular, looked at the potential geochemical impacts of CO₂-fluid interaction on typical cements used in regional wellbore completions, as well as the surrounding caprock. The diffusive flow of CO₂ and the mixing of brine fluids results in a reaction within the Portlandite wellbore cement, forming calcite. The calcite formation within the cement reduces the porosity of the cement, effectively sealing pathways. The calcium-silica-hydrate

in the Portlandite, conversely, is not significantly degraded by the CO₂-fluids, suggesting that the wellbore maintains its integrity and structure. These self-sealing attributes of the wellbore cements of the FWU wells suggest that CO₂ injected into the Morrow B is not at risk of leakage to overlying units, USDWs or the atmosphere.

5.2 Groundwater Monitoring Wells

Since 2013, the Southwest Regional Partnership on Carbon Sequestration (SWP) has been regularly sampling and analyzing fluids from Ogallala aquifer groundwater wells in around the FWU (Figure 5.2-1). The SWP performs major ion and trace metal analyses to evaluate leakage of CO₂, brine and/or hydrocarbons from the Morrow B and shallower zones, and/or wellbores. To date, no indication of fluid leakage has been identified from any of the 14 groundwater monitoring wells in the area. Perdure is unlikely to continue monitoring USDW wells for CO₂ or brine contamination, as SWP studies (see section 5.1) have suggested minimal risk of groundwater contamination from CO₂ leakage from depth.

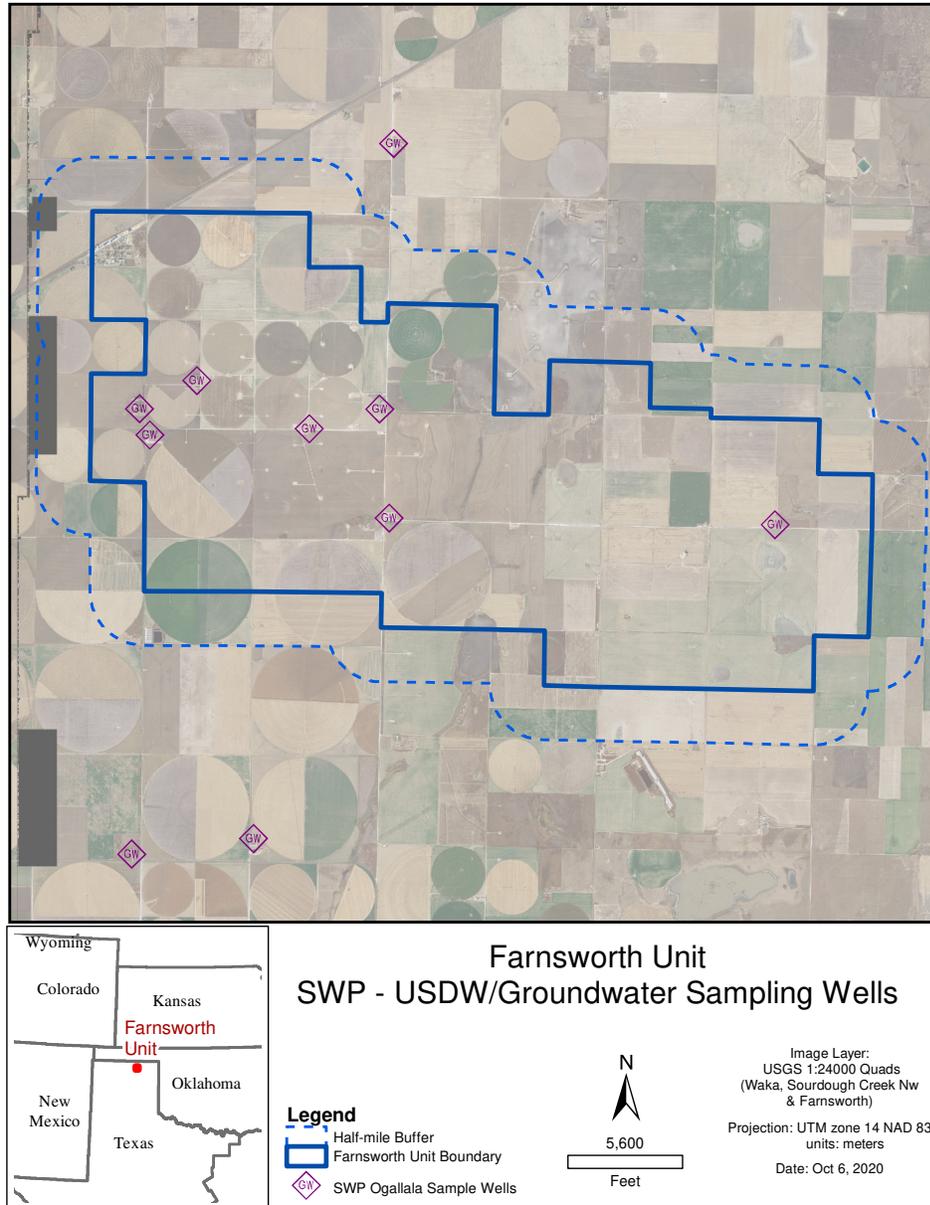


Figure 5.2-1: Ogallala groundwater monitoring wells

5.3 Soil CO₂ Monitoring

Since 2013, SWP has been conducting regular soil flux surveys within the western half of the FWU, to evaluate CO₂ leakage from the Morrow B. The SWP installed 94 PVC soil flux chamber collars around the 13-10A injection well (Figure 5.3-1); CO₂ soil flux was measured on a monthly basis, using a LiCor LI-8100 infrared gas analyzer, for a little over a year and then surveys were scaled back to once every 3 months. Soil flux values observed from the SWP surveys generally range between 3 and 15 μmol/m²/sec, with generally higher values in the summer due to plant respiration. To date, all CO₂ soil flux variations have been attributed to seasonal changes, and crop growth and rotation. The SWP soil flux collar

network has identified no CO₂ leakage at the FWU, from any sources since monitoring activities began.

The data collected from the SWP has estimated that the atmospheric (approximately 3-meter elevation above the ground surface) baseline CO₂ concentration in the FWU area to be 390±10 ppmv (Parts Per Million by Volume), with CO₂ concentrations on the lower end of this range during the summer months and on the higher end of this range during the winter months. Any significant and consistent variance from this baseline will be investigated to determine the source of the CO₂ and if the CO₂ is determined to be leakage from the FWU then appropriate steps will be taken to measure and report the volumes, mitigate any leaks, and make any adjustments to the MRV plan that are required.

Atmospheric CO₂ values at the FWU have been determined by a SWP eddy tower installation. In winter 2019, the eddy system malfunctioned and has not been repaired due to COVID travel restrictions. However, the atmospheric CO₂ concentration data from the FWU eddy tower are in very good agreement with values obtained from the NOAA Global Monitoring Laboratory station in Moody, Texas (Station: WKT). Atmospheric CO₂ concentrations from the Moody, Texas station can be used for background CO₂ values in the FWU area.

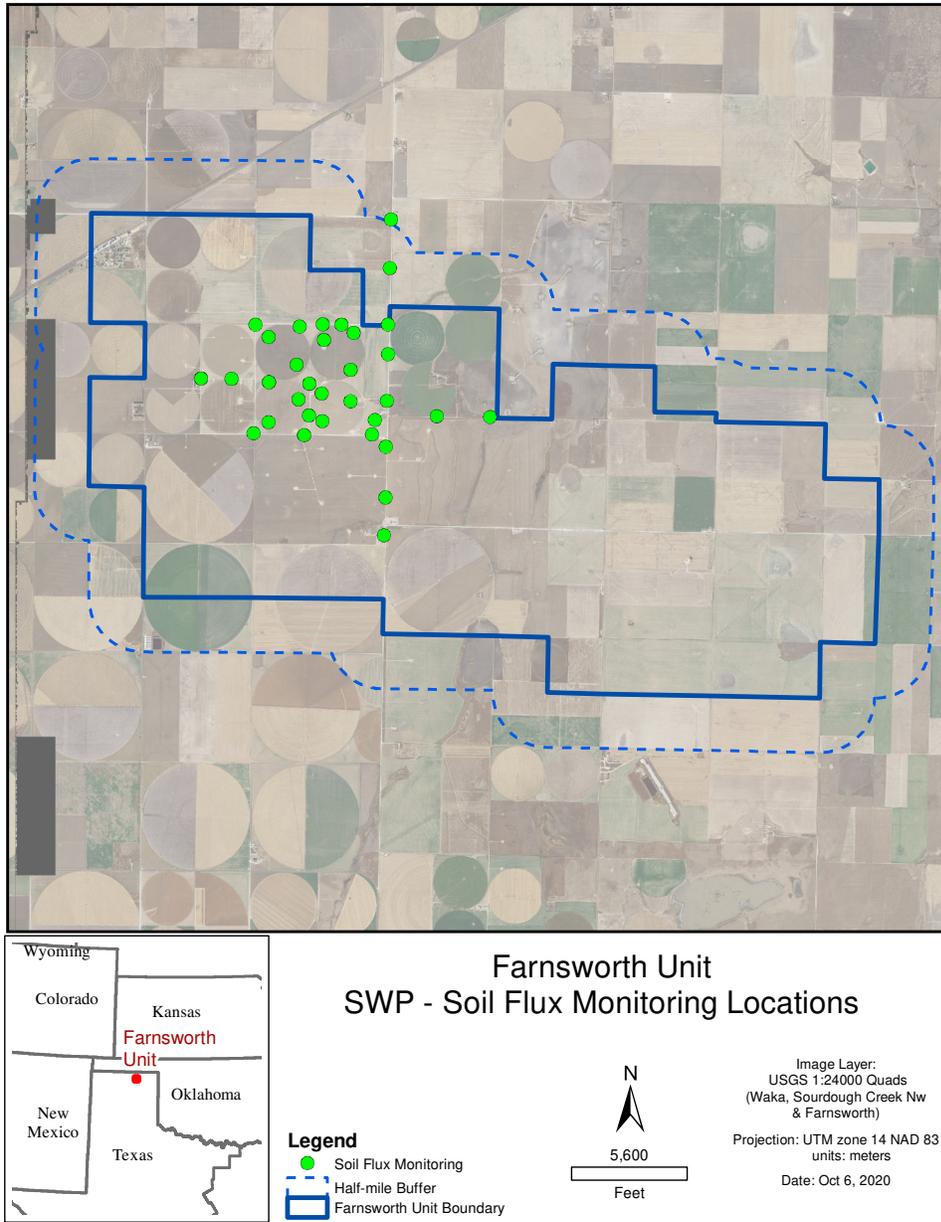


Figure 5.3 -1: Soil Flux

5.4 Visual Inspection

Perdure operational field personnel visually inspect surface equipment daily and report and act upon any event indicating leakage.

5.5 Well Surveillance

Perdure adheres to the requirements of Rule 46 for the TRRC governing fluid injection into productive reservoirs. Rule 46 includes requirements for monitoring, reporting, and testing of Class II injection wells. Furthermore, TRRC includes special conditions regarding monitoring, reporting, and testing in the individual permits for each injection well if they are deemed necessary.

Perdure also adheres to the requirements of Rule 20 for the TRRC governing the notification of a fires, breaks, leaks, or escapes. Rule 20 requires that all operators report leaks to TRRC including measured or estimated quantities of product leaked.

6 Site Specific Considerations for Determining the Mass of CO₂ Sequestered

Of the twelve RR equations in 98.443 of Subpart RR, the following are relevant to Perdure's operations.

6.1 Determining Mass of CO₂ Received

Perdure currently receives CO₂ to its FWU facility through their own pipeline from the Arkalon Ethanol plant in Liberal, Kansas. Perdure also recycles CO₂ from their production wells in the FWU.

$$CO_{2T,r} = \sum_{r=1}^4 (r, - S_r) * D * C_{CO_2,p,r} \quad (\text{Equation RR-2})$$

where:

$CO_{2T,r}$ = Net annual mass of CO₂ received through flow meter r (metric tons).

$r,$ = Quarterly volumetric flow through a receiving flow meter r in quarter p at standard conditions (standard cubic meters).

$S_r,$ = Quarterly volumetric flow through a receiving flow meter r that is redelivered to another facility without being injected into your well in quarter p (standard cubic meters).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

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

p = Quarter of the year.

r = Receiving flow meter.

6.2 Determining Mass of CO₂ Injected

Perdure injects CO₂ into the injection wells listed in Appendix 1.

$$CO_{2,u} = \sum_{u=1}^4 ,u * D * C_{CO_2,p,u} \quad (\text{Equation RR-5})$$

where:

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

$Q_{p,u}$ = Quarterly volumetric flow rate measurement for flow meter u in quarter p at standard conditions (standard cubic meters per quarter).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

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

p = Quarter of the year.

u = Flow meter.

6.3 Determining Mass of CO₂ Produced from Oil Production Wells

Perdure also recycles CO₂ from its production wells which are part of its operations in the FWU. Therefore, the following equation is relevant to its operations.

$$CO_{2,w} = \sum_{p=1}^4 Q_{p,w} * D * C_{CO_2,p,w} \quad \text{(Equation RR-8)}$$

Where:

$CO_{2,w}$ = Annual CO₂ mass produced (metric tons) through separator w.

$Q_{p,w}$ = Volumetric gas flow rate measurement for separator w in quarter p at standard conditions (standard cubic meters).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

$C_{CO_2,p,w}$ = CO₂ concentration measurement in flow for separator w in quarter p (vol. percent CO₂, expressed as a decimal fraction).

p = Quarter of the year.

w = Separator.

To aggregate production data, Perdure will sum the mass of all of the CO₂ separated at each gas-liquid separator in accordance with the procedure specified in Equation RR-9 below:

$$CO_{2P} = (1 + X) * \sum_{w=1}^W CO_{2,w} \quad \text{(Equation RR-9)}$$

Where:

CO_{2P} = Total annual CO₂ mass produced (metric tons) through all separators in the reporting year.

$CO_{2,w}$ = Annual CO₂ mass produced (metric tons) through separator w in the reporting year.

X = Entrained CO₂ in produced oil or other fluid divided by the CO₂ separated through all separators in the reporting year (weight percent CO₂, expressed as a decimal fraction).

w = Separator.

6.4 Determining Mass of CO₂ Emitted by Surface Leakage

As required by 98.448 (d) of Subpart RR, Perdure will assess leakage from the relevant surface equipment listed in Sections 98.233 and 98.234 of Subpart W. According to 98.233 (r) (2) of Subpart W, the emissions factor listed in Table W-1A of Subpart W shall be used to estimate all streams of gases, including recycle CO₂ stream, for facilities that conduct EOR operations.

Perdure will calculate the total annual mass of CO₂ emitted from all leakage pathways in accordance with the procedure specified in Equation RR-10 below:

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

where:

CO_{2E} = Total annual CO₂ mass emitted by surface leakage (metric tons) in the reporting year.

$CO_{2,x}$ = Annual CO₂ mass emitted (metric tons) at leakage pathway x in the reporting year.

x = Leakage pathway.

6.5 Determining Mass of CO₂ Sequestered

The following Equation RR-11 pertains to facilities that are actively producing oil or natural gas.

$$CO_2 = CO_{2I} - CO_{2P} - CO_{2E} - CO_{2FI} - CO_{2FP} \quad \text{(Equation RR-11)}$$

Where:

CO_2 = Total annual CO₂ mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

CO_{2I} = Total annual CO₂ mass injected (metric tons) in the well or group of wells in the reporting year.

CO_{2P} = Total annual CO₂ mass produced (metric tons) in the reporting year.

CO_{2E} = Total annual CO₂ mass emitted (metric tons) by surface leakage in the reporting year.

CO_{2FI} = Total annual CO₂ mass emitted (metric tons) from equipment leaks and vented emissions of CO₂ 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 of the GHGRP.

CO_{2FP} = Total annual CO₂ mass emitted (metric tons) from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity, for which a calculation procedure is provided in subpart W of the GHGRP.

The following Equation RR-12 pertains to facilities that are not actively producing oil or natural gas. This equation may become relevant to Perdure's operation as it evolves in the future. However, this does not apply to Perdure's current operations.

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

CO_2 = Total annual CO₂ mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

CO_{2I} = Total annual CO₂ mass injected (metric tons) in the well or group of wells in the reporting year.

CO_{2E} = Total annual CO₂ mass emitted (metric tons) by surface leakage in the reporting year.

CO_{2FI} = Total annual CO₂ mass emitted (metric tons) from equipment leaks and vented emissions of CO₂ 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 of the GHGRP.

7 Estimated Schedule for implementation of MRV plan

Perdure expects to begin implementing the approved MRV plan when the new CO₂ capture facility is operational, January 1, 2022.

8 GHG Monitoring and Quality Assurance Program

Perdure will meet the monitoring and QA/QC requirements of 98.444 of Subpart RR including those of Subpart W for emissions from surface equipment as required by 98.444 (d).

8.1 GHG Monitoring

As required by 40 CFR 98.3(g)(5)(i), Perdure's 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 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.

8.1.1 General

Measurement of CO₂ Concentration – All measurements of CO₂ concentrations of any CO₂ quantity will be conducted according to an appropriate standard method published by a consensus-based standards organization or an industry standard practice such as the Gas Producers Association (GSA) standards.

Measurement of CO₂ Volume – All measurements of CO₂ volumes will be converted to the following standard industry temperature and pressure conditions for use in Equations RR-2, RR-5 and RR-8 of Subpart RR of the GHGRP: Standard cubic meters at a temperature of 60 degrees Fahrenheit and at an absolute pressure of 1 atmosphere. Perdure will adhere to the American Gas Association (AGA) Report #3 – (ORIFICE METERING OF NATURAL GAS AND OTHER RELATED HYDROCARBON FLUIDS)

8.1.2 CO₂ received.

Daily totalized volumetric flow meters are used to record CO₂ received via pipeline from the Arkalon ethanol plant in Liberal, Kansas. using a volumetric totalizer using accepted flow calculations for CO₂ according to the AGA Report #3.

8.1.3 CO₂ injected.

Daily CO₂ injection is recorded by combining the totals for the recycle compressor meter and the received CO₂ meter from Arkalon based on what's delivered on a 24-hour basis. This data is taken from the meter daily and stored in Perdure's data warehouse for records and reservoir management.

8.1.4 CO₂ produced.

The point of produced gas measurement is from a meter downstream of the compressors prior to being combined with purchase CO₂. The produced gas is sampled at least quarterly for the CO₂ content.

8.1.5 CO₂ emissions from equipment leaks and vented emissions of CO₂.

As required by 98.444 (d), Perdure will follow the monitoring and QA/QC requirements specified in Subpart W of the GHGRP for equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead and between the flow meter used to measure production quantity and the production wellhead.

As required by 98.448 (d) of Subpart RR, Perdure will assess leakage from the relevant surface equipment listed in Sections 98.233 and 98.234 of Subpart W. According to 98.233 (r) (2) of Subpart W, the emissions factor listed in Table W-1A of Subpart W shall be used to estimate all streams of gases, including recycle CO₂ stream, for facilities that conduct EOR operations. The default emission factors for production equipment are applied to the carbon capture utilization and storage (CCUS) injection operations reporting under Subpart RR.

8.1.6 Measurement devices.

As required by 40 CFR 98.444(e), Perdure 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) of 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, the American National Standards Institute (ANSI), the American Gas Association (AGA), the Gas Producers Association (GPA), the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API), and the North American Energy Standards Board (NAESB).
- All flow meters are National Institute of Standards and Technology (NIST) traceable.

8.2 QA/QC Procedures

Perdure will adhere to all QA/QC requirements in Subparts A, RR, and W of the GHGRP, 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.

8.3 Estimating Missing Data

Perdure will estimate any missing data according to the following procedures in 40 CFR 98.445 of Subpart RR of the GHGRP, as required.

- A quarterly flow rate of CO₂ received that is missing would be estimated using invoices or using a representative flow rate value from the nearest previous time period.
- A quarterly CO₂ concentration of a CO₂ stream received that is missing would be estimated using invoices or using a representative concentration value from the nearest previous time period.
- A quarterly quantity of CO₂ injected that is missing would be estimated using a representative quantity of CO₂ injected from the nearest previous period of time at a similar injection pressure.
- For any values associated with CO₂ emissions from equipment leaks and vented emissions of CO₂ from surface equipment at the facility that are reported in this subpart, missing data estimation procedures specified in subpart W of 40 CFR Part 98 would be followed.
- The quarterly quantity of CO₂ produced from subsurface geologic formations that is missing would be estimated using a representative quantity of CO₂ produced from the nearest previous period of time.

8.4 Revisions of the MRV Plan

Perdure will revise the MRV Plan as needed to reflect changes in production processes, monitoring instrumentation, and quality assurance procedures; or to improve procedures for the maintenance and repair of monitoring systems to reduce the frequency of monitoring equipment downtime.

9 Records Retention

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

- (1) A list of all units, operations, processes, and activities for which GHG emissions were calculated.
- (2) The data used to calculate the GHG emissions for each unit, operation, process, and activity. These data include:
 - (i) The GHG emissions calculations and methods used.
 - (ii) Analytical results for the development of site-specific emissions factors, if applicable.
 - (iii) The results of all required analyses.
 - (iv) Any facility operating data or process information used for the GHG emission calculations.
- (3) The annual GHG reports.
- (4) Missing data computations. For each missing data event, Perdure will retain a record of the cause of the event and the corrective actions taken to restore malfunctioning monitoring equipment.
- (5) A copy of the most recent revision of this MRV Plan.
- (6) 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.
- (7) Maintenance records for all continuous monitoring systems, flow meters, and other instrumentation used to provide data for the GHGs reported.
- (8) Quarterly records of CO₂ received, including mass flow rate of contents of container (mass or volumetric) at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- (9) Quarterly records of produced CO₂, including mass flow or volumetric flow at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- (10) Quarterly records of injected CO₂ including mass flow or volumetric flow at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.

- (11) Annual records of information used to calculate the CO₂ emitted by surface leakage from leakage pathways.
- (12) Annual records of information used to calculate the CO₂ emitted from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead.
- (13) Annual records of information used to calculate the CO₂ emitted from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity.
- (14) Any other records as specified for retention in this EPA-approved MRV plan.

10 Appendices

Appendix 1 - Perdure Wells

Table A1. 1 – Production wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#15-1	42357000600000	Oil Prod	Active	CO2	1	0
#8-2	42357004140000	Oil Prod	Active	CO2	1	0
#13-6	42357007960000	Oil Prod	Active	CO2	1	0
#9-1	42357009390000	Oil Prod	Active	CO2	1	0
#20-8	42357020580000	Oil Prod	Active	CO2	1	0
#7-1	42357020620000	Oil Prod	Active	CO2	1	0
#6-2	42357020630000	Oil Prod	Active	CO2	1	0
#8-1	42357020650000	Oil Prod	Active	CO2	1	0
#9-4	42357022130000	Oil Prod	Active	CO2	1	0
#23-10	42357300490000	Oil Prod	Active	CO2	1	0
#18-2	42357319870000	Oil Prod	Active	CO2	1	0
#8-6	42357330090000	Oil Prod	Active	CO2	1	0
#13-12	42357330130000	Oil Prod	Active	CO2	1	0
#9-9	42357330610000	Oil Prod	Active	CO2	1	0
#16-6	42357329830000	Oil Prod	Active	CO2	1	0
#15-8	42357330630000	Oil Prod	Active	CO2	1	0
#11-2	42357330000000	Oil Prod	Active	CO2	1	0
#13-14	42357331890000	Oil Prod	Active	CO2	1	0
#13-15	42357333730000	Oil Prod	Active	CO2	1	0
#13-16	42357331930000	Oil Prod	Active	CO2	1	0

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#13-17	42357333990000	Oil Prod	Active	CO2	1	0
#13 -19	42357333740000	Oil Prod	Active	CO2	1	0
#16-2	42357000770002	Oil Prod	Active	CO2	1	0
#20-2	42357811240000	Oil Prod	Active	CO2	1	0
#5-1	42357810720000	Oil Prod	Active	CO2	1	0
#5-3	42357810740001	Oil Prod	Active	CO2	1	0
#5-6	42357334110000	Oil Prod	Active	CO2	1	0
#6-1	42357020640001	Oil Prod	Active	CO2	1	0
#7-2	42357810800000	Oil Prod	Active	CO2	1	0
#8-7	42357334050000	Oil Prod	Active	CO2	1	0
#8-8	42357334130000	Oil Prod	Active	CO2	1	0
#9-7	42357810910000	Oil Prod	Active	CO2	1	0
#30-1	42357002490000	Oil Prod	Inactive	CO2	0	0
#30-2	42357002510000	Oil Prod	Inactive	CO2	0	0
#20-1	42357004700000	Oil Prod	Inactive	CO2	0	0
#40-4	42357005140000	Oil Prod	Inactive	CO2	0	0
#23-2	42357007760000	Oil Prod	Inactive	CO2	0	0
#19-2	42357806010000	Oil Prod	Inactive	CO2	0	0
#41-1	42357009990000	Oil Prod	Inactive	CO2	0	0
#20-32	42357020390000	Oil Prod	Inactive	CO2	0	0
#23-6	42357811400000	Oil Prod	Inactive	CO2	0	0
#21-3	42357020670000	Oil Prod	Inactive	CO2	0	0
#41-2	42357021920000	Oil Prod	Inactive	CO2	0	0
#32-3	42357022060000	Oil Prod	Inactive	CO2	0	0
#36-2	42357023350000	Oil Prod	Inactive	CO2	0	0
#31-1	42357023370000	Oil Prod	Inactive	CO2	0	0
#32-1	42357023450000	Oil Prod	Inactive	CO2	0	0
#23-5	42357023680000	Oil Prod	Inactive	CO2	0	0
#25-2A	42357300990000	Oil Prod	Inactive	CO2	0	0
#23-11	42357313550000	Oil Prod	Inactive	CO2	0	0
#32-6	42357319890000	Oil Prod	Inactive	CO2	0	0
#40-1	42357811720000	Oil Prod	Inactive	CO2	0	0
#25-1	42357811450000	Oil Prod	Inactive	CO2	0	0
#26-1	42357811480000	Oil Prod	Inactive	CO2	0	0
#32-8	42357334100000	Oil Prod	Inactive	CO2	0	0
#39-1	42357811710000	Oil Prod	Inactive	CO2	0	0
#43-2	42357008020000	Oil Prod	Inactive	CO2	0	0
J ORTHA E 1	42357005100002	Oil Prod	Inactive	CO2	0	0
#42-1	42357000040000	Oil Prod	P&A	CO2	0	0
#4-1	42357001560000	Oil Prod	P&A	CO2	0	0
#16-4	42357004760000	Oil Prod	P&A	CO2	0	0

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#23-8	42357007790000	Oil Prod	P&A	CO2	0	0
#3-1	42357009340000	Oil Prod	P&A	CO2	0	0
#9-3	42357009400000	Oil Prod	P&A	CO2	0	0
#17-1	42357003410000	Oil Prod	P&A	CO2	0	0
#19-4	42357806030000	Oil Prod	P&A	CO2	0	0
#15-4	42357023340000	Oil Prod	P&A	CO2	0	0
#31-2	42357023360000	Oil Prod	P&A	CO2	0	0
#40-2	42357023480000	Oil Prod	P&A	CO2	0	0
#13-8	42357023490000	Oil Prod	P&A	CO2	0	0
#13-2	42357023500000	Oil Prod	P&A	CO2	0	0
#13-4	42357023510000	Oil Prod	P&A	CO2	0	0
#13-7	42357023520000	Oil Prod	P&A	CO2	0	0
#9-2	42357023530000	Oil Prod	P&A	CO2	0	0
#17-1	42357003410000	Oil Prod	P&A	CO2	0	0
#19-4	42357806030000	Oil Prod	P&A	CO2	0	0
#15-4	42357023340000	Oil Prod	P&A	CO2	0	0
#31-2	42357023360000	Oil Prod	P&A	CO2	0	0
#40-2	42357023480000	Oil Prod	P&A	CO2	0	0
#13-8	42357023490000	Oil Prod	P&A	CO2	0	0
#13-2	42357023500000	Oil Prod	P&A	CO2	0	0
#13-4	42357023510000	Oil Prod	P&A	CO2	0	0
#13-7	42357023520000	Oil Prod	P&A	CO2	0	0
#37-1	42357811680000	Oil Prod	P&A	CO2	0	0
BOESE 1	42357003010000	Oil Prod	P&A	CO2	0	0

Table A1.2 – Water Alternating Gas (WAG) Injection Wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#13-1 (INJ)	42357007950000	WAG Inj	Active	CO2	0	1
#13-3 (INJ)	42357007940000	WAG Inj	Active	CO2	0	1
#13-5 (INJ)	42357007990000	WAG Inj	Active	CO2	0	1
#13-9 (INJ)	42357811020000	WAG Inj	Active	CO2	0	1
#13-10A (INJ)	42357331790000	WAG Inj	Active	CO2	0	1
#13-13 (INJ)	42357333320000	WAG Inj	Active	CO2	0	1
#14-1 (INJ)	42357020410000	WAG Inj	Active	CO2	0	1
#15-2 (INJ)	42357811100000	WAG Inj	Active	CO2	0	1
#15-5 (INJ)	42357020300000	WAG Inj	Active	CO2	0	1
#15-6 (INJ)	42357301210000	WAG Inj	Active	CO2	0	1
#16-3 (INJ)	42357004720000	WAG Inj	Active	CO2	0	1
#5-2 (INJ)	42357023310000	WAG Inj	Active	CO2	0	1

#8-3 (INJ)	42357810840000	WAG Inj	Active	CO2	0	1
#8-4 (INJ)	42357003990000	WAG Inj	Active	CO2	0	1
#8-5 (INJ)	42357301160000	WAG Inj	Active	CO2	0	1
#9-10 (INJ)	42357330770000	WAG Inj	Active	CO2	0	1
#9-8 (INJ)	42357301860000	WAG Inj	Active	CO2	0	1
#11-1 (INJ)	42357020350000	WAG Inj	Inactive	CO2	0	0
#13-10 (INJ)	42357301030000	Monitor	Inactive	None	0	0

Table A1.3 – Water Source Wells (WSW)

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#1 (WSW)	42357810690000	WSW	Active	CO2	0	0
#2 (WSW)	42357810700000	WSW	Active	CO2	1	0

Table A1.4 – Water Injection Wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#23-9 (INJ)	42357020380000	Wtr Inj	Inactive	CO2	0	0
#30-3 (INJ)	42357020470000	Wtr Inj	Inactive	CO2	0	0
#32-2 (INJ)	42357811590000	Wtr Inj	Inactive	CO2	0	0
#32-4 (INJ)	42357811610000	Wtr Inj	Inactive	CO2	0	0
#32-5 (INJ)	42357317680001	Wtr Inj	Inactive	CO2	0	0
#34-1 (INJ)	42357020500000	Wtr Inj	Inactive	CO2	0	0
#40-3 (INJ)	42357811740000	Wtr Inj	Inactive	CO2	0	0
#42-2 (INJ)	42357811820000	Wtr Inj	Inactive	CO2	0	0
#42-3 (INJ)	42357020330001	Wtr Inj	Inactive	CO2	0	0
#6-3 (INJ)	42357303410000	Wtr Inj	Inactive	CO2	0	0
#7-3 (INJ)	42357302540000	Wtr Inj	Inactive	CO2	0	0
#9-6 (INJ)	42357020340000	Wtr Inj	Inactive	CO2	0	0
#10-1 (INJ)	42357009380000	Wtr Inj	Inactive	CO2	0	0
#14-2 (INJ)	42357002670001	Wtr Inj	Inactive	CO2	0	0
#16-5 (INJ)	42357020370000	Wtr Inj	P&A	CO2	0	0
#19-3 (INJ)	42357806020000	Wtr Inj	P&A	CO2	0	0
#20-5 (INJ)	42357252290000	Wtr Inj	P&A	CO2	0	0
#20-6 (INJ)	42357020360000	Wtr Inj	P&A	CO2	0	0
#20-7 (INJ)	42357020450000	Wtr Inj	P&A	CO2	0	0
#21-1 (INJ)	42357020310000	Wtr Inj	P&A	CO2	0	0
#21-2 (INJ)	42357020270000	Wtr Inj	P&A	CO2	0	0
#21-4 (INJ)	42357020280000	Wtr Inj	P&A	CO2	0	0
#25-3 (INJ)	42357020460000	Wtr Inj	P&A	CO2	0	0
#26-2 (INJ)	42357020420000	Wtr Inj	P&A	CO2	0	0
#31-3 (INJ)	42357020480000	Wtr Inj	P&A	CO2	0	0
#33-1 (INJ)	42357000290000	Wtr Inj	P&A	CO2	0	0
#33-3 (INJ)	42357021340000	Wtr Inj	P&A	CO2	0	0
#34-2 (INJ)	42357008730000	Wtr Inj	P&A	CO2	0	0
#36-1 (INJ)	42357020490000	Wtr Inj	P&A	CO2	0	0
#37-2 (INJ)	42357811690000	Wtr Inj	P&A	CO2	0	0
#40-7 (INJ)	42357811780000	Wtr Inj	P&A	CO2	0	0
#42-4 (INJ)	42357010010000	Wtr Inj	P&A	CO2	0	0
#14-3 (INJ)	42357020660000	Wtr Inj	P&A	CO2	0	0
#15-3 (INJ)	42357006060000	Wtr Inj	P&A	CO2	0	0
#16-1 (INJ)	42357020400000	Wtr Inj	P&A	CO2	0	0
#23-7 (INJ)	42357020430000	Wtr Inj	P&A	CO2	0	0
#40-9 (INJ)	42357020570000	Wtr Inj	P&A	CO2	0	0

Appendix 2 - Referenced Regulations

U.S. Code > Title 26. INTERNAL REVENUE CODE > Subtitle A. Income Taxes > Chapter 1. NORMAL TAXES AND SURTAXES > Subchapter A. Determination of Tax Liability > Part IV. CREDITS AGAINST TAX > Subpart D. Business Related Credits > [Section 45Q - Credit for carbon oxide sequestration](#)

Texas Administrative Code (TAC) > Title 16 - Economic Regulation > Part 1 – Railroad Commission of Texas > [Chapter 3 – Oil and Gas Division](#)

Rules

- §3.1 Organization Report; Retention of Records; Notice Requirements
- §3.2 Commission Access to Properties
- §3.3 Identification of Properties, Wells, and Tanks
- §3.4 Oil and Geothermal Lease Numbers and Gas Well ID Numbers Required on All Forms
- §3.5 Application to Drill, Deepen, Reenter, or Plug Back
- §3.6 Application for Multiple Completion
- §3.7 Strata to Be Sealed Off
- §3.8 Water Protection
- §3.9 Disposal Wells
- §3.10 Restriction of Production of Oil and Gas from Different Strata
- §3.11 Inclination and Directional Surveys Required
- §3.12 Directional Survey Company Report
- §3.13 Casing, Cementing, Drilling, Well Control, and Completion Requirements
- §3.14 Plugging
- §3.15 Surface Equipment Removal Requirements and Inactive Wells
- §3.16 Log and Completion or Plugging Report
- §3.17 Pressure on Bradenhead
- §3.18 Mud Circulation Required
- §3.19 Density of Mud-Fluid
- §3.20 Notification of Fire Breaks, Leaks, or Blow-outs
- §3.21 Fire Prevention and Swabbing
- §3.22 Protection of Birds
- §3.23 Vacuum Pumps
- §3.24 Check Valves Required
- §3.25 Use of Common Storage
- §3.26 Separating Devices, Tanks, and Surface Commingling of Oil
- §3.27 Gas to be Measured and Surface Commingling of Gas
- §3.28 Potential and Deliverability of Gas Wells to be Ascertained and Reported
- §3.29 Hydraulic Fracturing Chemical Disclosure Requirements
- §3.30 Memorandum of Understanding between the Railroad Commission of Texas (RRC) and the Texas Commission on Environmental Quality (TCEQ)
- §3.31 Gas Reservoirs and Gas Well Allowable
- §3.32 Gas Well Gas and Casinghead Gas Shall Be Utilized for Legal Purposes

§3.33	Geothermal Resource Production Test Forms Required
§3.34	Gas To Be Produced and Purchased Ratably
§3.35	Procedures for Identification and Control of Wellbores in Which Certain Logging Tools Have Been Abandoned
§3.36	Oil, Gas, or Geothermal Resource Operation in Hydrogen Sulfide Areas
§3.37	Statewide Spacing Rule
§3.38	Well Densities
§3.39	Proration and Drilling Units: Contiguity of Acreage and Exception Thereto
§3.40	Assignment of Acreage to Pooled Development and Proration Units
§3.41	Application for New Oil or Gas Field Designation and/or Allowable
§3.42	Oil Discovery Allowable
§3.43	Application for Temporary Field Rules
§3.45	Oil Allowables
§3.46	Fluid Injection into Productive Reservoirs
§3.47	Allowable Transfers for Saltwater Injection Wells
§3.48	Capacity Oil Allowables for Secondary or Tertiary Recovery Projects
§3.49	Gas-Oil Ratio
§3.50	Enhanced Oil Recovery Projects--Approval and Certification for Tax Incentive
§3.51	Oil Potential Test Forms Required
§3.52	Oil Well Allowable Production
§3.53	Annual Well Tests and Well Status Reports Required
§3.54	Gas Reports Required
§3.55	Reports on Gas Wells Commingling Liquid Hydrocarbons before Metering
§3.56	Scrubber Oil and Skim Hydrocarbons
§3.57	Reclaiming Tank Bottoms, Other Hydrocarbon Wastes, and Other Waste Materials
§3.58	Certificate of Compliance and Transportation Authority; Operator Reports
§3.59	Oil and Gas Transporter's Reports
§3.60	Refinery Reports
§3.61	Refinery and Gasoline Plants
§3.62	Cycling Plant Control and Reports
§3.63	Carbon Black Plant Permits Required
§3.70	Pipeline Permits Required
§3.71	Pipeline Tariffs
§3.72	Obtaining Pipeline Connections
§3.73	Pipeline Connection; Cancellation of Certificate of Compliance; Severance
§3.76	Commission Approval of Plats for Mineral Development
§3.78	Fees and Financial Security Requirements
§3.79	Definitions
§3.80	Commission Oil and Gas Forms, Applications, and Filing Requirements
§3.81	Brine Mining Injection Wells
§3.83	Tax Exemption for Two-Year Inactive Wells and Three-Year Inactive Wells

- §3.84 Gas Shortage Emergency Response
- §3.85 Manifest to Accompany Each Transport of Liquid Hydrocarbons by Vehicle
- §3.86 Horizontal Drainhole Wells
- §3.91 Cleanup of Soil Contaminated by a Crude Oil Spill
- §3.93 Water Quality Certification Definitions
- §3.95 Underground Storage of Liquid or Liquefied Hydrocarbons in Salt Formations
- §3.96 Underground Storage of Gas in Productive or Depleted Reservoirs
- §3.97 Underground Storage of Gas in Salt Formations
- §3.98 Standards for Management of Hazardous Oil and Gas Waste
- §3.99 Cathodic Protection Wells
- §3.100 Seismic Holes and Core Holes
- §3.101 Certification for Severance Tax Exemption or Reduction for Gas Produced From High-Cost Gas Wells
- §3.102 Tax Reduction for Incremental Production
- §3.103 Certification for Severance Tax Exemption for Casinghead Gas Previously Vented or Flared
- §3.106 Sour Gas Pipeline Facility Construction Permit
- §3.107 Penalty Guidelines for Oil and Gas Violations

Appendix 3 - References

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Appendix 4 - Abbreviations and Acronyms

2D – 2 dimensional
3D – 3 dimensional
AGA – American Gas Association
AMA – Active Monitoring Area
ANSI – American National Standards Institute
API – American Petroleum Institute
ASTM - American Society for Testing and Materials
Bscf – billion standard cubic feet
B/D – barrels per day
bopd – barrels of oil per day
C4 – butane
C5 – pentane
C7 – heptane
C7+ - standard heptane plus
CCE – constant composition expansion
CCUS – carbon capture utilization and storage
cf – cubic feet
CH₄ – methane
CO₂ – carbon dioxide
EOR – Enhanced Oil Recovery
EOS – Equation of State
EPA – US Environmental Protection Agency
ESD – Emergency Shutdown Device
FWU – Farnsworth Unit
GHG – Greenhouse Gas
GHGRP – Greenhouse Gas Reporting Program
GPA – Gas Producers Association
H₂S – hydrogen sulfide
mD – millidarcy(ies)
MICP – mercury injection capillary pressure
MIT – mechanical integrity test
MMA – maximum monitoring area
MMB – million barrels
MMP – minimum miscible pressure
MMscf – million standard cubic feet
MMstb – million stock tank barrels
MRV – Monitoring, Reporting, and Verification
MMMT – Million metric tonnes
MT -- Metric tonne
NIST - National Institute of Standards and Technology
NAESB – North American Energy Standards Board
OOIP – Original Oil-In-Place

OWC – oil water contact
PPM – Parts Per Million
psia – pounds per square inch absolute
PVT – pressure, volume, temperature
QA/QC – quality assurance/quality control
RMS – root mean square
SEM – scanning electron microscope
SWP - Southwest Regional Partnership on Carbon Sequestration
TAC – Texas Administrative Code
TD – total depth
TRRC – Texas Railroad Commission
TSD – Technical Support Document
TVDSS – True Vertical Depth Subsea
UIC – Underground Injection Control
USDW – Underground Source of Drinking Water
WAG – Water Alternating Gas (Gas is recycled CO₂ and purchase CO₂)
XRD – x-ray diffraction

Appendix 5 - Conversion Factors

Perdure reports CO₂ at standard conditions of temperature and pressure as defined in the State of Texas in the Texas Administrative Code for the Oil and Gas Division, Rule 3.79 as follows:

Cubic foot of gas or standard cubic foot of gas--The volume of gas contained in one cubic foot of space at a standard pressure base and at a standard temperature base. The standard pressure base shall be 14.65 pounds per square inch absolute, and the standard temperature base shall be 60 degrees Fahrenheit.

To calculate CO₂ mass from CO₂ volume, EPA recommends using the database of thermodynamic properties developed by the National Institute of Standards and Technology (NIST). This online database is available at:

<https://webbook.nist.gov/chemistry/fluid/>

It provides density of CO₂ using the Span and Wagner equation of state (EOS) at a wide range of temperature and pressures.

At State of Texas standard conditions, the Span and Wagner EOS gives a density of CO₂ of 0.002641684 lb-moles per cubic foot. Converting the CO₂ density in units of metric tonnes per cubic foot:

$$Density_{CO_2} \left(\frac{MT}{ft^3} \right) = Density_{CO_2} \left(\frac{lb - moles}{ft^3} \right) \times MW_{CO_2} \times \frac{1 MT}{2204.62 lbs}$$

Where:

$$Density_{CO_2} = \text{Density of CO}_2 \text{ in metric tonnes (MT) per cubic foot}$$

$$Density_{CO_2} = 0.002641684$$

$$MW_{CO_2} = 44.0095$$

$$Density_{CO_2} = 5.2734 \times 10^{-5} \frac{MT}{ft^3} \text{ or } 5.2734 \times 10^{-2} \frac{MT}{Mcf}$$

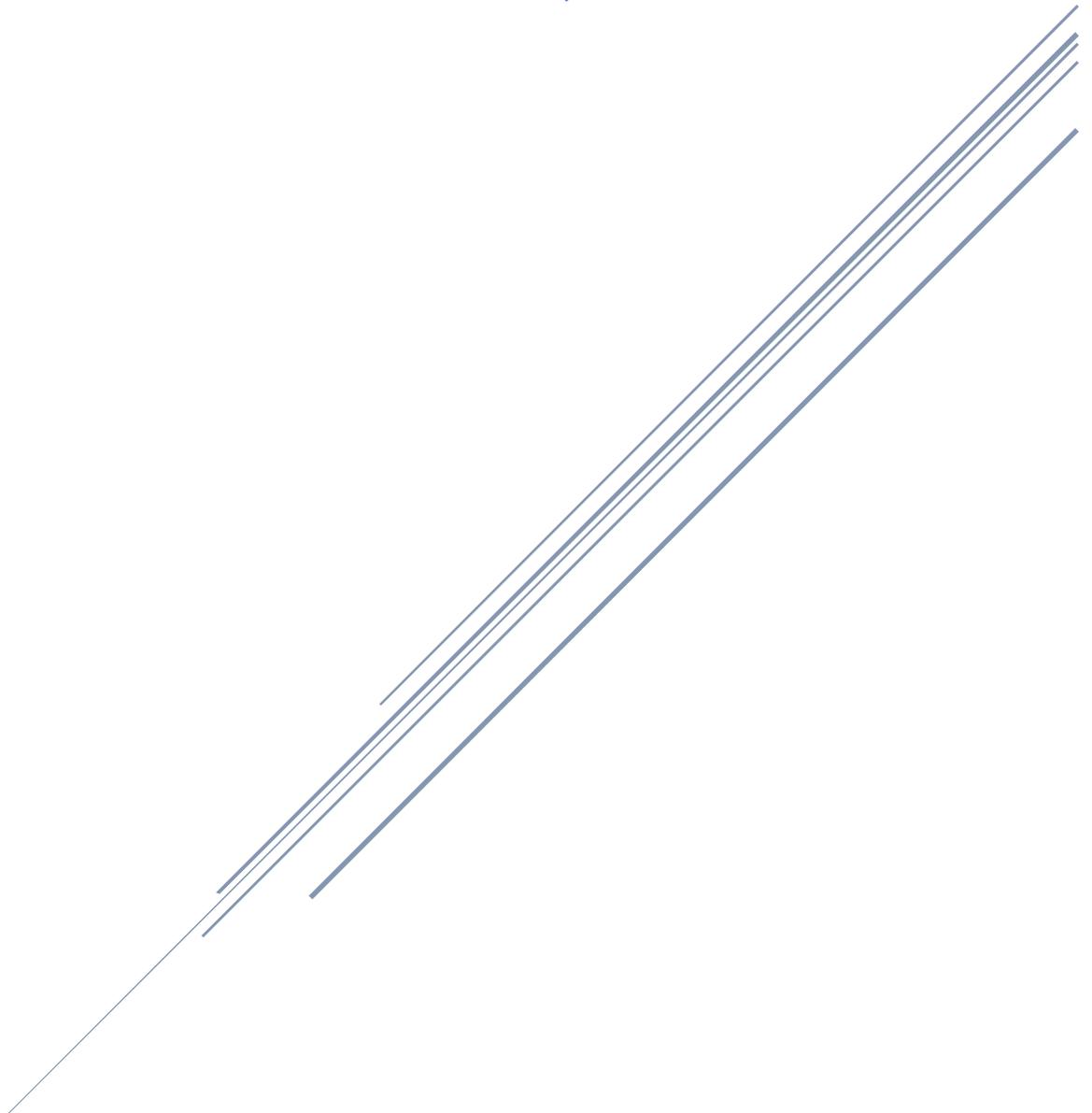
The conversion factor 5.2734×10^{-2} MT/Mcf is used to convert CO₂ volumes in standard cubic feet to CO₂ mass in metric tonnes.

Appendix B: Submissions and Responses to Requests for Additional Information

Farnsworth Unit, Texas (FWU)

MONITORING, REPORTING, AND VERIFICATION PLAN

Perdure Petroleum, LLC



May, 2021

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Introduction

Perdure Petroleum, LLC (Perdure) operates the Farnsworth Unit (FWU) located in Ochiltree County, Texas for the primary purpose of enhanced oil recovery (EOR) using carbon dioxide (CO₂) with a subsidiary or ancillary purpose of geologic sequestration of CO₂ in a subsurface geologic formation. The discovery date of the field was October 26, 1955 and the FWU was unitized December 6, 1963 by Union Oil Company of California for the purpose of waterflooding with fresh water sourced from the Ogallala formation. The field structure is a lenticular bedding sand trending northwest to southeast with the average top of sand at 7990 feet, true vertical depth. Perdure has been operating the FWU since 2017. Perdure acquired the FWU from Chaparral Energy LLC, which initiated the CO₂-EOR project in December 2010. Perdure intends to continue CO₂-EOR operations until the end of the economic life of the CO₂-EOR program using various Class II injection wells as defined by Underground Injection Control (UIC) regulations and permitted under Texas Railroad Commission Statewide Rule 46. In this document, the term “gas” usually means a mixture of hydrocarbon light end components and the CO₂ component that can be produced as part of the EOR process.

Perdure has chosen to submit this Monitoring, Reporting, and Verification (MRV) plan to EPA for approval according to 40 CFR 98.440 (c)(1), Subpart RR of the Greenhouse Gas Reporting Program (GHGRP) for the purpose of qualifying for the tax credit in section 45Q of the federal Internal Revenue Code.

This MRV Plan contains ten sections:

Section 1 contains facility information.

Section 2 contains the project description including: a detailed description of the injection operation including the duration and volume of CO₂ to be injected; a detailed description of the geology and hydrogeology of the FWU located on the northwest shelf of the Anadarko basin and a detailed characterization of the injection reservoir and modeling techniques employed.

Section 3 contains the delineation of the maximum monitoring area (MMA) and the active monitoring area (AMA), both defined in 40 CFR 98.449, and as required by 40 CFR 98.448(a)(1), Subpart RR of the GHGRP.

Section 4 identifies the potential surface leakage pathways for CO₂ in the MMA and evaluates the likelihood, magnitude, and timing, of surface leakage of CO₂ through these pathways as required by 40 CFR 98.448(a)(2), Subpart RR of the GHGRP. This section also describes the strategy for detecting, verifying, and quantifying any surface leakage of CO₂ as required by 40 CFR 98.448(a)(3), Subpart RR of the GHGRP. Finally, this section also demonstrates that the risk of CO₂ leakage through the identified pathways is minimal.

Section 5 describes the strategy for establishing the expected baselines for monitoring CO₂ surface leakage as required by 40 CFR 98.448(a)(4), Subpart RR of the GHGRP.

Section 6 provides a summary of the considerations used to calculate site-specific variables for the mass balance equation as required by 40 CFR 98.448(a)(5), Subpart RR of the GHGRP.

Section 7 provides the estimated schedule for implementation of this MRV Plan as required by 40 CFR 98.448(a)(7).

Section 8 describes the quality assurance and quality control procedures that will be implemented for each technology applied in the leak detection and quantification process. This section also includes a discussion of the procedures for estimating missing data as detailed in 40 CFR 98.445.

Section 9 describes the records to be retained according to the requirements of 40 CFR 98.3(g) of Subpart A of the GHGRP and 40 CFR 98.447 of Subpart RR of the GRGRP.

Section 10 includes Appendices supporting the narrative of the MRV Plan.

1 Facility Information

1.1 Reporter number

The Farnsworth Unit CO₂ Flood reports under Greenhouse Gas Reporting Program Identification number 544683.

1.2 UIC permit class

For injection wells that are the subject of this MRV plan, the Texas Railroad Commission (TRRC) has issued Underground Injection Control (UIC) Class II enhanced recovery permits under its State Rule 46 (see Appendix 2). All wells in the FWU, including both injection and production wells, are regulated by TRRC, which has primacy to implement the UIC Class II program.

1.3 UIC injection well identification numbers

A list of the injection wells in the FWU is provided in Appendix 1. The details of the injection process are provided in Section 2.3.

2 Project Description

2.1 Project characteristics

2.1.1 Estimated years of CO₂ injection

It is currently projected that Perdure will inject CO₂ for an additional 12 years.

2.1.2 Estimated volume of CO₂ injected over lifetime of project

The chart to the left in Figure 2.4-7 in Section 2.4 - Reservoir Characterization Modeling shows the forecasted simulated cumulative CO₂ injection volume of approximately 180 billion standard cubic feet (Bscf) or 9.5 million metric tonnes (MMMT) through October 2032. For the period September 2020 through October 2032, an additional 52.5 Bscf or 2.77 MMMT will be stored in the FWU.

2.2 Environmental Setting of the MMA

2.2.1 Boundary of the MMA

Perdure has defined the boundary of the MMA as equivalent to the boundary of the FWU plus ½ mile beyond. A discussion of the methods used in delineating the MMA and the AMA are presented in Section 3.

2.2.2 Geology and hydrogeology

The geological discussions in Sections 2.2.2 and 4.3-4.4 are based on analysis of logs from over 140 wells, descriptions of cores from 8 wells including 3 recently cored that included sections from overlying seals as well as the shale underlying the main reservoirs, petrographic thin section descriptions and point counts as well as a variety of special analytical techniques including X-ray diffraction (XRD), which is the science of determining the atomic and molecular structure of rock crystals with an X-ray beam; scanning electron microscope (SEM) analysis; which uses a beam of electrons to define the surface of crystals; carbon isotope analysis to estimate the age of the sample; and a variety of mechanical tests. Two dimensional (2D) and three dimensional (3D) geophysical surveys were also used as part of this study. Details of recent geological investigations can be found in Gallagher (2014), Gragg (2016), Rasmussen et al (2019), Rose-Coss et al (2015), Trujillo (2018), Hobbs et al (2019), and Gragg et al (2018).

2.2.2.1 Tectonic Setting and Stratigraphy

The FWU is located on the northwest shelf of the Anadarko basin (Figure 2.2-1) and is one of many oil fields in the area that produce from a sequence of alternating sandstones and mudstones deposited during the late-Pennsylvanian Morrowan period. Oil production and CO₂ injection at FWU is restricted to the operationally-named Morrow B sandstone; the uppermost Morrow sandstone encountered below the Atokan Thirteen Finger limestone. The primary caprock intervals at FWU are comprised of the upper Morrow shale and the Thirteen Finger limestone (Figure 2.2-2). The Morrowan and Atokan intervals were deposited approximately 315-300 million years ago. Overlying stratigraphy includes Late Pennsylvanian through the middle Permian shales and limestones, with lesser amounts of dolomite, sandstone and evaporites.

The reservoir is approximately 60 feet thick through the field and lies at a depth of approximately 7600-7700 feet. The primary seal rocks of the Morrow shale and the Thirteen Finger Limestone comprise a package of approximately 180-200 feet thick in the field and are overlain by thousands of feet of Atokan and younger limestones and shales.

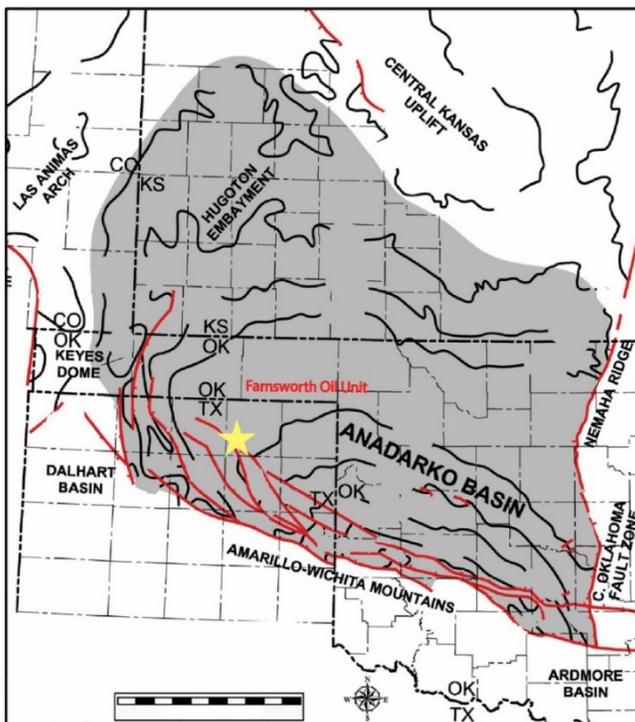


Figure 2.2-1- Location of the Farnsworth Unit (FWU) on the Northwest Shelf of the Anadarko Basin in West Texas. Red lines are approximate locations of faults that have been documented in the region.

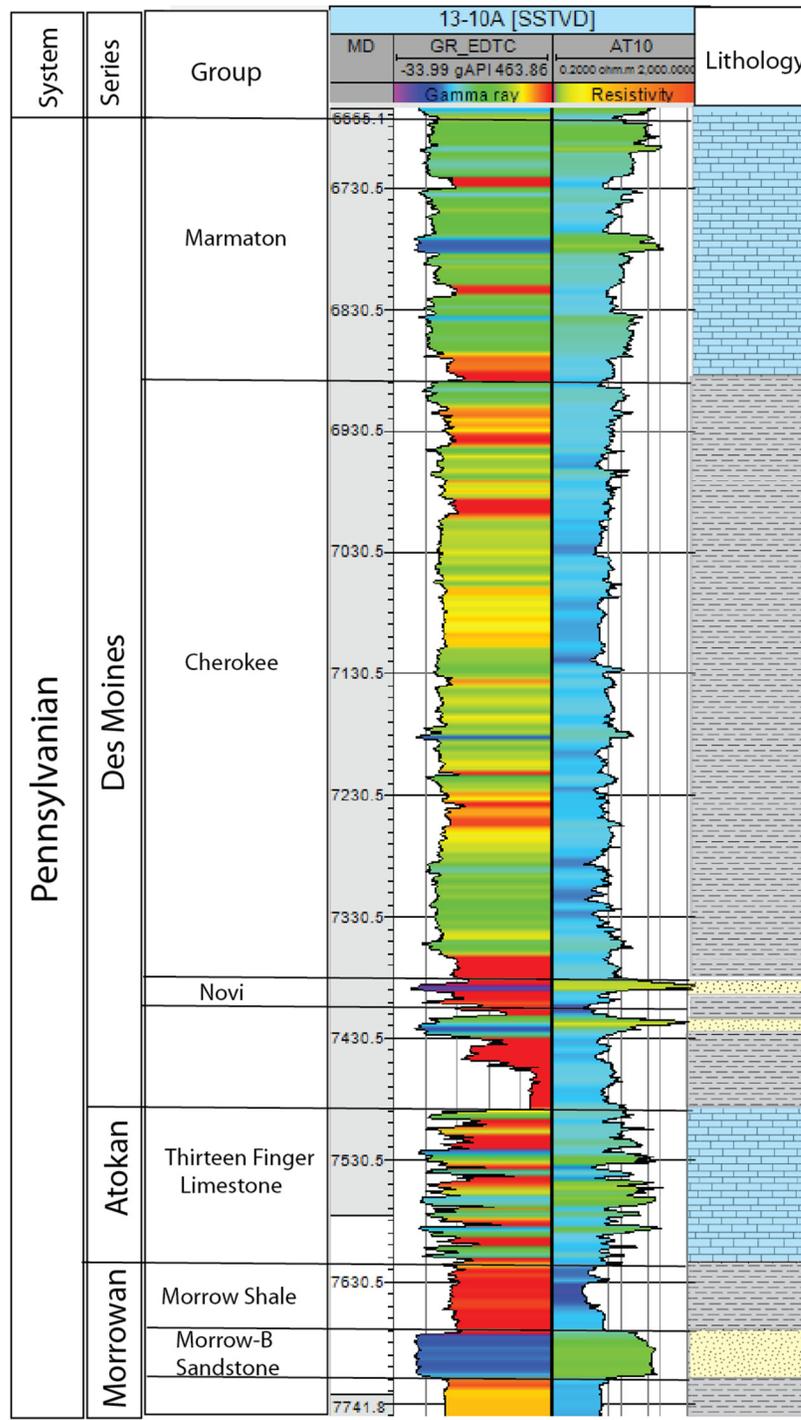


Figure 2.2-2- Stratigraphic section of the FWU.

Tectonic Setting

From FWU's location on the western edge of the basin, the Anadarko Basin plunges to the southeast where it reaches depths of over 40,000 feet (12,192 meters) adjacent to the Amarillo-Wichita Uplift (Perry, 1989). Maximum rates of subsidence occurred during

Morrowan to Atokan times (Evans, 1979; Perry, 1989; Higley, 2014). Positive features that might have influenced deposition within the region include the Ancestral Rockies to the north, the Central Kansas uplift to the northeast, and the Wichita-Amarillo uplift to the south (Evans, 1979; Munson, 1989). Of note is the fact that during Pennsylvanian time the FWU was located on the basin shelf in an area that was not affected greatly by tectonic deformation. Although faults have been reported previously in the northwest Anadarko Basin, we found no direct evidence for tectonic faults within the FWU (see Section 4).

Stratigraphy

Reservoir

Upper Morrowan sandstones in the Anadarko Basin margins have long been recognized as fluvial deposits (Swanson, 1979; Sonnenberg, 1985; Munson, 1989; Krystinik and Blakeney, 1990; Bowen et al., 1990; Al-Shaieb et al., 1995; Mckay and Noah, 1996; Puckette et al., 1996; Bowen and Weimer, 2003, 2004; Devries 2005; Puckette et al., 2008; Gallagher, 2014). At FWU, the Morrow B is a relatively coarse-grained subarkosic sandstone. The upper Morrowan facies in FWU, with sequences of basal conglomerate, coarse-grained sandstone, and fine-grained sandstone appear to be typical of incised valley deposits, as described by Wheeler et al. (1990), Krystinik and Blakeney (1990), Bowen et al. (1990), Blakeney et al. (1990), Sonnenberg et al. (1990) and Puckette et al. (2008). Typical reservoir porosity ranges from almost 0-25% with an average of ~15%, and permeability from 1-780 millidarcies (mD) with an average of ~35 mD (Rose-Coss, 2017)

Primary Seals

The Morrow B sandstones at FWU are encased above and below by shales. Contacts with shale both below and above the sandstone are sharp and irregular. The Morrow shale generally fines upwards in a series of thin beds (1-2 inches or 2.5-5 centimeters) that alternate between upper fine sands and fine to medium muds. Sand content decreases upwards through the section.

The Thirteen Finger limestone formation has two different lithofacies: diagenetic limestone (cementstone) and pyrite and fossil bearing fine to medium mudstone and coal. The two facies are intercalated with each other but tend to cluster in layers dominated more by one or the other. The number of limestone and mudstone beds varies from well to well; in one well 13-10A, 60-70 individual limestone beds were counted.

The entire Thirteen Finger interval is 130 feet (39.6 meters) thick, with approximately 40% of the thickness comprised of mudstone, 4% coal, and 46% is limestone. The cementstone is calcite rich, with some dolomite, and is completely diagenetic in origin and probably formed relatively soon following deposition. The organic-rich mudstone contains fibrous calcite "beef" fractures that are observed in the mudstone and coal lithology between cementstone "layers".

2.2.2.2 Hydrogeology

Information about Morrowan and Atokan formation water flow during oil operations has not been discovered in any oil or gas company published reports or academic research

studies in the Anadarko Basin. Groundwater flow rates in confined deep Anadarko layers at present are considered to be low to no flow (Nelson and Gianoutsos, 2014). Their arguments are based on (1) restricted recharge in the western basin, (2) density barriers to flow in the east, and (3) an overpressure pocket inhibiting flow in the deep basin. Jorgenson (1989) suggested flow could be west to east, driven by potential recharge to elevated units in the west and discharge at lower elevation outcrops in the east. The FWU CO₂ injection and production operations will not cause water to flow to outcrops of the Late Carboniferous (Pennsylvanian) time period that extend from Brownwood, Texas, to the Jacksboro/Bowie, Texas, area, which are hundreds of miles away (The Paleontology Portal).

The Carboniferous is a geologic period and system that cover 60 million years from the Devonian Period 358.9 million years ago, to the beginning of the Permian Period, 298.9 million years ago. As noted in the Section 2.2.2.1, the Morrowan and Atokan intervals of the FWU were deposited approximately 315-300 million years ago and are contained in the Carboniferous period.

2.3 Description of the Injection Process

Figure 2.3-1 depicts is a simplified flow diagram of the facilities and equipment within the boundaries of the FWU. CO₂ captured from the ethanol plant fermentation process is delivered via pipeline to the field for injection. The plant in Liberal KS is the only source of CO₂ to the field. The amount delivered is dependent on the production of CO₂ produced from the fermentation process. This amount will vary but should average 12 MMCFD. Once CO₂ enters the FWU there are three main processes involved in EOR operations. These processes are shown in Figure 2.3-1 and include:

1. CO₂ distribution and Injection. Purchased CO₂ is combined with recycled CO₂ from the FWU central tank battery and sent through the main CO₂ distribution system to various water alternating gas (WAG) injectors.
2. Produced Fluids Handling. Full well stream fluids are produced to the “all well test” site (AWT). The AWT site has two major purposes; 1) to individually test a well’s performance by separating and metering oil, gas and water, and 2) to separate all gas from liquid then send these two phases to the Central Tank Battery for final separation.
3. Produced Gas Processing. All phases from the AWTs are transferred to the central tank battery to separate the oil, gas and water using a series of vessels and storage tanks.

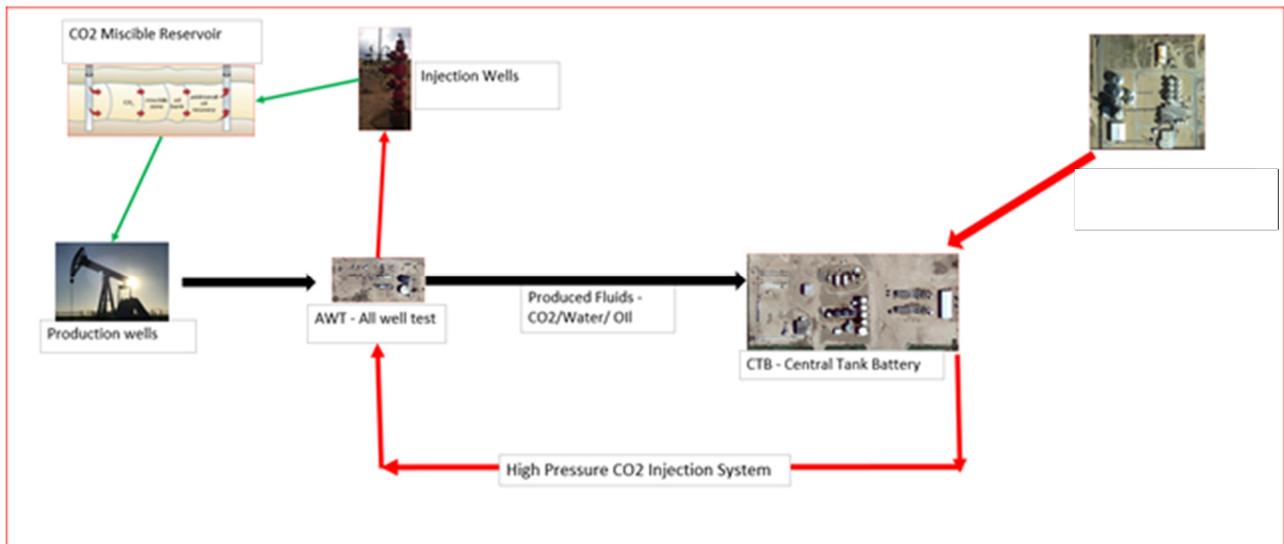


Figure 2.3-1 - Simplified flow diagram of the facilities and equipment within the boundaries of the Farnsworth Unit.

2.3.1 CO₂ Distribution and Injection

Perdure purchases CO₂ from Conestoga Energy Partners, the parent company of the Arkalon Ethanol plant located in Liberal Kansas. A custody transfer meter is located in the compression facility owned and operated by Perdure. The purchased CO₂ from the fermentation process is transported via a United States Department of Transportation (DOT) regulated pipeline to the FWU. A totalizer meter, for the purchased CO₂, is located in the field where instantaneous data is summed into a 24-hour flow rate which is recorded. A totalizer meter is a meter approved by American Gas Association (AGA) Report #3 to measure the flowrate of gases. The actual measurements taken are temperature, line pressure and differential pressure across the meter. Gas produced, recycled CO₂, from the wells is compressed and metered by a similar totalizer meter as the purchase CO₂ meter and is recorded daily.

Perdure currently has three active injection manifolds and approximately 17 active injection wells that the CO₂ is distributed through. When the MRV plan becomes active, the daily injection volume of the combined purchased CO₂ and recycled CO₂ will be approximately 24 MMCFD. Of this volume 12 MMCFD is purchased CO₂ and 12 MMCFD is recycled CO₂. This ratio of purchased CO₂ to recycled CO₂ is expected to change over time, with the percentage of recycled CO₂ increasing and purchased CO₂ decreasing. The current reservoir management plan projects that CO₂ purchases will remain constant at 12 MMCFD for 12 years and decline after 2033. (Per Reservoir Characterization and Modelling, the CO₂ purchases ceased at the end of 2033 which may or may not be true as ultimately production and the economic viability of the flood will dictate when purchased CO₂ is no longer required.) A reservoir management plan is an integrated process using various, surveillance techniques, economic evaluations, and accepted petroleum technical practices to efficiently operate enhanced oil recovery projects.

The three injection manifolds currently in the field distribute the CO₂ to the field. These manifolds have valves to switch to water when the time is called for. Depending on the

reservoir management plan the WAG cycle will be adjusted to maximize oil recovery and minimize CO₂ utilization in each injection pattern. At each injection well pad is a totalizer to measure the volumes injected every 24 hours. This data is collected daily by the field personnel and input into the data warehouse to be allocated for the pattern injection.

The two totalizer meters as described above will be used to determine the total volume injected used in section 7 for the mass balance equations necessary to determine annual and cumulative volumes of the stored CO₂.

2.3.2 Produced Fluids Handling

As injected CO₂ and water migrate through the reservoir, a mixture of oil, gas, and water (referred to as “produced fluids”) flows to the production wells. Gathering lines bring the produced fluids from each production well to the “all well test” (AWT) sites. Perdure has approximately 32 active production wells producing at any time. Each AWT has two separators. The first separator is used for testing individual wells to separate the gas, oil, and water produced from an individual well. This gas, oil and water is subsequently measured and recorded for the well. Each producing well is production tested every 30 to 60 days after the last production test, or after the well is returned to production. Depending on the reservoir management plan well testing can be more frequent to obtain data. The second separator is used to separate the gas from the oil/water mixture from the other wells producing into the AWT and the gas and liquids are displaced from the vessel in separate lines. Leaving the AWT sites are two lines transporting produced fluids. One for the liquid phase, a mixture of oil and water, and one for the gas phase.

When gas and liquid lines enter the CTB a series of vessels separate the oil, gas, and water to be accounted for and distributed for sales or reinjected. The liquid phase line has vessels to separate the oil from the water using density and residence time. The gas phase vessels collect any free liquids entrained with the gas. These free liquids are then combined back into the liquid phase line. All gas and water are reinjected, and the oil, which contains an estimated 2,930 ppm CO₂ (0.293%), is sold out of tanks. Annually, the oil from the stock tank is analyzed by a laboratory using ASTM crude oil analysis methods to determine the CO₂ content in the oil being sold.

After separation, the gas phase, which is approximately 89-93% CO₂, is mixed with reservoir volatile components, compressed, and distributed throughout the high-pressure distribution system using reciprocal compression and high-pressure horizontal pumps.

The water is transferred from the separation vessels to tanks for reinjection. After the water is conditioned, it is either reinjected at the WAG skids or disposed of into permitted disposal wells. Although Perdure is not required to determine or report the amount of dissolved CO₂ in the water, analyses have shown the water typically contains <690 ppm (0.069%) CO₂.

FWU production has trace amounts of hydrogen sulfide (H₂S), which is toxic. There are approximately 8-10 workers on the ground in the FWU at any given time, and all field and contractor personnel are always required to wear H₂S detectors. The primary purpose of the H₂S detectors is protecting people from the risk of being harmed. The detection limit of

the H₂S detectors is quantified for readings in the range of 0-100 ppm and will sound an alarm above 10 ppm. The secondary purpose H₂S detectors would be to provide an indication of emissions of gas from a pipeline or surface equipment, that might go unnoticed by other observations or measurements. No gas volumes can be calculated based on the detector reading or alarm; only a H₂S leakage is detected and located. Once identified, further a further response will be initiated and CO₂ volumes will be quantified as discussed in sections 4.5, 4.6, 5.4 and 8.1.5 of this MRV plan.

2.3.3 Produced Gas Handling

Produced gas separated at the central tank battery (CTB) is stripped by a series of vessels of entrained and free water. The water content has been recorded to be < 20 pounds mass per MMCF, thus dehydration is not necessary. The gas is then sent to a centralized compression system to be compressed and placed in the high-pressure distribution system. This compression turns the CO₂ into a variable density liquid, which is then transported out via high pressure lines to the AWTs where a manifold splits this dense CO₂ to the wells that are on CO₂ injection at that time.

2.3.4 Facilities Locations

The locations of the “all well test” sites (AWT) are positioned in the field to access both injection distribution and production gathering. The central tank battery (CTB) is where the final separation and injection equipment is maintained and operated. The water injection station is where the horizontal pumps are located to reinject the produced brine.

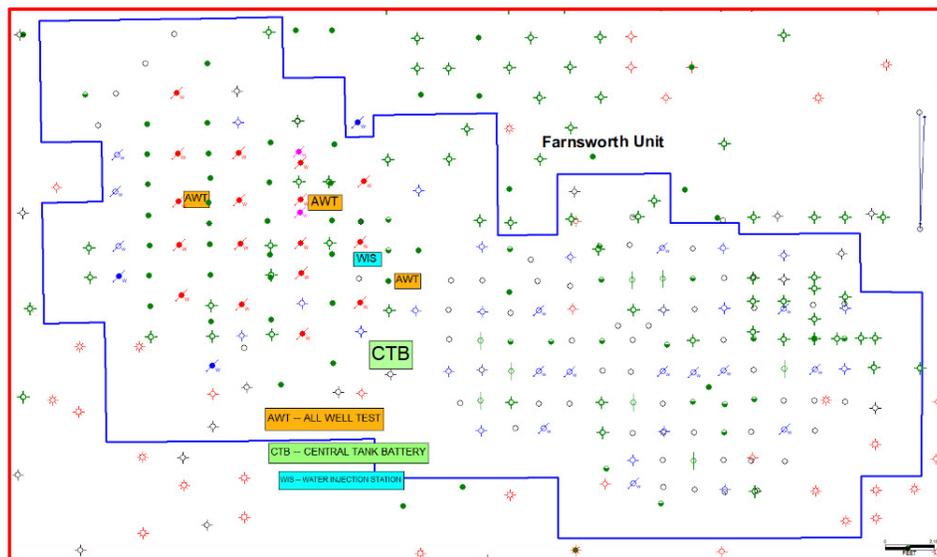


Figure 2.3-2 – Location of All Well Test (AWT) sites, Central Tank Battery (CTB) and Water Injection Station (WIS) in the FWU

2.3.5 Water Conditioning and Injection

Produced water collected at the central tank battery is collected in a series of vessels and tanks in a cascade system. This allows any entrained oil to further separate to the top of the tanks because of the density difference and is skimmed off and put back in the oil separation system. The clean water is then transferred to the water injection system where

it is boosted in pressure and sent out to the AWTs for distribution to all wells that are currently on water injection.

2.3.6 Well Operation and Permitting

The Texas Railroad Commission rules (Appendix 1) govern well location, construction, operation, maintenance, and closure for all wells in permitted units and wells. Perdure follows these rules and regulations to maintain safe and efficient operations. This includes complying with all current and updated information for mechanical integrity testing, well repairs for injection wells, drilling and completion permitting and reporting.

Briefly current rules require, among other provisions:

- That fluids be constrained in the strata in which they are encountered.
- That activities governed by the rule cannot result in the pollution of subsurface or surface water.
- That wells adhere to specified casing, cementing, drilling well control, and completion requirements designed to prevent fluids from moving from the strata they are encountered into strata with oil and gas, or into subsurface and surface waters.
- That wells file a completion report including basic electric log (e.g., a density, sonic, or resistivity (except dip meter) log run over the entire wellbore).
- That all wells be equipped with a Bradenhead gauge, measure the pressure between casing strings using the Bradenhead gauge, and follow procedures to report and address any instances where pressure on the Bradenhead is detected.
- And that all wells follow plugging procedures that require advance approval from the Director and allow consideration of the suitability of the cement based on the use of the well, the location and setting of plugs.

2.3.7 Number, Location and Depth of Injection Wells

Perdure's FWU injection wells are listed in Appendix 1. Injection is into the Upper Morrowan, a lenticular bedded sandstone trending northwest to southeast with the average top of sand at 7990 feet, true vertical depth. The Upper Morrowan is described in section 2.2.2.1 above.

2.4 Reservoir Characterization Modeling

2.4.1 Reservoir Model Description

The target reservoir Morrow B is a sandstone formation overlain by the Morrow shale and Thirteen Finger limestone, which serve as excellent seals for injected CO₂ (Ampomah et al., 2016a). The Morrow B sandstone reservoir is at a depth between 7550 feet and 7950 feet subsurface with an average dip of less than one degree (Figure 2.4-1). The productive limit of the FWU extends laterally to about 8300 acres. The maximum pay thickness is 54 feet with an average of 22 feet.

The FWU is approximately 4 mi by 7 mi and is usually divided into eastern and western portions because the two sides of this field have exhibited different reservoir behavior. The

eastern side was more prolific under primary production. However, the CO₂ –EOR study for FWU has concentrated on the west half of the field, which showed a better response to waterflood initiated in the 1960's and which is where the field operator is focusing their efforts (Ampomah et al., 2016b).

In the property modelling process, a hydraulic flow unit (HFU) methodology based on the Winland R35 method was used to describe and characterize heterogeneity within the Morrow B reservoir. The R35 parameter refers to the pore throat aperture radius when core samples are 35% saturated during a mercury injection porosimetry test. This captures pore throat size at which pore networks become interconnected and form continuous flow paths. Fifty-one (51) wells with core porosity and permeability measurements were used to define eight distinct porosity/permeability relationships (Figure 2.4-2). These eight relationships were based on depositional/diagenetic facies described from core and thin section analysis. The facies have differences, often subtle, that appear to greatly affect reservoir properties (Ross-Coss et al., 2016). There appears to be a strong relationship between the delineated hydraulic flow units and depositional and diagenetic trends that was not noted in early investigations into reservoir properties (Gallagher, 2014, Munson, 1989). After HFUs and porosity/permeability relationships were established, a Gaussian simulation method, cokriged with the facies model, was used to model porosity and net-to-gross ratio.

The geocellular structural model has a grid cell distribution of 1573*962*23 with a grid dimension of 25 feet × 25 feet. and includes the reservoir formation and several of the overlying seal formations. This model was upscaled to a reasonable size to decrease computational time for simulation purposes. The upscaled model, which uses only the western half of FWU, has a grid size of 176×163× 8 for a total of 229,504 cells that are approximately 100 feet by 100 feet on the top view perspective.

Figure 2.4-3 shows porosity and permeability distribution for the western half of FWU used in this study. Reservoir porosity ranges from 9.2% to 24% with a mean of 14.6% and shows a normal population distribution. Permeability ranges from 0.01 mD to 181 mD with an average value of 58 mD. The permeability histogram shows a log-normal population distribution.

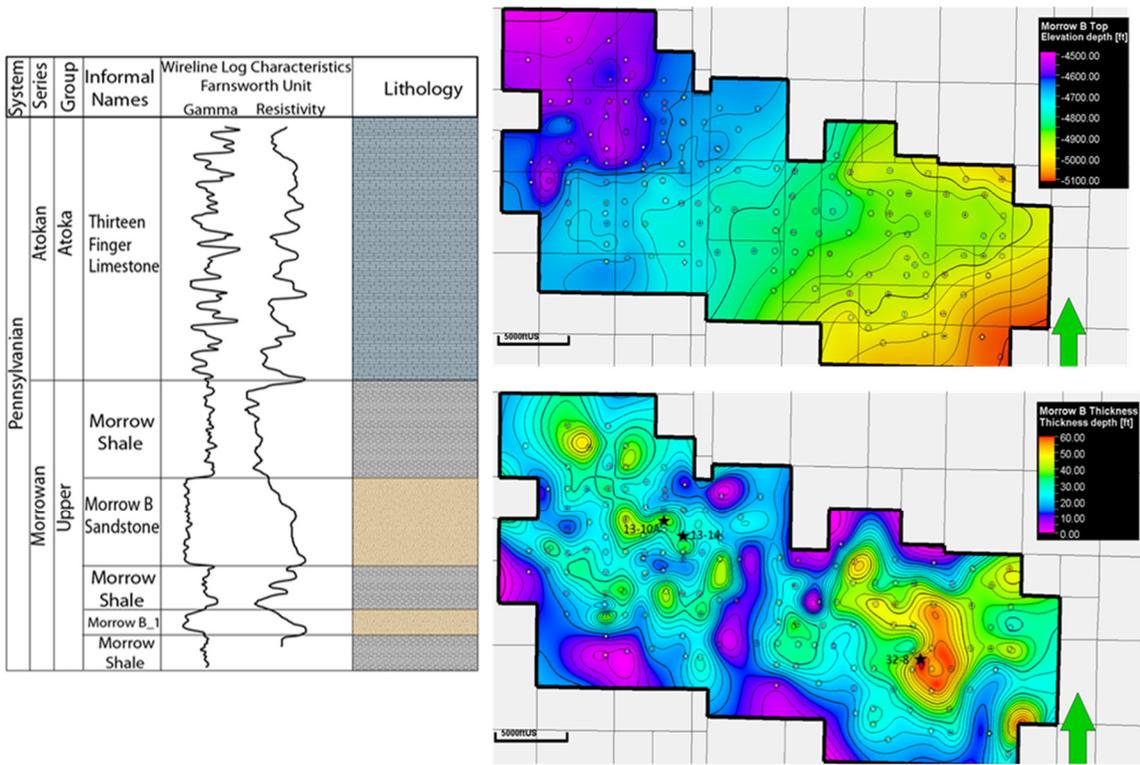


Figure 2.4-1- (Left) Type log of FWU caprock and reservoir. (Upper Right) Surface contour of Morrow B top. (Lower right) Thickness map of Morrow B sands (Gallagher 2014).

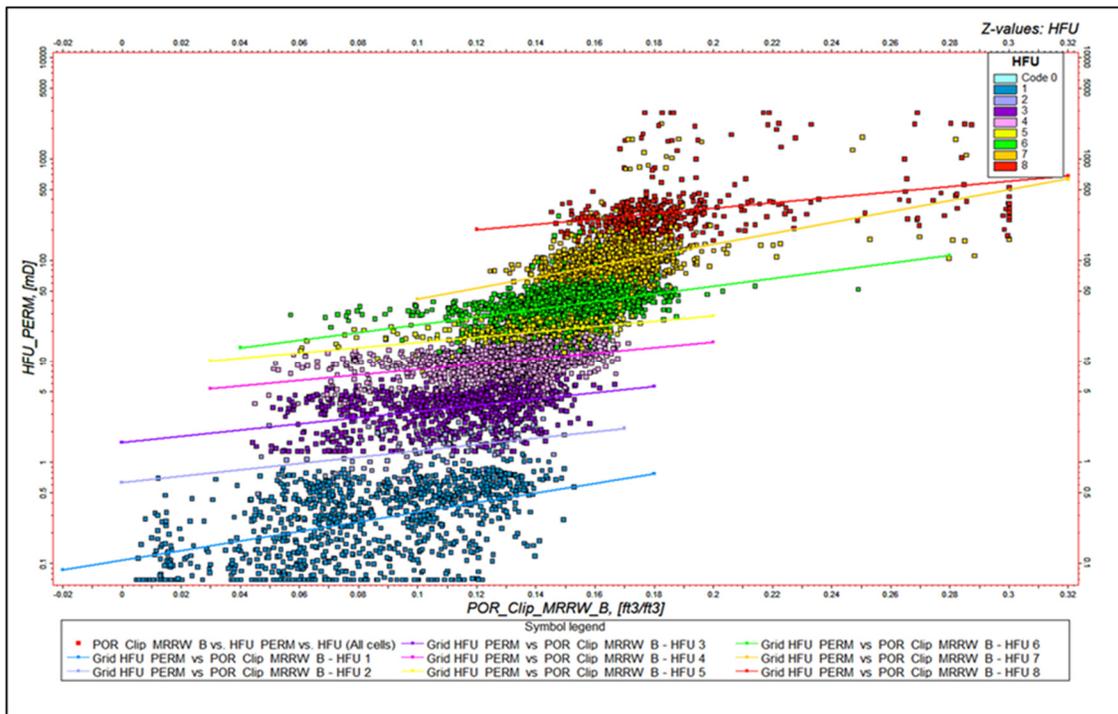


Figure 2.4-2 - Porosity versus permeability for the 51 cored wells, separated by pore throat size into hydraulic flow units.

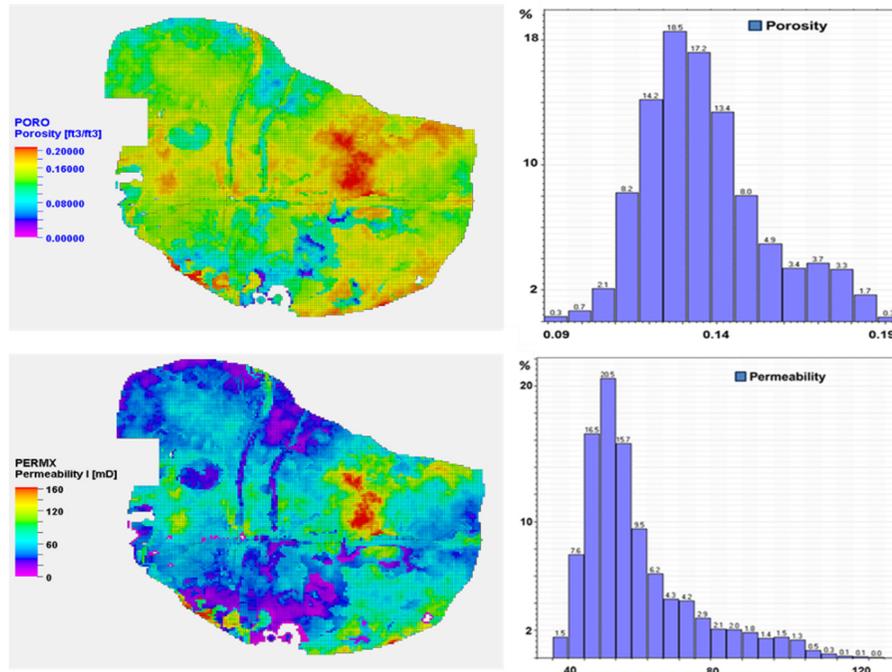


Figure 2.4-1- (Upper left) Porosity distribution using a Gaussian Simulation method for the west section of FWU used in the work. (Upper right) shows histogram illustrating a normal distribution of porosity with a mean of 14%. (Lower left) Permeability distribution constructed from porosity-permeability cross plots based on eight hydraulic flow units. (Lower right) Histogram illustrates a lognormal distribution of permeability.

2.4.2 Reservoir Fluid Modeling

The compositional fluid model was constructed from laboratory experiments tuned to an equation of state (Gunda et al., 2015). The process for the FWU involved comprehensive splitting and lumping of the C7+ fractions. The experimental data from PVT experiments including constant composition expansion (CCE), saturation pressure, differential liberation (DL), multi-stage separator tests and viscosity tests conducted on FWU fluid sample were used for the validation of the tuning process (Gunda et al., 2015). The mixing rules by Pedersen (Pedersen et al. 1989) were followed to split the C7+ fractions into two pseudocomponents using the average molecular weight, average specific gravity and the total mole percent. The isomers of C4 (butane) and C5 (pentane) were also lumped using the same methodology. A regression process was performed manually to achieve acceptable calibration to the laboratory data. The critical parameters for the two pseudocomponents were calculated based on Pedersen’s approach (Pedersen 2002) using Calsep’s PVTsim™ software package. The 3- parameter Peng Robinson equation of state (Peng and Robinson 1976) with Peneloux volume correction (Peneloux et al. 1982) was used to perform all the calculations. The viscosity modeled using the Lohrenz-Bray-Clark correlation (Lohrenz et al. 1964). After calibrating the fluid model to equation of state, a slim tube simulation experiment was conducted to obtain the minimum miscible pressure (MMP) for FWU. A one-dimensional 200 cell model was used for the experiment with a CO₂ injection rate of 1.2 pore volume. Figure 2.4-4 shows a plot of oil recovery vs. pressure illustrating the MMP of FWU computed from the simulation experiment. The MMP of 4009 psia realized from the simulation as compared to an MMP value 4200 psia derived from

laboratory experiments provided by the operator represents a less than 5% error (Gunda et al., 2015).

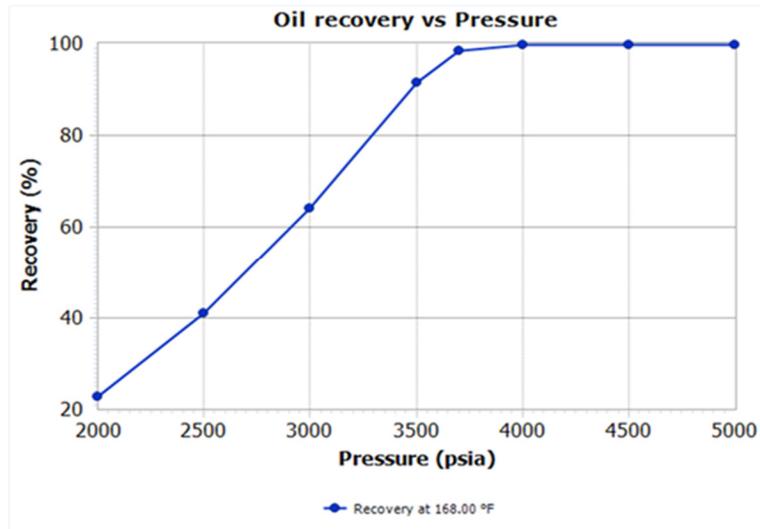


Figure 2.4-4. Oil recovery plot for 1D slim tube test

2.4.3 Assisted History Matching using Reduced Order Model

This section presents computer assisted history matching efforts for primary, secondary and tertiary recovery processes for FWU. Eclipse E300 (Schlumberger) was used throughout this study for all simulation runs. Most efforts were directed at matching secondary and tertiary processes by assigning higher weights in objective function formulation as compared to primary processes. Gas production field history was not available for primary recovery. The primary and secondary history processes lasted for 55 years until December 2010. The tertiary CO₂ flood was performed between December 2010 and August 2020. The parameters included in the objective function formulation were oil production, water production, water-cut, gas oil ratio (during waterflood), and injection rate. Pressure measurements including those made initially, prior to waterflood and at the end of waterflood were also used in the calibration process. Heath et al., (2015) conducted geomechanical analysis on FWU rock samples and determined a fracture pressure between 5400 to 5600 psia.

During primary recovery, there were a total of 60 production wells. As there were no recorded gas-oil or water-oil contacts, all grid blocks were assigned an initial oil saturation of 69% and 31% connate water saturation. With initial reservoir pressure of 2217.7 psia assigned to the datum depth of 4900 feet TVDSS, original average pressure in the model was 2150 psia. Oil originally in place (OOIP) for FWU west half in this model was about 71.4 MMstb with 23.8 MMscf of dissolved natural gas. During waterflood, there were 47 producer wells with 13 wells converted from producers to injector wells. An additional 6 water injector wells drilled during this period. The initial sensitivity analysis performed on primary and secondary recovery processes showed that well bottomhole pressure, oil-water contact (OWC), and bottomhole injection pressure were the most important parameters.

These uncertain variables were included in the history matching process to optimize the objective function at acceptable data uncertainty ranges.

From the history matching results it was deduced that OWC of an average value of 5000 feet TVDSS was appropriate to yield the best history match model. The bottomhole pressure had an optimum value of 4800 psia to improve history matching efforts. Sensitivity analysis showed global permeability was not particularly sensitive to the objective function. However, a few local permeabilities were furthered adjusted to improve the overall history matching. The overall RMS was about 10%, which was mostly contributed by gas-oil ratio match. This confirms some doubts the operator had on gas production history measurements during the primary and secondary recovery processes of the field. Figure 2.4-5 shows oil production and water cut profiles. Various waterflood patterns swept to residual oil saturation of about 27%, a successful flood. This is not unexpected given the relatively good mobility ratio of about 1.6 and high injection throughput of at least 1.7 displaceable pore volumes. From the simulation results, nearly 6 MMstb represents 10% of OOIP produced prior to the initiation of waterflood. A total of 25.65 MMstb of cumulative oil has been produced at the end of secondary from the west half of FWU, which represents nearly 40% of OOIP. During the tertiary history match, an initial simulation run showed a good calibration of compared to observed history until CO₂ breakthrough. Simulated gas production and CO₂ injection rates were unable to match measured volumes after the CO₂ breakthrough, which could be attributed to a potential change in wettability and interfacial tension. There is a possibility of the Morrow B transitioning into a mixed-wet wettability system. Corey parameters were adjusted to improve calibration of the CO₂ flood history match. An optimization approach was utilized to identify optimum values for Corey parameters. Figure 2.4-6 shows simulated results compared to historical oil production, gas production, CO₂ injection and water production profiles.

At the end of August 2020, according to simulation results, a total of 4.8 MMstb of oil has been produced from the west half of FWU since CO₂-WAG commenced (December 2010). About 93% of the purchased CO₂ remains as of August 2020.

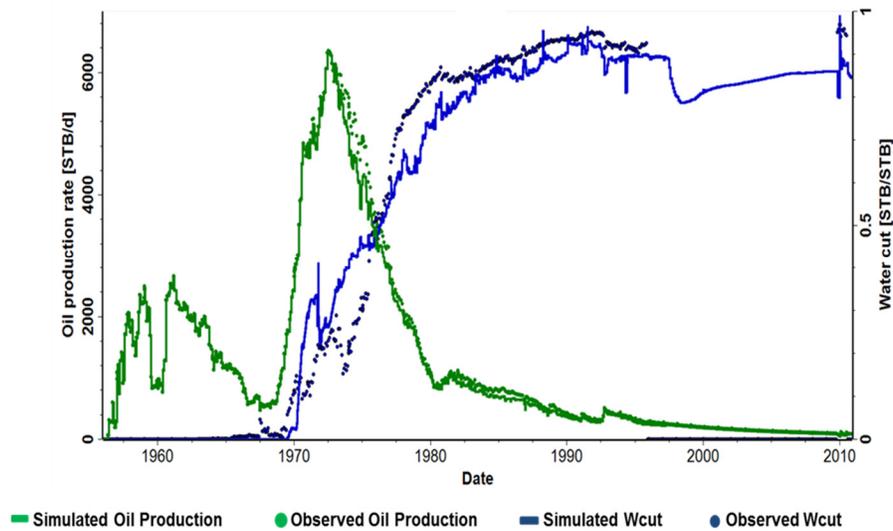


Figure 2.4-5- Calibration of simulated oil production rate and water cut vs. observed for primary and secondary history matching process.

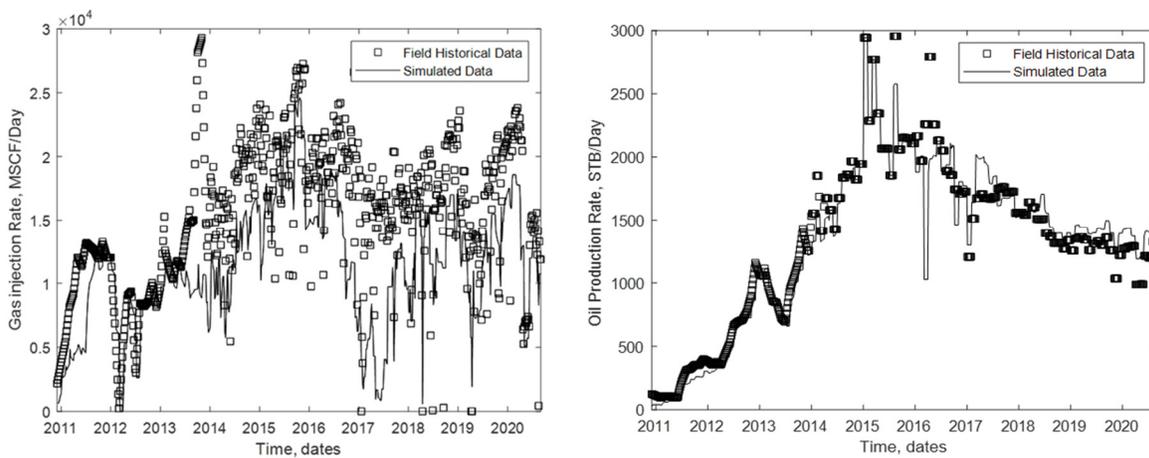


Figure 2.4-6- Calibration of simulated vs observed responses for tertiary recovery including CO₂ injection (left) and oil production rate (right).

2.4.4 CO₂ –EOR Performance Scenarios

Once an acceptable history match was reached, CO₂ flood performance could be predicted to optimize oil production and CO₂ storage. Several prediction cases based on different injection scenarios were run to maximize the potential of the projected flood. Per the current plan of the operator, five existing water injection wells will be converted to WAG injection wells and were included in the CO₂ prediction model. There is an anticipated constant CO₂ purchase of 12 MMscf/d and a flexible compressor capacity to recycle produced gas for reinjection purposes. A user-defined algorithm was developed in the numerical simulator to use purchased CO₂ in addition to produced gas (recycled) as a group injection rate target for the run scenarios. The model was performed for a 12-year period with bottomhole pressure and oil rate target constraints. Per §98.449 Definitions, the modelled area is projected to contain the free phase CO₂ plume at the end of year t + 5. The

injection profile shows the storage capacity of the Morrow B storage complex. Significant amount of produced CO₂ was recycled back into the injection stream (Figure 2.4-7). The compressor capacity will be expanded to compensate for high volume recycle volumes in the future.

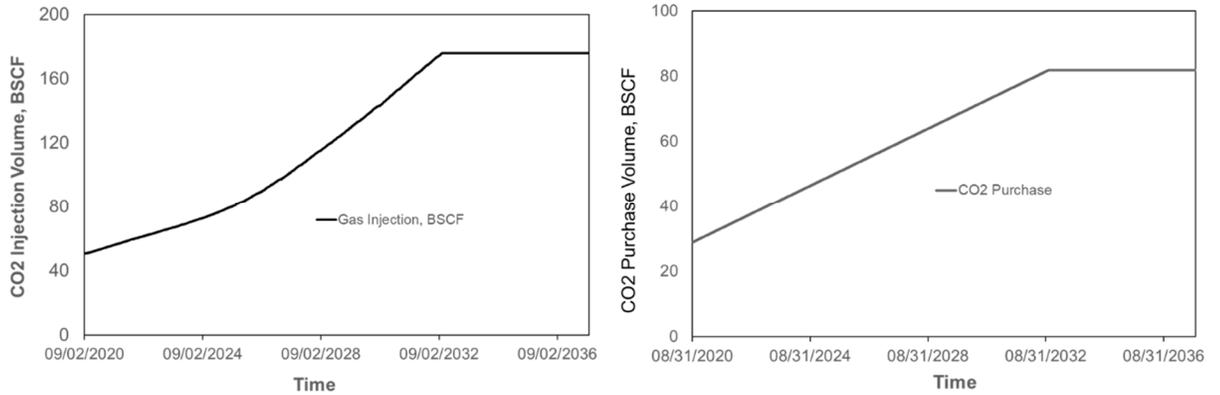


Figure 2.4-7 - Simulated Cumulative CO₂ injection Volume and CO₂ purchase volume for the Forecasting Scenario

3 Delineation of the monitoring areas

3.1 MMA

As defined in Subpart RR, the maximum monitoring area (MMA) is equal to or greater than the area expected to contain the free phase CO₂ plume until the CO₂ plume has stabilized plus an all-around buffer zone of at least one-half mile. The purchase volumes that are displayed in figure 2.4.7 and the mapped CO₂ composition results that are displayed in Section 3.1.1 indicate that all of the CO₂ will remain in modelled area is projected to contain the free phase CO₂ plume at the end of year t + 5; barring unforeseen future operational issues. Therefore, Perdure is defining the MMA as the boundary of the FWU plus an additional one-half mile buffer zone. This will allow for operational expansion throughout the FWU for the next 12 years, the anticipated life of the project.

3.1.1 Determination of free phase plume extent

Figure 3.1-1 shows the modeling simulation of the total CO₂ composition depicting the lateral extent of CO₂ in the injection zone. The injection area shows the significant high concentration of CO₂ which reiterates the containment within the injection zone and area. The simulation depicts the tertiary CO₂ flood that was performed between December 2010 and October 2032 with additional 5-year post-injection monitoring (Figure 3.1-2). The high green color shows almost zero CO₂ fraction which illustrates most of the CO₂ injected has not reach the model boundary even after a total of 22 years of potential CO₂ injection into the Morrow B formation.

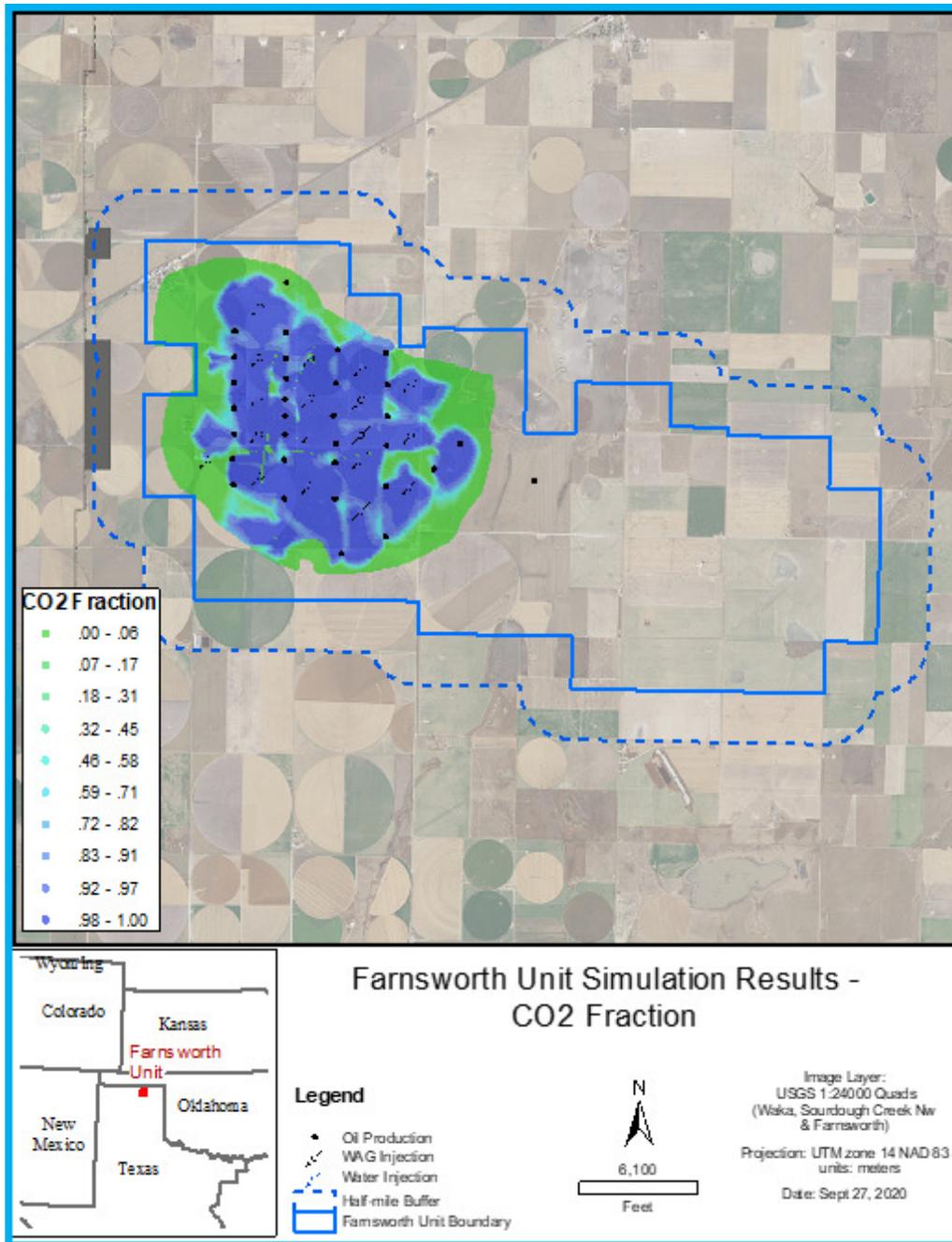


Figure 3.1-1: Model simulation of the tertiary CO₂ flood

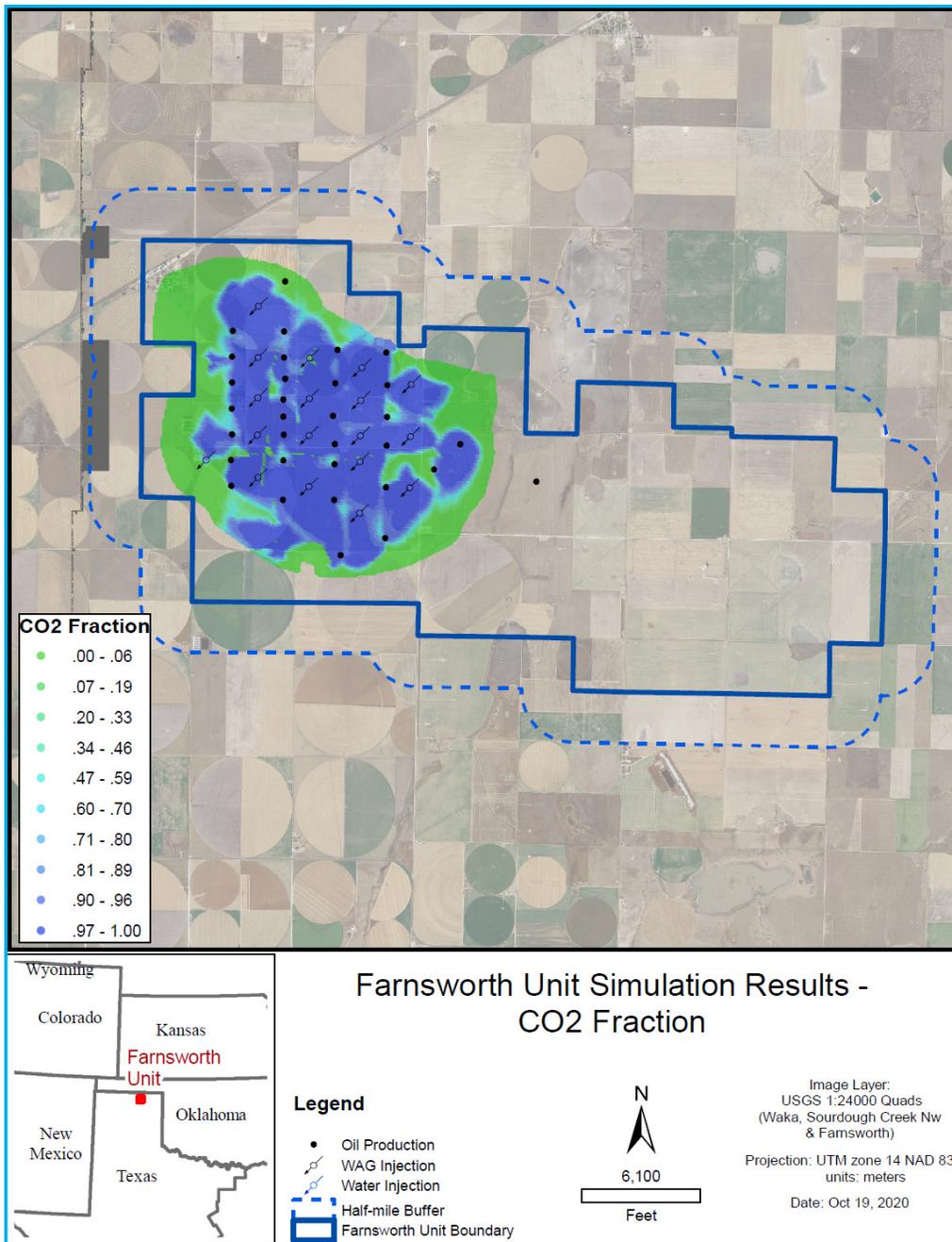


Figure 3.1-2 – CO₂ Plume Extent 5 years after Injection ceased.

3.1.2 Determination of buffer zone

Perdure intends to implement a buffer zone of one-half mile around the FWU, the minimum required by Subpart RR, because the site characterization of the FWU did not reveal any leakage pathways that would allow free-phase CO₂ to migrate laterally thereby warranting a buffer zone greater than one-half mile.

3.2 AMA

Currently, Perdure's operations are focused in the western portion of the FWU. However, it is anticipated as the project develops additional activity will occur in the eastern portion of the FWU; therefore, requiring active monitoring in that area. However, project development is driven by the market price of oil so Perdure is unable to provide a specific time in the future when the eastern portion of the FWU will be actively monitored. Therefore, for the purposes of this MRV plan, Perdure has chosen to include the entire FWU in the AMA.

4 Identification and Evaluation of Leakage Pathways

Since its discovery in 1955, its unitization in 1963, and the commencement of CO₂ EOR in 2010; the FWU has undergone extensive investigation and documentation as indicated in Section 2. From this body of work, Perdure has identified the following potential pathways of CO₂ leakage to the surface. This section will also address detection, verification, and quantification of leakage from each pathway.

4.1 Leakage from Surface Equipment

The surface equipment and pipelines utilize materials of construction and control processes that are standard in the oil and gas industry for CO₂ EOR projects. Ongoing field surveillance of pipelines, wellheads and other surface equipment via personnel instructed how to detect surface leaks and other equipment failure minimizes releases. In addition, requirements in the Texas Administrative Code (TAC) rules for the Texas Railroad Commission (TRRC) Oil and Gas Division to report and quantify leaks, both serve to minimize leakage of GHG from surface equipment. Operating and maintenance practices currently follow and will continue to follow demonstrated industry standards. As described in Section 6.4 below, should leakage from surface equipment occur it will be quantified according to the procedures in Subpart W of the GHGRP.

4.2 Leakage from Wells

Perdure has identified 61 abandoned wells, 32 injection wells (17 active), 58 production wells (32 active) and 2 monitoring wells within the MMA and assessed their potential for leakage of CO₂ to the surface as listed in Appendix 1.

4.2.1 Abandoned Wells

Figure 4.2-1 shows all wells plugged and abandoned in the FWU. Because the FWU was unitized in 1963, all plugging and abandonment activities of wells within the FWU have been conducted under the regulations of the TRRC for plugging wells. Perdure concludes that leakage of CO₂ to the surface through abandoned wells is unlikely. However, strategies for leak detection are in place that are discussed in Section 4.5 and the strategy to quantify the leak is discussed in Section 4.6.

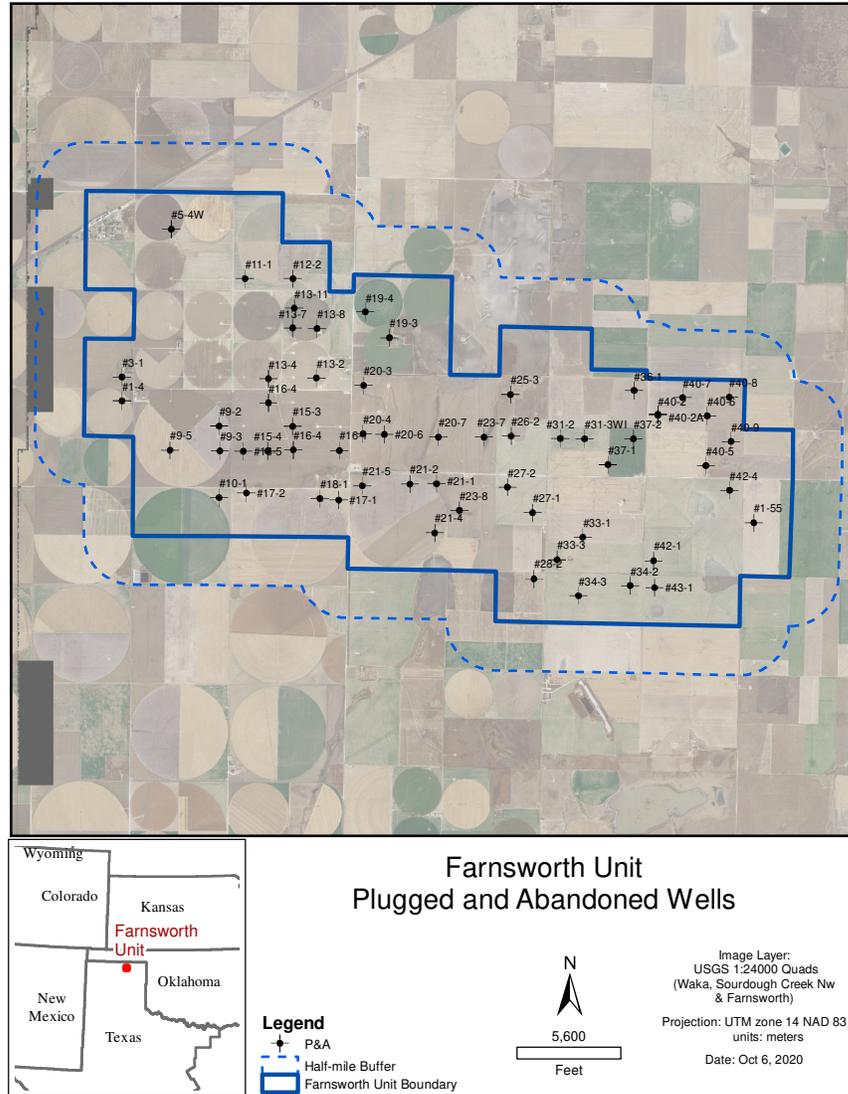


Figure 4.2-1: Plugged and Abandoned Wells in the FWU

4.2.2 Injection Wells

Mechanical integrity testing (MIT) is an essential requirement of the Underground Injection Control (UIC) program in demonstrating that injection wells themselves do not act as conduits for leakage into underground sources of drinking water (USDWs) and to the surface environment. Rule 46 and any special conditions pertaining to mechanical integrity testing the TRRC includes in the Class II permits issued to Perdure, ensure that active injection wells operate to be protective of subsurface and surface resources and the environment. Figure 4.2-2 and 4.2-3 shows the active and inactive, respectively, injection wells in the FWU. Perdure concludes that leakage of CO₂ to the surface through injection wells is unlikely.

4.2.3 Production Wells

Figure 4.2-2 4.2-3 shows the active and inactive, respectively, oil production wells in the FWU. However, as the project develops in the FWU additional production wells may be added and will be constructed according to the relevant rules of the TRRC. Additionally,

inactive wells may become active according to the rules of the TRRC. Perdure concludes that leakage of CO₂ to the surface through production wells is unlikely.

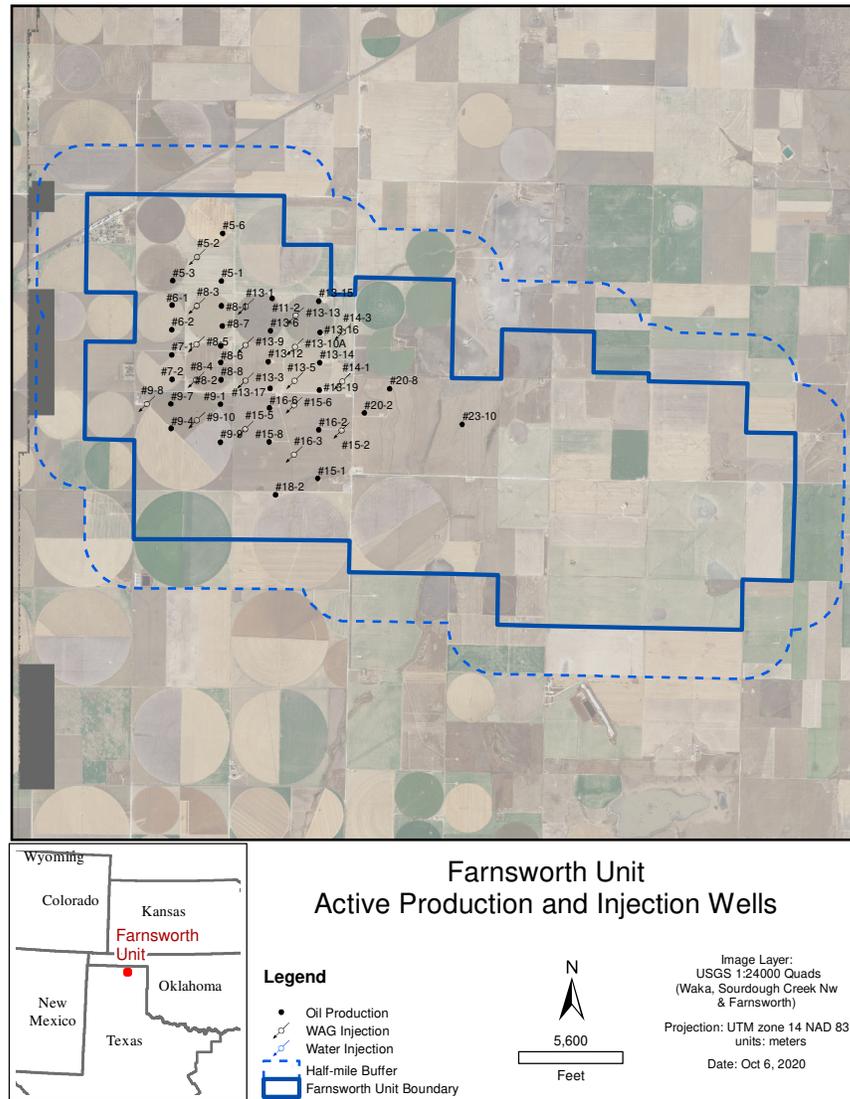


Figure 4.2-2: Active Production and Injection Wells in the FWU

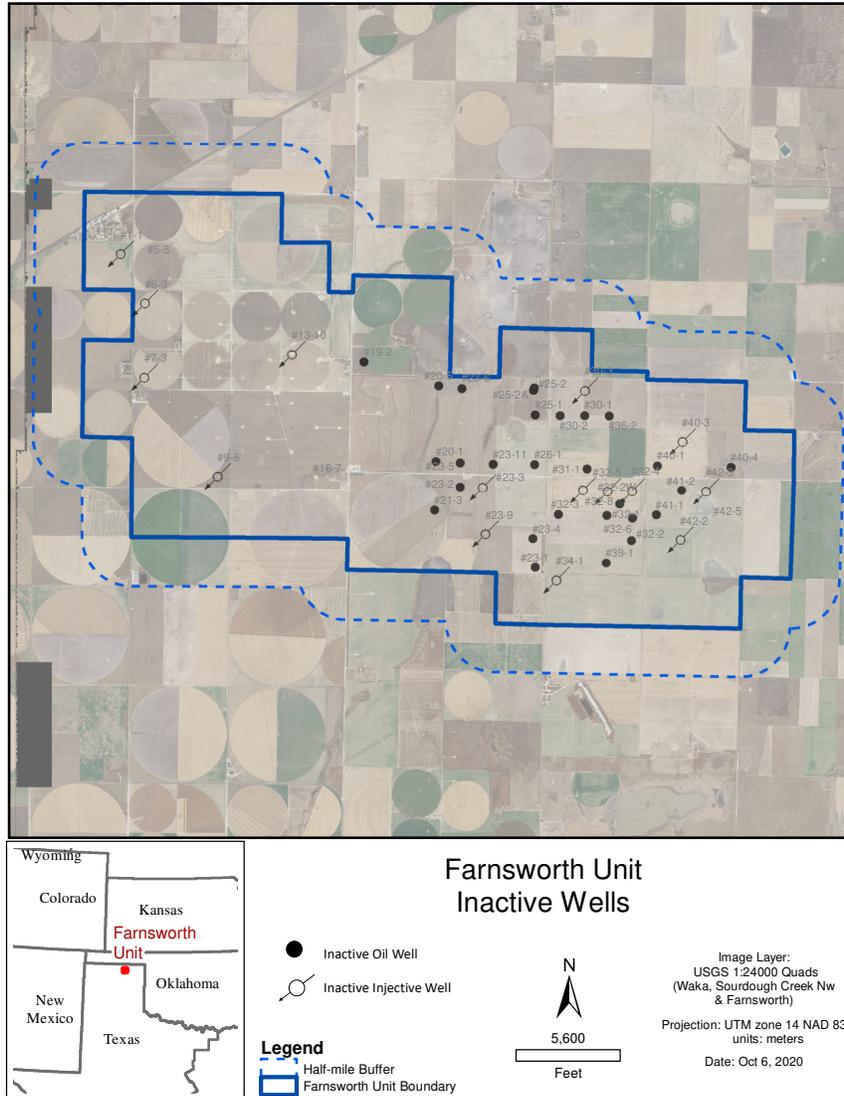


Figure 4.2-3: Inactive Production and Injection Wells in the FWU

4.2.4 Monitoring Well #13-10

The SWP has conducted monitoring of the Morrow B injection horizon and overlying seals in the area immediately adjacent to the new WAG injection well (#13-10A), through the use of a dedicated monitoring well (#13-10). This old WAG injection well (#13-10), drilled in 1971 to a total depth (TD) of 7770 feet, was repurposed for monitoring reservoir pressure and temperature, borehole temperature and microseismicity. To accomplish the task, the following equipment were permanently installed in the well:

- Downhole pressure and temperature gauges: Real time pressure and temperature monitoring of the reservoir
- Distributed Temperature Sensing (DTS): Real time monitoring of temperature along the wellbore for leakage detection.
- Sixteen level geophone array: Pseudo real time monitoring of passive and active (during injection and draw down cycles) microseismic activities within the FWU.

- Twenty surface seismometer stations: Monitor microseismic activities at the surface. Data is integrated with data from borehole geophone array to enhance event detection and location.

After the SWP has finished their Real time monitoring and their research efforts are completed Perdure may continue to observe and collect the data, but it will not be an ongoing part of the FWU MRV plan.

4.2.5 New Wells

As the project develops, new production wells and injection wells may be added to the FWU. All new wells will be constructed according to the relevant rules for the TRRC which ensure protection of subsurface and surface resources and the environment.

All wells in Texas oilfields, including both injection and production wells, are regulated by TRRC, which has primacy to implement the UIC Class II program in Texas, under TAC Title 16 Part 1 Chapter 3.

TRRC rules govern well siting, construction, operation, maintenance, and closure for all wells in oilfields. Briefly current rules require, among other provisions:

- That fluids be constrained in the strata in which they are encountered;
- That activities governed by the rule cannot result in the pollution of subsurface or surface water;
- That wells adhere to specified casing, cementing, drilling well control, and completion requirements designed to prevent fluids from moving from the strata they are encountered into strata with oil and gas, or into subsurface and surface water;
- That wells file a completion report including basic electric logs;
- That all wells be equipped with a Bradenhead gauge, measure the pressure between casing strings using the Bradenhead gauge, and follow procedures to report and address any instances where pressure on the Bradenhead is detected;
- And that all wells follow plugging procedures that require advance approval from the Director and allow consideration of the suitability of the cement based on the use of the well, the location and setting of plugs.

New well construction is based on existing best practices, established during the drilling of existing wells in FWU and follows TRRC rules, which significantly limits any potential leakage from well pathways. Additionally, the existing wells followed TRRC rules.

In public databases, the area of FWU plus one mile past the unit boundary contains over 100 wells that were drilled deeper than the Morrow formation and none of these wells were productive in reservoirs deeper than the Morrow. Therefore, it is very unlikely that anyone will ever drill through the AMA reservoir in the future. In the event a well is drilled within the AMA, the operator would be required to follow all TRRC rules and procedures in the drilling the well and the potential for leakage would be similar to any well that Perdure drills within the AMA. In addition, Perdure's visual inspection process during routine field operation will identify any unapproved drilling activity in the FWU.

4.3 Leakage from Fractures, Faults and Bedding Plane Partings

Primary seals at FWU have been demonstrated to be mechanically very competent (see Section 2.2.2), thus the main concern of CO₂ migration at FWU is via seal bypass systems along fracture networks. The following several lines of analysis have been used to assess this risk in the area.

4.3.1 Presence of Hydrocarbons

The first and foremost argument against present day up-fault transmissibility is the 120 MMB of oil that was found trapped in the reservoir at the time of discovery (Munson, 1988). If significant escape pathways existed, oil would have drained from the reservoir prior to the current day.

4.3.2 Structural Analysis

The second argument against up-fault leakage are the results of an extensive field and regional analysis of core, 2D and 3D seismic data. 3D Reflection seismic data of the FWU was acquired in 2013 and reprocessed in 2017 to obtain a better image resolution. In-depth analysis of the reprocessed data gives us confidence that there are no significant faults or fractures in the field area. The Morrow B is only 60 feet thick in the area; below the resolution of the seismic signal to pick an exact top and base. Horizons identified as the Kansas City top, Thirteen Finger base, and as a reflector in the proximity of the Morrow B reservoir unit were picked in the 3D seismic data. Two horizons below the Morrow B, tentatively identified as the top of the Hunton limestone and top of the Sylvan shale, were also used in the structural analysis. A detailed isopach map of the Morrow B created from interpretation of 346 well logs were also used to crosscheck the seismic interpretation.

Reprocessed data (Hobbs et al.) shows a series of seismic horizons that dip gently and thicken slightly to the southeast (Figure 4.3-1), consistent with the location of FWU on the western edge of the Anadarko basin dictating that sedimentary packages should thicken and dip towards the center of the basin. The most prominent feature of the seismic data is an increase in the intensity of the reflectors in the central and western part of the field (Figure 4.3-2). Based on the bifurcation of reflectors and on their lateral morphological changes they are interpreted as facies changes between carbonate or sandstone shelf deposits that transition laterally to shales. It is possible that such facies changes or channels could form preferential flow paths; however, these are relatively discontinuous, anastomosing, and irregular features that would not constitute a pathway to the surface. The structures visible in the seismic data can be interpreted as sedimentary/diagenetic features that include lateral facies changes, channel infills and karst collapse features.

In addition to the field-scale 3D seismic survey, over 70 mi of 2D seismic line in the region were used to constrain larger scale structural risk in the region. No faults were observed in any of the 2D lines.

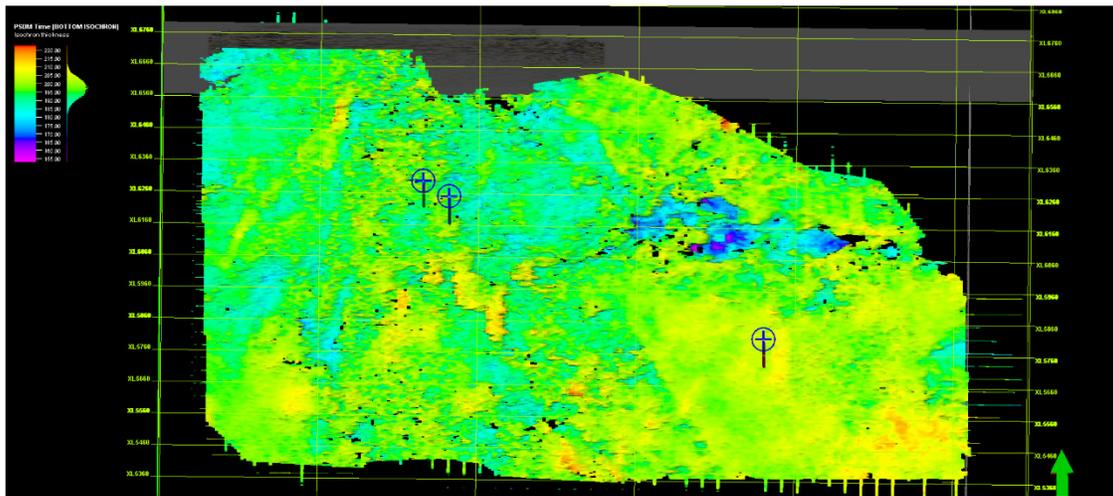
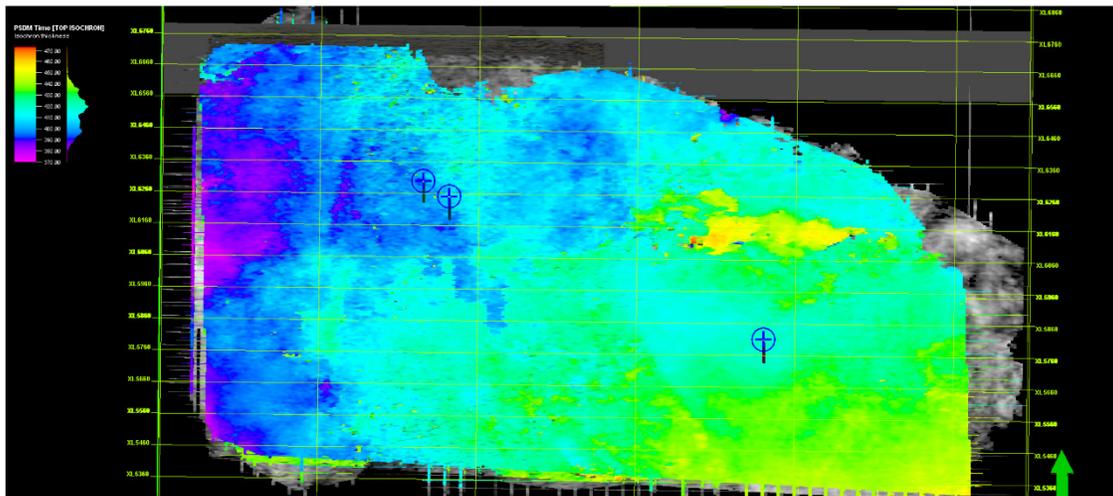
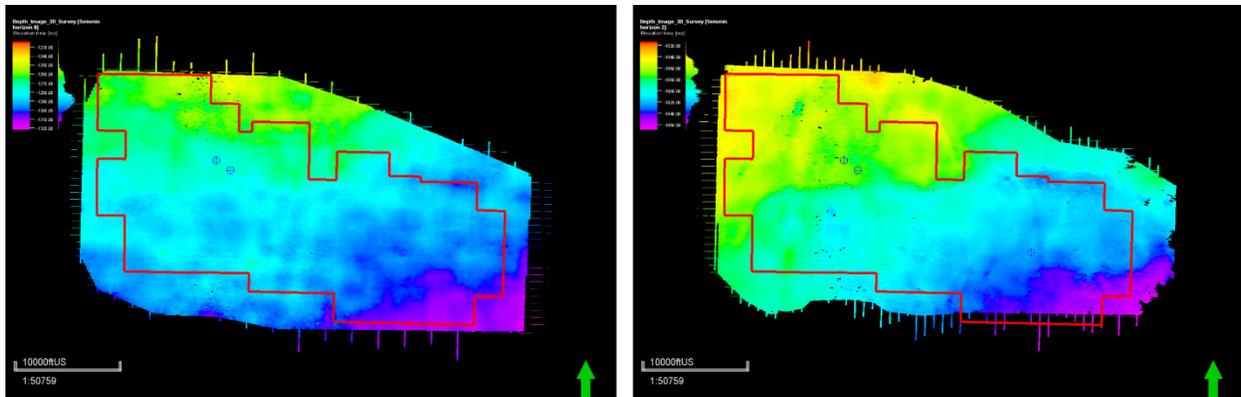


Figure 4.3-1 – a) depth (time) image of the Kansas City horizon (scale bar range – 1220-1320 milliseconds). b) depth (time) image of the Hunton base horizon (scale bar range – 1820-1960 milliseconds). c) Woodford base – Kansas City base isochron map (scale bar range – 470-370 milliseconds). d) Hunton base – Woodford base isochron map (scale bar range – 220-155 milliseconds).

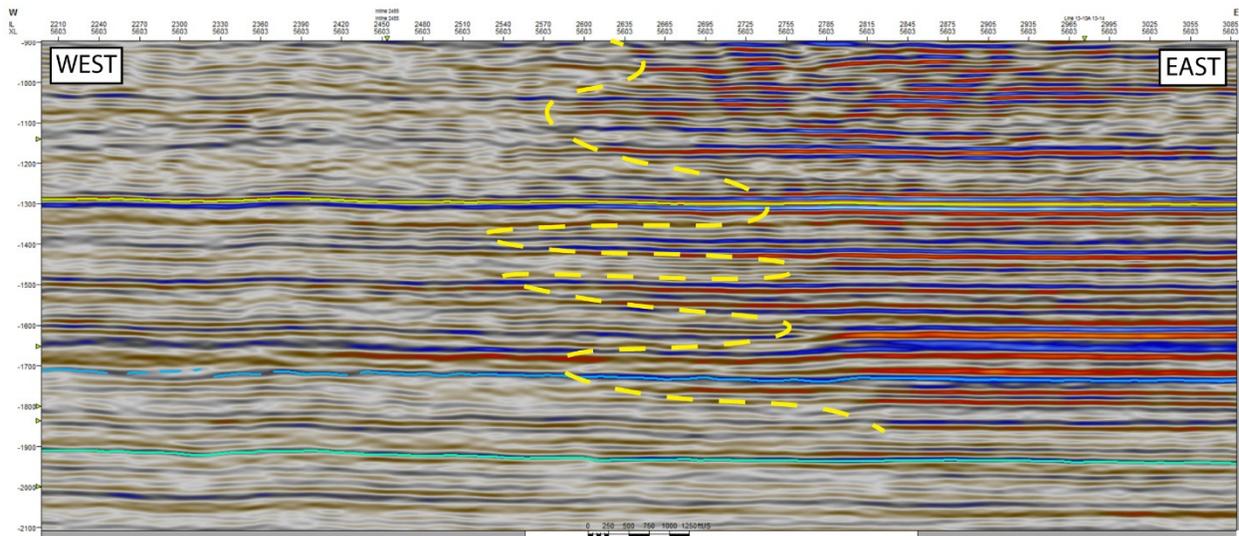
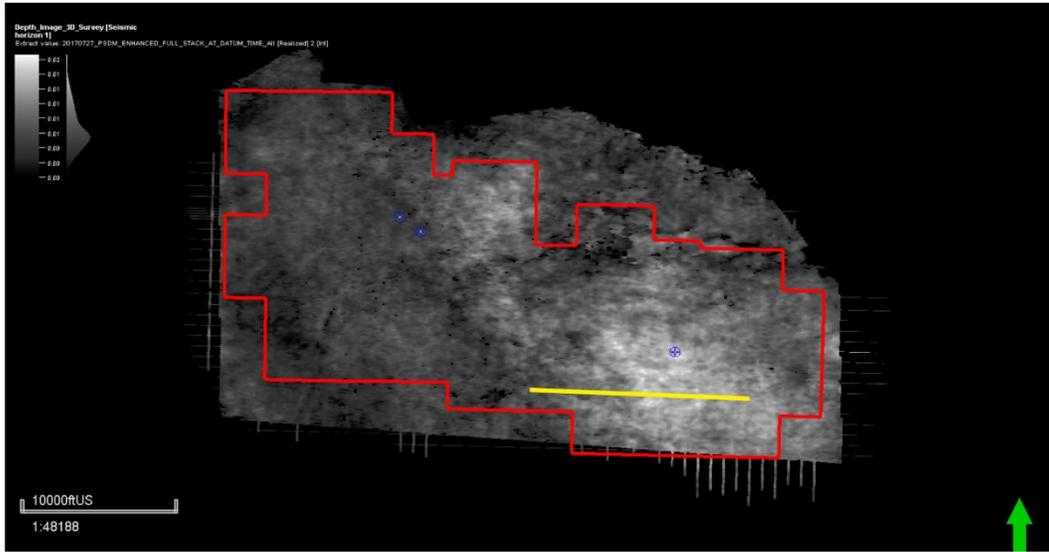


Figure 4.3-2 – a) amplitude intensity map of the base of the Woodford, yellow line shows location of the vertical seismic section. b) Lateral facies changes.

4.3.3 Fracture Analysis

Small aperture fractures were noted but not common in most of the reservoir cores we examined but most of these fractures appear to be drilling induced. Fractures in the Thirteen Finger limestone caprock were described using an industry-standard format for fracture class type, orientation, fracture dip, type of mineral fill, fracture porosity, fracture spacing, and intensity. Again, drilling induced fractures are most common. Natural mineral-filled fractures are quite rare, were formed during diagenesis at shallow depths, and are of Late Carboniferous age. Unless significantly damaged by large changes in reservoir pressure they are highly unlikely to provide migration pathways.

In the unlikely event CO₂ leakage occurs as a result of leakage through the faults and fractures it is unlikely that the leak would result in surface leakage. As with any CO₂ leakage, Perdure has strategies for leak detection in place that are discussed in Section 4.5 and the strategy to quantify the leak is discussed in Section 4.6.

4.4 Lateral Fluid Movement

Morrow strata in FWU was primarily a deltaic sequence that prograded toward the south east, resulting in deposition of mainly shales with lenticular, discontinuous coarse sandstones separated with very fine sandstone, minor conglomerates and shale. The likelihood of any extensive migration of fluid outside of the AMA is very low.

Since CO₂ is lighter than the water remaining in the reservoir it will migrate to the top of each lenticular structure as it is filled. The producing wells, which create low pressure points in the field, will drain the water and keep the CO₂ within each discontinuous sandstone.

4.5 Leakage Through Confining / Seal System

A variety of analytical methods were used for caprock (confining system) analysis. Petrologic examination included standard thin section petrography and backscattered electron microscopy. Petrophysical analytical methods include retort analysis, pulse-decay permeability measurement, pressure decay permeability analysis for tight rocks, and mercury injection porosimetry, which is also known as mercury injection capillary pressure (MICP). Geomechanical analysis involved a standard series of mechanical tests: Brazil tension, unconfined compression, triaxial compression, and multi-stress compression.

Results of the MICP analysis show that the mudstone lithologies in the Morrow Shale and Thirteen Finger Limestone can support CO₂ column heights of ~1,000 to 10,000 feet. At an order of magnitude over the thickness of the Morrow reservoir, this should prove an effective seal for CO₂ storage in the Morrow B injection horizon.

Failure analyses show that the Morrow B sands are weaker than overlying lithologies, so that any fracture initiation around the injection well would not be expected to propagate into the overlying sealing units. Mechanical properties of the overlying shale and limestones provide an interesting and effective combination of strength and elasticity. Limestone layers are strong but brittle, while the shale layers are weaker but sufficiently ductile to prevent extensive fracture propagation.

It is unlikely for hydrocarbon migration pathways that charged the Morrow reservoir to be potential CO₂ migration pathways via primary pore networks today. Any potential CO₂ migration would be most likely due to leakage from wellbores or bypass through fault and fracture networks, discussed in Sections 4.2 and 4.3.

In the unlikely event CO₂ leakage occurs as a result of leakage through the confining seal it is unlikely that the leak would result in surface leakage. As with any CO₂ leakage, Perdure has strategies for leak detection in place that are discussed in Section 4.5 and the strategy to quantify the leak is discussed in Section 4.6.

4.6 Natural and Induced Seismic Activity

Figure 4.6 shows the map of earthquakes with magnitudes measured at greater than 2.5 as defined by the United States Geological Survey (USGS). While past earthquake data cannot predict future earthquakes, the small number of events near FWU after the waterflood operations were initiated in 1969 implies the area is not seismically sensitive to injection. Also, no documentation exists that any of the distant earthquake events caused a disruption in injectivity or damage to any of the wellbores in FWU.

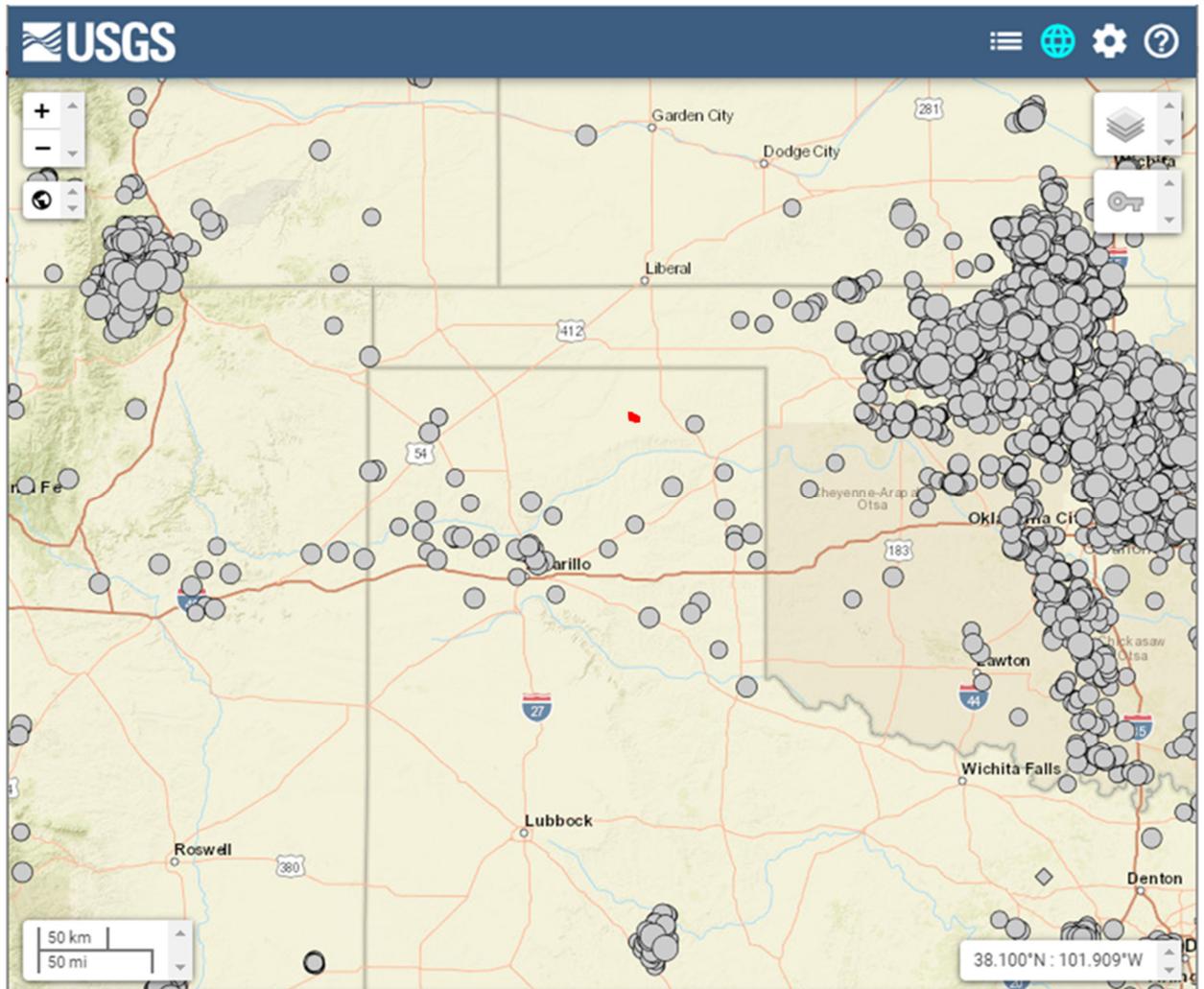


Figure 4.6: USGS earthquakes (>2.5 magnitude) for last 40 years with FWU highlighted red

There is no direct evidence that natural seismic activity poses a significant risk for loss of CO₂ to the surface in the FWU.

In the unlikely event that induced seismicity resulted in a pathway for material amounts of CO₂ to migrate from the injection zone, other reservoir fluid monitoring provisions (e.g., reservoir pressure, well pressure, and pattern monitoring) would lead to further investigation.

4.7 Strategy for Detection and Response of CO₂ Loss

As discussed above, the potential sources of leakage include fairly routine issues, such as problems with surface equipment (pumps, valves, etc.) or subsurface equipment (well bores), and unique events such as induced fractures. Table 1 summarizes some of these potential leakage scenarios, the monitoring activities designed to detect those leaks, Perdure’s standard response, and other applicable regulatory programs requiring similar reporting.

The potential CO₂ losses discussed in the table are identified by type. Once the type is reported to a response manager the correct resources and personnel can be mobilized to develop the optimal response procedure. The procedure will address and mitigate further CO₂ leakage.

Table 1 Response Plan for CO₂ Loss		
Known Potential Leakage Risks	Monitoring Methods and Frequency	Anticipated Response Plan
Tubing Leak	Monitor changes in annulus pressure; MIT for injectors	Workover crews respond within days
Casing Leak	Weekly field inspection; MIT for injectors; extra attention to high-risk wells	Workover crews respond within days
Wellhead Leak	Weekly field inspection	Workover crews respond within days
Loss of Bottom-hole pressure control	Blowout during well operations (weekly inspection but field personnel present daily)	Maintain well kill procedures
Unplanned wells drilled through Morrow	Weekly field inspection to prevent unapproved drilling; compliance with TRRC permitting for planned wells.	Assure compliance with TRRC regulations
Loss of seal in abandoned wells	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Re-enter and reseal abandoned wells
Pumps, valves, etc.	Weekly field inspection	Workover crews respond within days
Leakage along faults	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Shut in injectors near faults
Leakage laterally	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Fluid management along lease lines
Leakage through induced fractures	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Comply with rules for keeping pressures below parting pressure
Leakage due to seismic event	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Shut in injectors near seismic event

4.8 Strategy for Quantifying CO₂ Losses

Major CO₂ losses are typically event driven and require a process to assess, address, track, and if applicable quantify potential CO₂ leakage to the surface. Perdure will reconcile the Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.

Given the uncertainty concerning the nature and characteristics of leaks that will be encountered, it is not clear the method for quantifying the volume, or magnitude, of leaked CO₂ that would be most appropriate. In the event leakage occurs, Perdure will determine

the most appropriate method for quantifying the volume, or magnitude, leaked and will report the methodology used as required as part of the annual Subpart RR submission

Any volume, or magnitude, of CO₂ detected leaking to surface will be quantified using acceptable emission factors such as those found in 40 CFR Part 98 Subpart W or engineering estimates of leak amounts based on measurements in the subsurface, Perdure's field experience, and other factors such as the frequency of inspection. As indicated in Sections 6.4, leaks will be documented, and the records of leakage events will be retained in the electronic environmental documentation and reporting system. Repairs requiring a work order will be documented in the electronic equipment maintenance system.

Available studies of actual well leaks and natural analogs (e.g., naturally occurring CO₂ geysers) suggest that the amount released from routine leaks would be small as compared to the amount of CO₂ that would remain stored in the formation.

5 Strategy for Determining CO₂ Baselines for CO₂ Monitoring

Since conversion to a CO₂ EOR project in 2010, ongoing operational monitoring and several research projects at the FWU have provided data for establishing baselines of surface CO₂ leakage/emissions from the target injection zone for the CO₂, the Morrow B sandstone, and from surface equipment. The Site Characterization, Modeling, and Monitoring, Verification and Accounting (MVA) work conducted by the SWP provides the basis for established CO₂ baselines. Baseline groundwater monitoring conducted since 2013 indicates no leakage of CO₂ from underlying formations or wells into the local Ogallala aquifer. Soil flux monitoring also conducted since 2013 shows CO₂ flux ranging between 3 and 15 micromoles per second and square meter ($\mu\text{mol}/\text{m}^2/\text{sec}$) with variations generally attributed to seasonal changes and local crop growth patterns. Daily operational surface equipment inspection and periodic well surveillance monitoring are also conducted to ensure the integrity of infrastructure at the facility. Each of these is discussed in more detail below.

5.1 Site Characterization and Modeling

As described in Sections 2.2.2 and 2.4, the Morrow B sandstone is isolated both above and below by shale units of the Morrow. The primary seal consists of 180 – 200 ft of Morrow shale and Thirteen Finger Limestone which in turn is overlain by over a thousand feet of younger shale and limestone. These units provide a suitable seal to prevent the migration of CO₂ out of the injection reservoir. Additionally, no significant faults or fracture zones that cut across the seal units have been identified in the FWU, indicating that the most likely leakage pathway is from legacy wellbores that have been poorly completed/cemented.

Since 2013, several studies conducted by the SWP have evaluated the risk associated with leakage pathways through the seal units, including leakage of CO₂ to an overlying USDW or to the atmosphere through wellbores (Xiao et al, 2016, Xiao et al, 2017). The work of Ting et al (2017), in particular, looked at the potential geochemical impacts of CO₂-fluid interaction on typical cements used in regional wellbore completions, as well as the surrounding caprock. The diffusive flow of CO₂ and the mixing of brine fluids results in a reaction within the Portlandite wellbore cement, forming calcite. The calcite formation within the cement reduces the porosity of the cement, effectively sealing pathways. The calcium-silica-hydrate

in the Portlandite, conversely, is not significantly degraded by the CO₂-fluids, suggesting that the wellbore maintains its integrity and structure. These self-sealing attributes of the wellbore cements of the FWU wells suggest that CO₂ injected into the Morrow B is not at risk of leakage to overlying units, USDWs or the atmosphere.

5.2 Groundwater Monitoring Wells

Since 2013, the Southwest Regional Partnership on Carbon Sequestration (SWP) has been regularly sampling and analyzing fluids from Ogallala aquifer groundwater wells in around the FWU (Figure 5.2-1). The SWP performs major ion and trace metal analyses to evaluate leakage of CO₂, brine and/or hydrocarbons from the Morrow B and shallower zones, and/or wellbores. To date, no indication of fluid leakage has been identified from any of the 14 groundwater monitoring wells in the area. Perdure is unlikely to continue monitoring USDW wells for CO₂ or brine contamination, as SWP studies (see section 5.1) have suggested minimal risk of groundwater contamination from CO₂ leakage from depth.

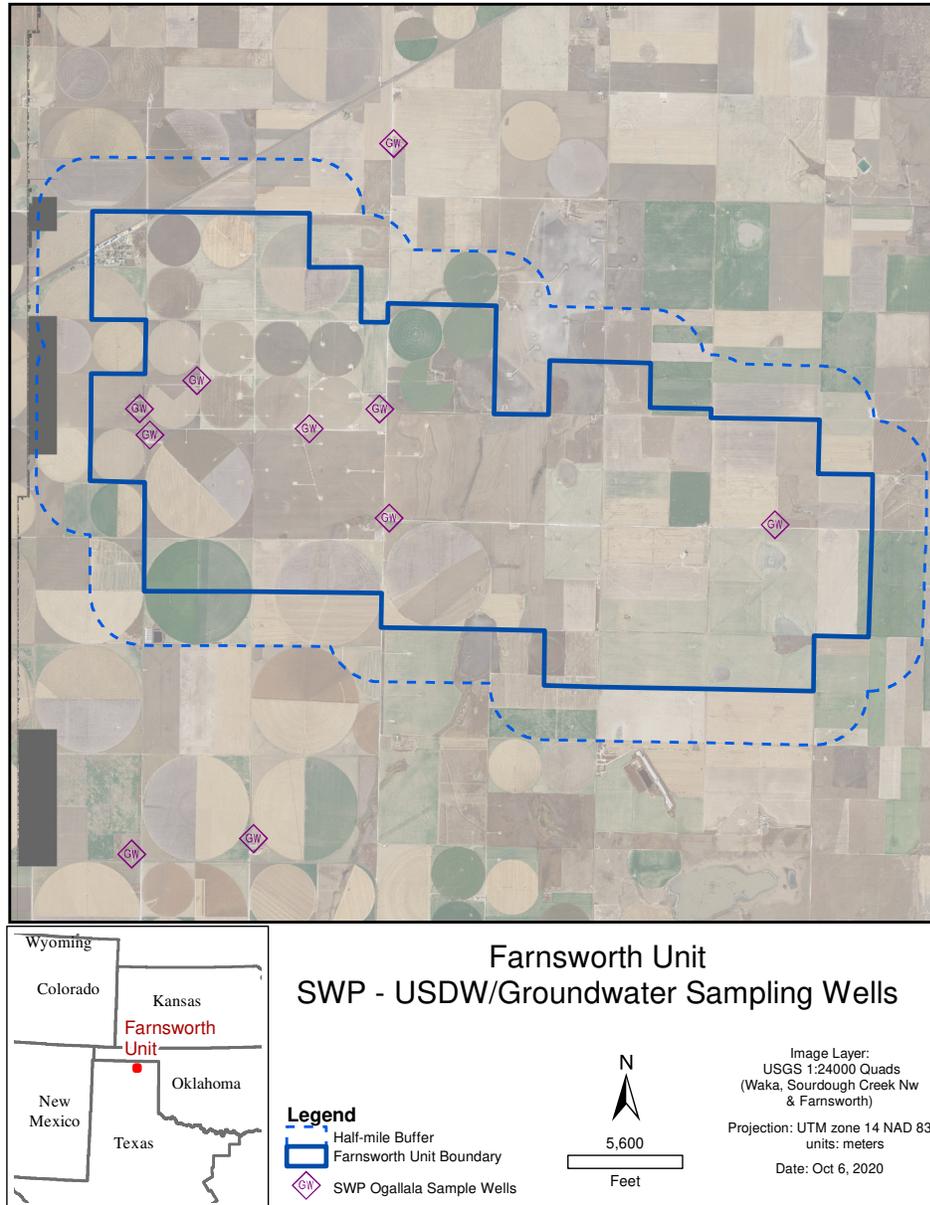


Figure 5.2-1: Ogallala groundwater monitoring wells

5.3 Soil CO₂ Monitoring

Since 2013, SWP has been conducting regular soil flux surveys within the western half of the FWU, to evaluate CO₂ leakage from the Morrow B. The SWP installed 94 PVC soil flux chamber collars around the 13-10A injection well (Figure 5.3-1); CO₂ soil flux was measured on a monthly basis, using a LiCor LI-8100 infrared gas analyzer, for a little over a year and then surveys were scaled back to once every 3 months. Soil flux values observed from the SWP surveys generally range between 3 and 15 μmol/m²/sec, with generally higher values in the summer due to plant respiration. To date, all CO₂ soil flux variations have been attributed to seasonal changes, and crop growth and rotation. The SWP soil flux collar

network has identified no CO₂ leakage at the FWU, from any sources since monitoring activities began.

The data collected from the SWP has estimated that the atmospheric (approximately 3-meter elevation above the ground surface) baseline CO₂ concentration in the FWU area to be 390±10 ppmv (Parts Per Million by Volume), with CO₂ concentrations on the lower end of this range during the summer months and on the higher end of this range during the winter months. Any significant and consistent variance from this baseline will be investigated to determine the source of the CO₂ and if the CO₂ is determined to be leakage from the FWU then appropriate steps will be taken to measure and report the volumes, mitigate any leaks, and make any adjustments to the MRV plan that are required.

Atmospheric CO₂ values at the FWU have been determined by a SWP eddy tower installation. In winter 2019, the eddy system malfunctioned and has not been repaired due to COVID travel restrictions. However, the atmospheric CO₂ concentration data from the FWU eddy tower are in very good agreement with values obtained from the NOAA Global Monitoring Laboratory station in Moody, Texas (Station: WKT). Atmospheric CO₂ concentrations from the Moody, Texas station can be used for background CO₂ values in the FWU area.

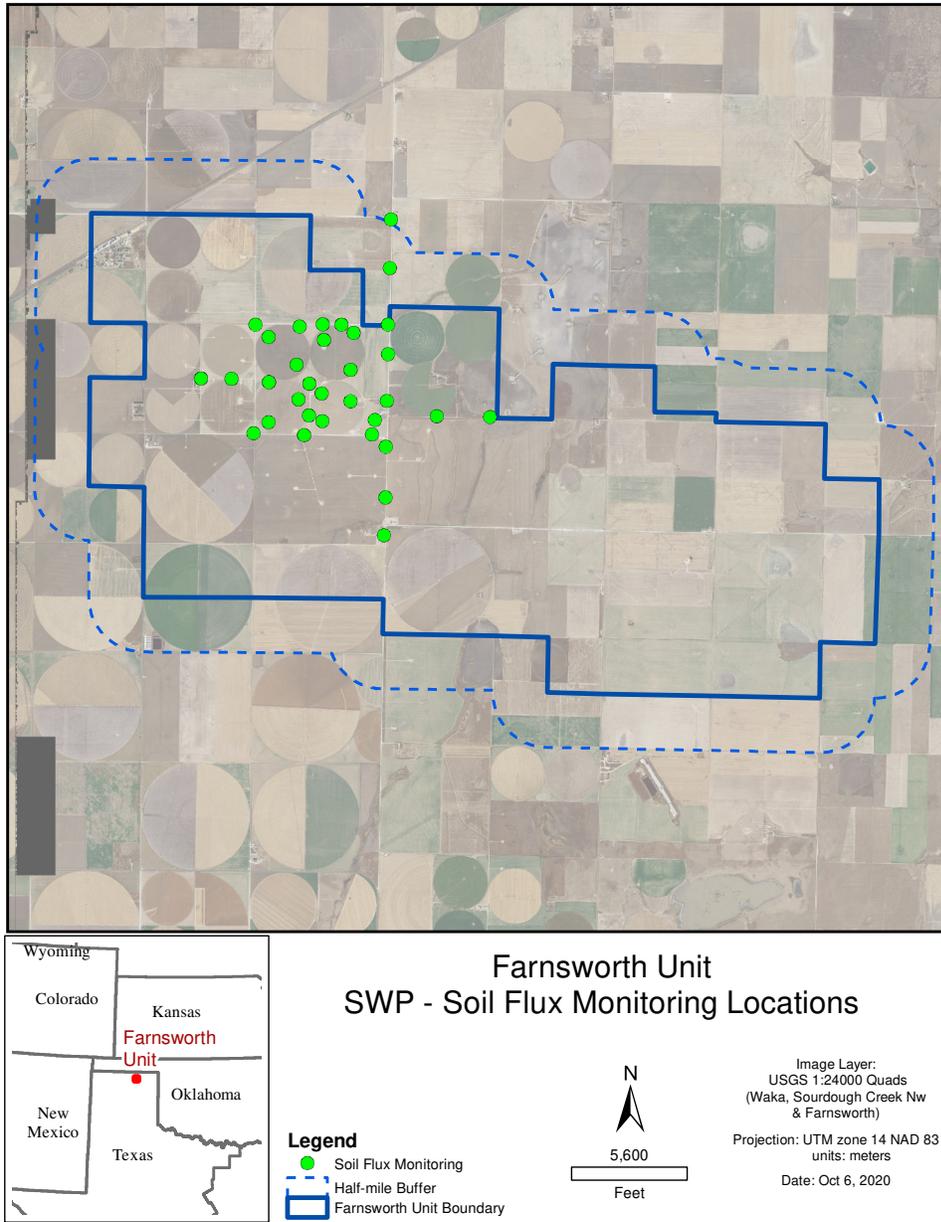


Figure 5.3 -1: Soil Flux

5.4 Visual Inspection

Perdure operational field personnel visually inspect surface equipment daily and report and act upon any event indicating leakage.

5.5 Well Surveillance

Perdure adheres to the requirements of Rule 46 for the TRRC governing fluid injection into productive reservoirs. Rule 46 includes requirements for monitoring, reporting, and testing of Class II injection wells. Furthermore, TRRC includes special conditions regarding monitoring, reporting, and testing in the individual permits for each injection well if they are deemed necessary.

Perdure also adheres to the requirements of Rule 20 for the TRRC governing the notification of a fires, breaks, leaks, or escapes. Rule 20 requires that all operators report leaks to TRRC including measured or estimated quantities of product leaked.

6 Site Specific Considerations for Determining the Mass of CO₂ Sequestered

Of the twelve RR equations in 98.443 of Subpart RR, the following are relevant to Perdure's operations.

6.1 Determining Mass of CO₂ Received

Perdure currently receives CO₂ to its FWU facility through their own pipeline from the Arkalon Ethanol plant in Liberal, Kansas. Perdure also recycles CO₂ from their production wells in the FWU.

$$CO_{2T,r} = \sum_{r=1}^4 (r, - S_r) * D * C_{CO_2,p,r} \quad (\text{Equation RR-2})$$

where:

$CO_{2T,r}$ = Net annual mass of CO₂ received through flow meter r (metric tons).

$r,$ = Quarterly volumetric flow through a receiving flow meter r in quarter p at standard conditions (standard cubic meters).

$S_r,$ = Quarterly volumetric flow through a receiving flow meter r that is redelivered to another facility without being injected into your well in quarter p (standard cubic meters).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

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

p = Quarter of the year.

r = Receiving flow meter.

6.2 Determining Mass of CO₂ Injected

Perdure injects CO₂ into the injection wells listed in Appendix 1.

$$CO_{2,u} = \sum_{u=1}^4 ,u * D * C_{CO_2,p,u} \quad (\text{Equation RR-5})$$

where:

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

$Q_{p,u}$ = Quarterly volumetric flow rate measurement for flow meter u in quarter p at standard conditions (standard cubic meters per quarter).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

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

p = Quarter of the year.

u = Flow meter.

6.3 Determining Mass of CO₂ Produced from Oil Production Wells

Perdure also recycles CO₂ from its production wells which are part of its operations in the FWU. Therefore, the following equation is relevant to its operations.

$$CO_{2,w} = \sum_{p=1}^4 Q_{p,w} * D * C_{CO_2,p,w} \quad \text{(Equation RR-8)}$$

Where:

$CO_{2,w}$ = Annual CO₂ mass produced (metric tons) through separator w.

$Q_{p,w}$ = Volumetric gas flow rate measurement for separator w in quarter p at standard conditions (standard cubic meters).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

$C_{CO_2,p,w}$ = CO₂ concentration measurement in flow for separator w in quarter p (vol. percent CO₂, expressed as a decimal fraction).

p = Quarter of the year.

w = Separator.

To aggregate production data, Perdure will sum the mass of all of the CO₂ separated at each gas-liquid separator in accordance with the procedure specified in Equation RR-9 below:

$$CO_{2P} = (1 + X) * \sum_{w=1}^W CO_{2,w} \quad \text{(Equation RR-9)}$$

Where:

CO_{2P} = Total annual CO₂ mass produced (metric tons) through all separators in the reporting year.

$CO_{2,w}$ = Annual CO₂ mass produced (metric tons) through separator w in the reporting year.

X = Entrained CO₂ in produced oil or other fluid divided by the CO₂ separated through all separators in the reporting year (weight percent CO₂, expressed as a decimal fraction).

w = Separator.

6.4 Determining Mass of CO₂ Emitted by Surface Leakage

As required by 98.448 (d) of Subpart RR, Perdure will assess leakage from the relevant surface equipment listed in Sections 98.233 and 98.234 of Subpart W. According to 98.233 (r) (2) of Subpart W, the emissions factor listed in Table W-1A of Subpart W shall be used to estimate all streams of gases, including recycle CO₂ stream, for facilities that conduct EOR operations.

Perdure will calculate the total annual mass of CO₂ emitted from all leakage pathways in accordance with the procedure specified in Equation RR-10 below:

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

where:

CO_{2E} = Total annual CO₂ mass emitted by surface leakage (metric tons) in the reporting year.

$CO_{2,x}$ = Annual CO₂ mass emitted (metric tons) at leakage pathway x in the reporting year.

x = Leakage pathway.

6.5 Determining Mass of CO₂ Sequestered

The following Equation RR-11 pertains to facilities that are actively producing oil or natural gas.

$$CO_2 = CO_{2I} - CO_{2P} - CO_{2E} - CO_{2FI} - CO_{2FP} \quad \text{(Equation RR-11)}$$

Where:

CO_2 = Total annual CO₂ mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

CO_{2I} = Total annual CO₂ mass injected (metric tons) in the well or group of wells in the reporting year.

CO_{2P} = Total annual CO₂ mass produced (metric tons) in the reporting year.

CO_{2E} = Total annual CO₂ mass emitted (metric tons) by surface leakage in the reporting year.

CO_{2FI} = Total annual CO₂ mass emitted (metric tons) from equipment leaks and vented emissions of CO₂ 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 of the GHGRP.

CO_{2FP} = Total annual CO₂ mass emitted (metric tons) from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity, for which a calculation procedure is provided in subpart W of the GHGRP.

The following Equation RR-12 pertains to facilities that are not actively producing oil or natural gas. This equation may become relevant to Perdure's operation as it evolves in the future. However, this does not apply to Perdure's current operations.

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

CO_2 = Total annual CO₂ mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

CO_{2I} = Total annual CO₂ mass injected (metric tons) in the well or group of wells in the reporting year.

CO_{2E} = Total annual CO₂ mass emitted (metric tons) by surface leakage in the reporting year.

CO_{2FI} = Total annual CO₂ mass emitted (metric tons) from equipment leaks and vented emissions of CO₂ 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 of the GHGRP.

7 Estimated Schedule for implementation of MRV plan

Perdure expects to begin implementing the approved MRV plan when the new CO₂ capture facility is operational, January 1, 2022.

8 GHG Monitoring and Quality Assurance Program

Perdure will meet the monitoring and QA/QC requirements of 98.444 of Subpart RR including those of Subpart W for emissions from surface equipment as required by 98.444 (d).

8.1 GHG Monitoring

As required by 40 CFR 98.3(g)(5)(i), Perdure's 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 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.

8.1.1 General

Measurement of CO₂ Concentration – All measurements of CO₂ concentrations of any CO₂ quantity will be conducted according to an appropriate standard method published by a consensus-based standards organization or an industry standard practice such as the Gas Producers Association (GSA) standards.

Measurement of CO₂ Volume – All measurements of CO₂ volumes will be converted to the following standard industry temperature and pressure conditions for use in Equations RR-2, RR-5 and RR-8 of Subpart RR of the GHGRP: Standard cubic meters at a temperature of 60 degrees Fahrenheit and at an absolute pressure of 1 atmosphere. Perdure will adhere to the American Gas Association (AGA) Report #3 – (ORIFICE METERING OF NATURAL GAS AND OTHER RELATED HYDROCARBON FLUIDS)

8.1.2 CO₂ received.

Daily totalized volumetric flow meters are used to record CO₂ received via pipeline from the Arkalon ethanol plant in Liberal, Kansas. using a volumetric totalizer using accepted flow calculations for CO₂ according to the AGA Report #3.

8.1.3 CO₂ injected.

Daily CO₂ injection is recorded by combining the totals for the recycle compressor meter and the received CO₂ meter from Arkalon based on what's delivered on a 24-hour basis. This data is taken from the meter daily and stored in Perdure's data warehouse for records and reservoir management.

8.1.4 CO₂ produced.

The point of produced gas measurement is from a meter downstream of the compressors prior to being combined with purchase CO₂. The produced gas is sampled at least quarterly for the CO₂ content.

8.1.5 CO₂ emissions from equipment leaks and vented emissions of CO₂.

As required by 98.444 (d), Perdure will follow the monitoring and QA/QC requirements specified in Subpart W of the GHGRP for equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead and between the flow meter used to measure production quantity and the production wellhead.

As required by 98.448 (d) of Subpart RR, Perdure will assess leakage from the relevant surface equipment listed in Sections 98.233 and 98.234 of Subpart W. According to 98.233 (r) (2) of Subpart W, the emissions factor listed in Table W-1A of Subpart W shall be used to estimate all streams of gases, including recycle CO₂ stream, for facilities that conduct EOR operations. The default emission factors for production equipment are applied to the carbon capture utilization and storage (CCUS) injection operations reporting under Subpart RR.

8.1.6 Measurement devices.

As required by 40 CFR 98.444(e), Perdure 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) of 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, the American National Standards Institute (ANSI), the American Gas Association (AGA), the Gas Producers Association (GPA), the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API), and the North American Energy Standards Board (NAESB).
- All flow meters are National Institute of Standards and Technology (NIST) traceable.

8.2 QA/QC Procedures

Perdure will adhere to all QA/QC requirements in Subparts A, RR, and W of the GHGRP, 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.

8.3 Estimating Missing Data

Perdure will estimate any missing data according to the following procedures in 40 CFR 98.445 of Subpart RR of the GHGRP, as required.

- A quarterly flow rate of CO₂ received that is missing would be estimated using invoices or using a representative flow rate value from the nearest previous time period.
- A quarterly CO₂ concentration of a CO₂ stream received that is missing would be estimated using invoices or using a representative concentration value from the nearest previous time period.
- A quarterly quantity of CO₂ injected that is missing would be estimated using a representative quantity of CO₂ injected from the nearest previous period of time at a similar injection pressure.
- For any values associated with CO₂ emissions from equipment leaks and vented emissions of CO₂ from surface equipment at the facility that are reported in this subpart, missing data estimation procedures specified in subpart W of 40 CFR Part 98 would be followed.
- The quarterly quantity of CO₂ produced from subsurface geologic formations that is missing would be estimated using a representative quantity of CO₂ produced from the nearest previous period of time.

8.4 Revisions of the MRV Plan

Perdure will revise the MRV Plan as needed to reflect changes in production processes, monitoring instrumentation, and quality assurance procedures; or to improve procedures for the maintenance and repair of monitoring systems to reduce the frequency of monitoring equipment downtime.

9 Records Retention

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

- (1) A list of all units, operations, processes, and activities for which GHG emissions were calculated.
- (2) The data used to calculate the GHG emissions for each unit, operation, process, and activity. These data include:
 - (i) The GHG emissions calculations and methods used.
 - (ii) Analytical results for the development of site-specific emissions factors, if applicable.
 - (iii) The results of all required analyses.
 - (iv) Any facility operating data or process information used for the GHG emission calculations.
- (3) The annual GHG reports.
- (4) Missing data computations. For each missing data event, Perdure will retain a record of the cause of the event and the corrective actions taken to restore malfunctioning monitoring equipment.
- (5) A copy of the most recent revision of this MRV Plan.
- (6) 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.
- (7) Maintenance records for all continuous monitoring systems, flow meters, and other instrumentation used to provide data for the GHGs reported.
- (8) Quarterly records of CO₂ received, including mass flow rate of contents of container (mass or volumetric) at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- (9) Quarterly records of produced CO₂, including mass flow or volumetric flow at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- (10) Quarterly records of injected CO₂ including mass flow or volumetric flow at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.

(11) Annual records of information used to calculate the CO₂ emitted by surface leakage from leakage pathways.

(12) Annual records of information used to calculate the CO₂ emitted from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead.

(13) Annual records of information used to calculate the CO₂ emitted from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity.

(14) Any other records as specified for retention in this EPA-approved MRV plan.

10 Appendices

Appendix 1 - Perdure Wells

Table A1. 1 – Production wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#15-1	42357000600000	Oil Prod	Active	CO2	1	0
#8-2	42357004140000	Oil Prod	Active	CO2	1	0
#13-6	42357007960000	Oil Prod	Active	CO2	1	0
#9-1	42357009390000	Oil Prod	Active	CO2	1	0
#20-8	42357020580000	Oil Prod	Active	CO2	1	0
#7-1	42357020620000	Oil Prod	Active	CO2	1	0
#6-2	42357020630000	Oil Prod	Active	CO2	1	0
#8-1	42357020650000	Oil Prod	Active	CO2	1	0
#9-4	42357022130000	Oil Prod	Active	CO2	1	0
#23-10	42357300490000	Oil Prod	Active	CO2	1	0
#18-2	42357319870000	Oil Prod	Active	CO2	1	0
#8-6	42357330090000	Oil Prod	Active	CO2	1	0
#13-12	42357330130000	Oil Prod	Active	CO2	1	0
#9-9	42357330610000	Oil Prod	Active	CO2	1	0
#16-6	42357329830000	Oil Prod	Active	CO2	1	0
#15-8	42357330630000	Oil Prod	Active	CO2	1	0
#11-2	42357330000000	Oil Prod	Active	CO2	1	0
#13-14	42357331890000	Oil Prod	Active	CO2	1	0
#13-15	42357333730000	Oil Prod	Active	CO2	1	0
#13-16	42357331930000	Oil Prod	Active	CO2	1	0

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#13-17	42357333990000	Oil Prod	Active	CO2	1	0
#13 -19	42357333740000	Oil Prod	Active	CO2	1	0
#16-2	42357000770002	Oil Prod	Active	CO2	1	0
#20-2	42357811240000	Oil Prod	Active	CO2	1	0
#5-1	42357810720000	Oil Prod	Active	CO2	1	0
#5-3	42357810740001	Oil Prod	Active	CO2	1	0
#5-6	42357334110000	Oil Prod	Active	CO2	1	0
#6-1	42357020640001	Oil Prod	Active	CO2	1	0
#7-2	42357810800000	Oil Prod	Active	CO2	1	0
#8-7	42357334050000	Oil Prod	Active	CO2	1	0
#8-8	42357334130000	Oil Prod	Active	CO2	1	0
#9-7	42357810910000	Oil Prod	Active	CO2	1	0
#30-1	42357002490000	Oil Prod	Inactive	CO2	0	0
#30-2	42357002510000	Oil Prod	Inactive	CO2	0	0
#20-1	42357004700000	Oil Prod	Inactive	CO2	0	0
#40-4	42357005140000	Oil Prod	Inactive	CO2	0	0
#23-2	42357007760000	Oil Prod	Inactive	CO2	0	0
#19-2	42357806010000	Oil Prod	Inactive	CO2	0	0
#41-1	42357009990000	Oil Prod	Inactive	CO2	0	0
#20-32	42357020390000	Oil Prod	Inactive	CO2	0	0
#23-6	42357811400000	Oil Prod	Inactive	CO2	0	0
#21-3	42357020670000	Oil Prod	Inactive	CO2	0	0
#41-2	42357021920000	Oil Prod	Inactive	CO2	0	0
#32-3	42357022060000	Oil Prod	Inactive	CO2	0	0
#36-2	42357023350000	Oil Prod	Inactive	CO2	0	0
#31-1	42357023370000	Oil Prod	Inactive	CO2	0	0
#32-1	42357023450000	Oil Prod	Inactive	CO2	0	0
#23-5	42357023680000	Oil Prod	Inactive	CO2	0	0
#25-2A	42357300990000	Oil Prod	Inactive	CO2	0	0
#23-11	42357313550000	Oil Prod	Inactive	CO2	0	0
#32-6	42357319890000	Oil Prod	Inactive	CO2	0	0
#40-1	42357811720000	Oil Prod	Inactive	CO2	0	0
#25-1	42357811450000	Oil Prod	Inactive	CO2	0	0
#26-1	42357811480000	Oil Prod	Inactive	CO2	0	0
#32-8	42357334100000	Oil Prod	Inactive	CO2	0	0
#39-1	42357811710000	Oil Prod	Inactive	CO2	0	0
#43-2	42357008020000	Oil Prod	Inactive	CO2	0	0
J ORTHA E 1	42357005100002	Oil Prod	Inactive	CO2	0	0
#42-1	42357000040000	Oil Prod	P&A	CO2	0	0
#4-1	42357001560000	Oil Prod	P&A	CO2	0	0
#16-4	42357004760000	Oil Prod	P&A	CO2	0	0

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#23-8	42357007790000	Oil Prod	P&A	CO2	0	0
#3-1	42357009340000	Oil Prod	P&A	CO2	0	0
#9-3	42357009400000	Oil Prod	P&A	CO2	0	0
#17-1	42357003410000	Oil Prod	P&A	CO2	0	0
#19-4	42357806030000	Oil Prod	P&A	CO2	0	0
#15-4	42357023340000	Oil Prod	P&A	CO2	0	0
#31-2	42357023360000	Oil Prod	P&A	CO2	0	0
#40-2	42357023480000	Oil Prod	P&A	CO2	0	0
#13-8	42357023490000	Oil Prod	P&A	CO2	0	0
#13-2	42357023500000	Oil Prod	P&A	CO2	0	0
#13-4	42357023510000	Oil Prod	P&A	CO2	0	0
#13-7	42357023520000	Oil Prod	P&A	CO2	0	0
#9-2	42357023530000	Oil Prod	P&A	CO2	0	0
#17-1	42357003410000	Oil Prod	P&A	CO2	0	0
#19-4	42357806030000	Oil Prod	P&A	CO2	0	0
#15-4	42357023340000	Oil Prod	P&A	CO2	0	0
#31-2	42357023360000	Oil Prod	P&A	CO2	0	0
#40-2	42357023480000	Oil Prod	P&A	CO2	0	0
#13-8	42357023490000	Oil Prod	P&A	CO2	0	0
#13-2	42357023500000	Oil Prod	P&A	CO2	0	0
#13-4	42357023510000	Oil Prod	P&A	CO2	0	0
#13-7	42357023520000	Oil Prod	P&A	CO2	0	0
#37-1	42357811680000	Oil Prod	P&A	CO2	0	0
BOESE 1	42357003010000	Oil Prod	P&A	CO2	0	0

Table A1.2 – Water Alternating Gas (WAG) Injection Wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#13-1 (INJ)	42357007950000	WAG Inj	Active	CO2	0	1
#13-3 (INJ)	42357007940000	WAG Inj	Active	CO2	0	1
#13-5 (INJ)	42357007990000	WAG Inj	Active	CO2	0	1
#13-9 (INJ)	42357811020000	WAG Inj	Active	CO2	0	1
#13-10A (INJ)	42357331790000	WAG Inj	Active	CO2	0	1
#13-13 (INJ)	42357333320000	WAG Inj	Active	CO2	0	1
#14-1 (INJ)	42357020410000	WAG Inj	Active	CO2	0	1
#15-2 (INJ)	42357811100000	WAG Inj	Active	CO2	0	1
#15-5 (INJ)	42357020300000	WAG Inj	Active	CO2	0	1
#15-6 (INJ)	42357301210000	WAG Inj	Active	CO2	0	1
#16-3 (INJ)	42357004720000	WAG Inj	Active	CO2	0	1
#5-2 (INJ)	42357023310000	WAG Inj	Active	CO2	0	1

#8-3 (INJ)	42357810840000	WAG Inj	Active	CO2	0	1
#8-4 (INJ)	42357003990000	WAG Inj	Active	CO2	0	1
#8-5 (INJ)	42357301160000	WAG Inj	Active	CO2	0	1
#9-10 (INJ)	42357330770000	WAG Inj	Active	CO2	0	1
#9-8 (INJ)	42357301860000	WAG Inj	Active	CO2	0	1
#11-1 (INJ)	42357020350000	WAG Inj	Inactive	CO2	0	0
#13-10 (INJ)	42357301030000	Monitor	Inactive	None	0	0

Table A1.3 – Water Source Wells (WSW)

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#1 (WSW)	42357810690000	WSW	Active	CO2	0	0
#2 (WSW)	42357810700000	WSW	Active	CO2	1	0

Table A1.4 – Water Injection Wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#23-9 (INJ)	42357020380000	Wtr Inj	Inactive	CO2	0	0
#30-3 (INJ)	42357020470000	Wtr Inj	Inactive	CO2	0	0
#32-2 (INJ)	42357811590000	Wtr Inj	Inactive	CO2	0	0
#32-4 (INJ)	42357811610000	Wtr Inj	Inactive	CO2	0	0
#32-5 (INJ)	42357317680001	Wtr Inj	Inactive	CO2	0	0
#34-1 (INJ)	42357020500000	Wtr Inj	Inactive	CO2	0	0
#40-3 (INJ)	42357811740000	Wtr Inj	Inactive	CO2	0	0
#42-2 (INJ)	42357811820000	Wtr Inj	Inactive	CO2	0	0
#42-3 (INJ)	42357020330001	Wtr Inj	Inactive	CO2	0	0
#6-3 (INJ)	42357303410000	Wtr Inj	Inactive	CO2	0	0
#7-3 (INJ)	42357302540000	Wtr Inj	Inactive	CO2	0	0
#9-6 (INJ)	42357020340000	Wtr Inj	Inactive	CO2	0	0
#10-1 (INJ)	42357009380000	Wtr Inj	Inactive	CO2	0	0
#14-2 (INJ)	42357002670001	Wtr Inj	Inactive	CO2	0	0
#16-5 (INJ)	42357020370000	Wtr Inj	P&A	CO2	0	0
#19-3 (INJ)	42357806020000	Wtr Inj	P&A	CO2	0	0
#20-5 (INJ)	42357252290000	Wtr Inj	P&A	CO2	0	0
#20-6 (INJ)	42357020360000	Wtr Inj	P&A	CO2	0	0
#20-7 (INJ)	42357020450000	Wtr Inj	P&A	CO2	0	0
#21-1 (INJ)	42357020310000	Wtr Inj	P&A	CO2	0	0
#21-2 (INJ)	42357020270000	Wtr Inj	P&A	CO2	0	0
#21-4 (INJ)	42357020280000	Wtr Inj	P&A	CO2	0	0
#25-3 (INJ)	42357020460000	Wtr Inj	P&A	CO2	0	0
#26-2 (INJ)	42357020420000	Wtr Inj	P&A	CO2	0	0
#31-3 (INJ)	42357020480000	Wtr Inj	P&A	CO2	0	0
#33-1 (INJ)	42357000290000	Wtr Inj	P&A	CO2	0	0
#33-3 (INJ)	42357021340000	Wtr Inj	P&A	CO2	0	0
#34-2 (INJ)	42357008730000	Wtr Inj	P&A	CO2	0	0
#36-1 (INJ)	42357020490000	Wtr Inj	P&A	CO2	0	0
#37-2 (INJ)	42357811690000	Wtr Inj	P&A	CO2	0	0
#40-7 (INJ)	42357811780000	Wtr Inj	P&A	CO2	0	0
#42-4 (INJ)	42357010010000	Wtr Inj	P&A	CO2	0	0
#14-3 (INJ)	42357020660000	Wtr Inj	P&A	CO2	0	0
#15-3 (INJ)	42357006060000	Wtr Inj	P&A	CO2	0	0
#16-1 (INJ)	42357020400000	Wtr Inj	P&A	CO2	0	0
#23-7 (INJ)	42357020430000	Wtr Inj	P&A	CO2	0	0
#40-9 (INJ)	42357020570000	Wtr Inj	P&A	CO2	0	0

Appendix 2 - Referenced Regulations

U.S. Code > Title 26. INTERNAL REVENUE CODE > Subtitle A. Income Taxes > Chapter 1. NORMAL TAXES AND SURTAXES > Subchapter A. Determination of Tax Liability > Part IV. CREDITS AGAINST TAX > Subpart D. Business Related Credits > [Section 45Q - Credit for carbon oxide sequestration](#)

Texas Administrative Code (TAC) > Title 16 - Economic Regulation > Part 1 – Railroad Commission of Texas > [Chapter 3 – Oil and Gas Division](#)

Rules

- §3.1 Organization Report; Retention of Records; Notice Requirements
- §3.2 Commission Access to Properties
- §3.3 Identification of Properties, Wells, and Tanks
- §3.4 Oil and Geothermal Lease Numbers and Gas Well ID Numbers Required on All Forms
- §3.5 Application to Drill, Deepen, Reenter, or Plug Back
- §3.6 Application for Multiple Completion
- §3.7 Strata to Be Sealed Off
- §3.8 Water Protection
- §3.9 Disposal Wells
- §3.10 Restriction of Production of Oil and Gas from Different Strata
- §3.11 Inclination and Directional Surveys Required
- §3.12 Directional Survey Company Report
- §3.13 Casing, Cementing, Drilling, Well Control, and Completion Requirements
- §3.14 Plugging
- §3.15 Surface Equipment Removal Requirements and Inactive Wells
- §3.16 Log and Completion or Plugging Report
- §3.17 Pressure on Bradenhead
- §3.18 Mud Circulation Required
- §3.19 Density of Mud-Fluid
- §3.20 Notification of Fire Breaks, Leaks, or Blow-outs
- §3.21 Fire Prevention and Swabbing
- §3.22 Protection of Birds
- §3.23 Vacuum Pumps
- §3.24 Check Valves Required
- §3.25 Use of Common Storage
- §3.26 Separating Devices, Tanks, and Surface Commingling of Oil
- §3.27 Gas to be Measured and Surface Commingling of Gas
- §3.28 Potential and Deliverability of Gas Wells to be Ascertained and Reported
- §3.29 Hydraulic Fracturing Chemical Disclosure Requirements
- §3.30 Memorandum of Understanding between the Railroad Commission of Texas (RRC) and the Texas Commission on Environmental Quality (TCEQ)
- §3.31 Gas Reservoirs and Gas Well Allowable
- §3.32 Gas Well Gas and Casinghead Gas Shall Be Utilized for Legal Purposes

§3.33	Geothermal Resource Production Test Forms Required
§3.34	Gas To Be Produced and Purchased Ratably
§3.35	Procedures for Identification and Control of Wellbores in Which Certain Logging Tools Have Been Abandoned
§3.36	Oil, Gas, or Geothermal Resource Operation in Hydrogen Sulfide Areas
§3.37	Statewide Spacing Rule
§3.38	Well Densities
§3.39	Proration and Drilling Units: Contiguity of Acreage and Exception Thereto
§3.40	Assignment of Acreage to Pooled Development and Proration Units
§3.41	Application for New Oil or Gas Field Designation and/or Allowable
§3.42	Oil Discovery Allowable
§3.43	Application for Temporary Field Rules
§3.45	Oil Allowables
§3.46	Fluid Injection into Productive Reservoirs
§3.47	Allowable Transfers for Saltwater Injection Wells
§3.48	Capacity Oil Allowables for Secondary or Tertiary Recovery Projects
§3.49	Gas-Oil Ratio
§3.50	Enhanced Oil Recovery Projects--Approval and Certification for Tax Incentive
§3.51	Oil Potential Test Forms Required
§3.52	Oil Well Allowable Production
§3.53	Annual Well Tests and Well Status Reports Required
§3.54	Gas Reports Required
§3.55	Reports on Gas Wells Commingling Liquid Hydrocarbons before Metering
§3.56	Scrubber Oil and Skim Hydrocarbons
§3.57	Reclaiming Tank Bottoms, Other Hydrocarbon Wastes, and Other Waste Materials
§3.58	Certificate of Compliance and Transportation Authority; Operator Reports
§3.59	Oil and Gas Transporter's Reports
§3.60	Refinery Reports
§3.61	Refinery and Gasoline Plants
§3.62	Cycling Plant Control and Reports
§3.63	Carbon Black Plant Permits Required
§3.70	Pipeline Permits Required
§3.71	Pipeline Tariffs
§3.72	Obtaining Pipeline Connections
§3.73	Pipeline Connection; Cancellation of Certificate of Compliance; Severance
§3.76	Commission Approval of Plats for Mineral Development
§3.78	Fees and Financial Security Requirements
§3.79	Definitions
§3.80	Commission Oil and Gas Forms, Applications, and Filing Requirements
§3.81	Brine Mining Injection Wells
§3.83	Tax Exemption for Two-Year Inactive Wells and Three-Year Inactive Wells

- §3.84 Gas Shortage Emergency Response
- §3.85 Manifest to Accompany Each Transport of Liquid Hydrocarbons by Vehicle
- §3.86 Horizontal Drainhole Wells
- §3.91 Cleanup of Soil Contaminated by a Crude Oil Spill
- §3.93 Water Quality Certification Definitions
- §3.95 Underground Storage of Liquid or Liquefied Hydrocarbons in Salt Formations
- §3.96 Underground Storage of Gas in Productive or Depleted Reservoirs
- §3.97 Underground Storage of Gas in Salt Formations
- §3.98 Standards for Management of Hazardous Oil and Gas Waste
- §3.99 Cathodic Protection Wells
- §3.100 Seismic Holes and Core Holes
- §3.101 Certification for Severance Tax Exemption or Reduction for Gas Produced From High-Cost Gas Wells
- §3.102 Tax Reduction for Incremental Production
- §3.103 Certification for Severance Tax Exemption for Casinghead Gas Previously Vented or Flared
- §3.106 Sour Gas Pipeline Facility Construction Permit
- §3.107 Penalty Guidelines for Oil and Gas Violations

Appendix 3 - References

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Appendix 4 - Abbreviations and Acronyms

2D – 2 dimensional
3D – 3 dimensional
AGA – American Gas Association
AMA – Active Monitoring Area
ANSI – American National Standards Institute
API – American Petroleum Institute
ASTM - American Society for Testing and Materials
Bscf – billion standard cubic feet
B/D – barrels per day
bopd – barrels of oil per day
C4 – butane
C5 – pentane
C7 – heptane
C7+ - standard heptane plus
CCE – constant composition expansion
CCUS – carbon capture utilization and storage
cf – cubic feet
CH₄ – methane
CO₂ – carbon dioxide
EOR – Enhanced Oil Recovery
EOS – Equation of State
EPA – US Environmental Protection Agency
ESD – Emergency Shutdown Device
FWU – Farnsworth Unit
GHG – Greenhouse Gas
GHGRP – Greenhouse Gas Reporting Program
GPA – Gas Producers Association
H₂S – hydrogen sulfide
mD – millidarcy(ies)
MICP – mercury injection capillary pressure
MIT – mechanical integrity test
MMA – maximum monitoring area
MMB – million barrels
MMP – minimum miscible pressure
MMscf – million standard cubic feet
MMstb – million stock tank barrels
MRV – Monitoring, Reporting, and Verification
MMMT – Million metric tonnes
MT -- Metric tonne
NIST - National Institute of Standards and Technology
NAESB – North American Energy Standards Board
OOIP – Original Oil-In-Place

OWC – oil water contact
PPM – Parts Per Million
psia – pounds per square inch absolute
PVT – pressure, volume, temperature
QA/QC – quality assurance/quality control
RMS – root mean square
SEM – scanning electron microscope
SWP - Southwest Regional Partnership on Carbon Sequestration
TAC – Texas Administrative Code
TD – total depth
TRRC – Texas Railroad Commission
TSD – Technical Support Document
TVDSS – True Vertical Depth Subsea
UIC – Underground Injection Control
USDW – Underground Source of Drinking Water
WAG – Water Alternating Gas (Gas is recycled CO₂ and purchase CO₂)
XRD – x-ray diffraction

Appendix 5 - Conversion Factors

Perdure reports CO₂ at standard conditions of temperature and pressure as defined in the State of Texas in the Texas Administrative Code for the Oil and Gas Division, Rule 3.79 as follows:

Cubic foot of gas or standard cubic foot of gas--The volume of gas contained in one cubic foot of space at a standard pressure base and at a standard temperature base. The standard pressure base shall be 14.65 pounds per square inch absolute, and the standard temperature base shall be 60 degrees Fahrenheit.

To calculate CO₂ mass from CO₂ volume, EPA recommends using the database of thermodynamic properties developed by the National Institute of Standards and Technology (NIST). This online database is available at:

<https://webbook.nist.gov/chemistry/fluid/>

It provides density of CO₂ using the Span and Wagner equation of state (EOS) at a wide range of temperature and pressures.

At State of Texas standard conditions, the Span and Wagner EOS gives a density of CO₂ of 0.002641684 lb-moles per cubic foot. Converting the CO₂ density in units of metric tonnes per cubic foot:

$$Density_{CO_2} \left(\frac{MT}{ft^3} \right) = Density_{CO_2} \left(\frac{lb - moles}{ft^3} \right) \times MW_{CO_2} \times \frac{1 MT}{2204.62 lbs}$$

Where:

$$Density_{CO_2} = \text{Density of CO}_2 \text{ in metric tonnes (MT) per cubic foot}$$

$$Density_{CO_2} = 0.002641684$$

$$MW_{CO_2} = 44.0095$$

$$Density_{CO_2} = 5.2734 \times 10^{-5} \frac{MT}{ft^3} \text{ or } 5.2734 \times 10^{-2} \frac{MT}{Mcf}$$

The conversion factor 5.2734×10^{-2} MT/Mcf is used to convert CO₂ volumes in standard cubic feet to CO₂ mass in metric tonnes.

Request for Additional Information: Farnsworth Unit (FWU)
April 22, 2021

Instructions: Please enter responses into this table. Any long responses, references, or supplemental information may be attached to the end of the table as an appendix. Supplemental information may also be provided in a resubmitted MRV plan.

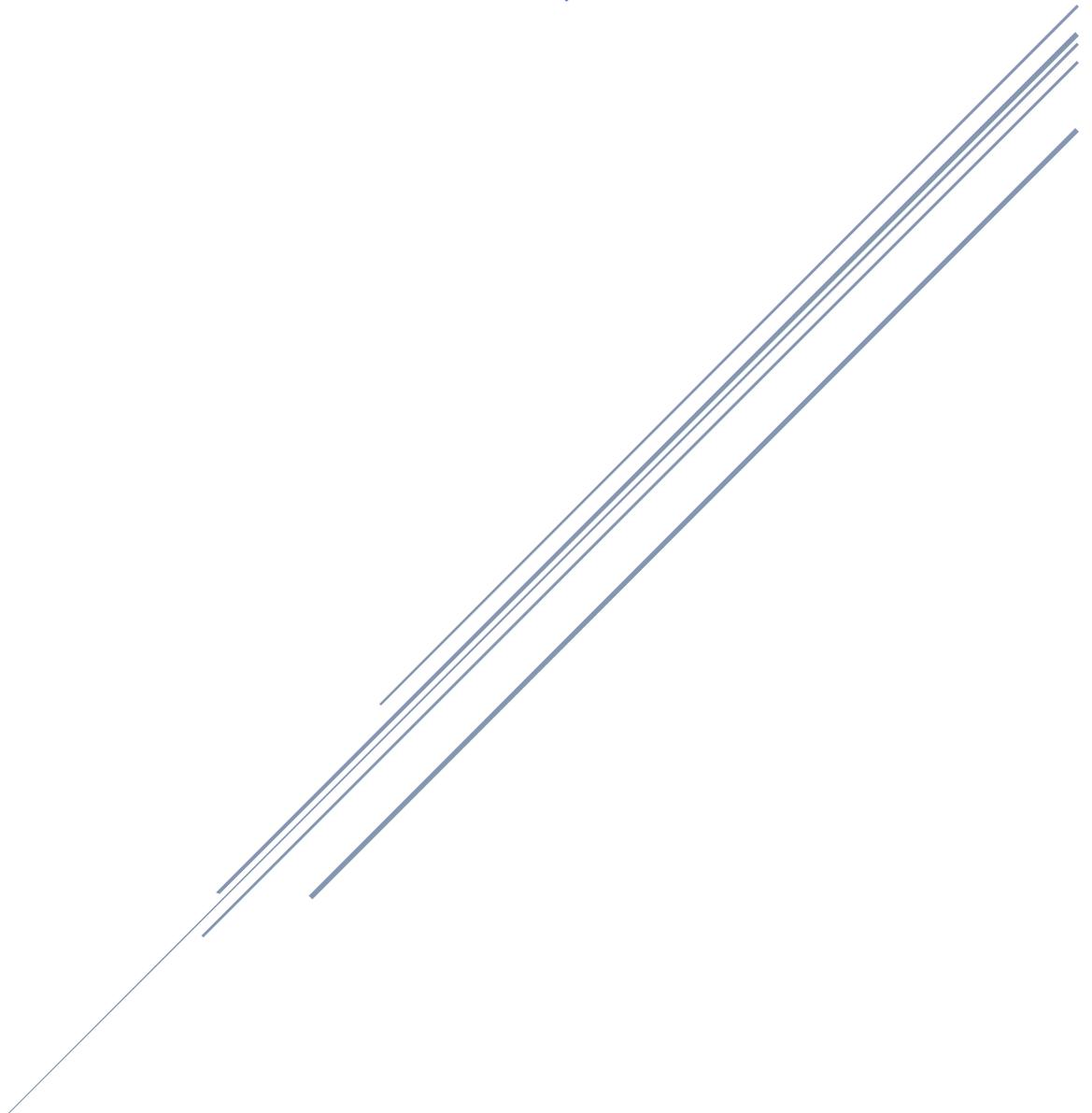
No.	MRV Plan		EPA Questions	Responses
	Section	Page		
1.	4.0	23-33	<p>Subpart RR specifies that the MRV plan address – “Potential surface leakage pathways for CO₂ in the MMA, and the likelihood, magnitude, and timing, of surface leakage of CO₂ through these pathways.”</p> <p>Section 4.2.5 identifies New Wells as a potential leakage pathway but does not provide a characterization of the likelihood, magnitude, or timing of potential leakage from these wells. Section 4 also does not provide a characterization of potential leakage due to lateral migration of CO₂ outside of the FWU. Please provide a characterization of leakage potential (likelihood, magnitude, etc.) from these pathways and provide more information as needed to support these characterizations.</p> <p>Furthermore, there are several leakage pathways that are listed in Table 1 that were not identified in the preceding sections (4.1-4.4) and/or do not have corresponding descriptive text regarding the likelihood, magnitude, and timing, of surface leakage of CO₂ through these pathways. For example, Table 1 of Section 4.5 identifies leakage due to seismic event as a leakage risk, but the plan does not provide a characterization of the likelihood, magnitude, or timing of potential leakage from natural or induced seismicity. Please provide additional detail on the likelihood, magnitude, and timing of surface leakage of CO₂ through all leakage pathways identified in Table 1.</p>	<p>Added further explanation of new well construction rules regulated by the Texas Railroad Commission in Section 4.2.5.</p> <p>Added new Section 4.4 to address lateral movement of fluids.</p> <p>Added new Section 4.6 to address seismic events.</p>

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
2.	4.0	23-33	<p>Related to Item #1, to improve the discussion of leakage pathways, please address the following questions to the extent possible:</p> <p><u>New Wells</u></p> <ul style="list-style-type: none"> - How do new wells pose a risk to CO2 surface leakage mitigation? - How will operators monitor for unapproved drilling activities? - Will newly constructed wells differ from existing wells in the unit? <p><u>Seismic</u></p> <ul style="list-style-type: none"> - Please elaborate on the potential leakage risk from natural or induced seismicity. Is there any existing data, literature, or operating experience that gives an indication of the risk of likelihood, magnitude, and timing of surface leakage of CO2 through natural or induced seismicity? - Are you aware of any trends in seismic activity that are relevant to this MRV plan? <p><u>Lateral Migration</u></p> <ul style="list-style-type: none"> - Please elaborate on the potential leakage risk from lateral migration of CO2 outside of the FWU. - How does the subsurface stratigraphy impact lateral migration of fluids in combination with operational injection patterns? - How will lateral migration of CO2 be monitored? - How will CO2 and injected fluids be contained within the unit? 	Addressed all questions to the extent possible in the edits outlines in Item 1 above.
3.	4.5	32	The table heading in Table 1 is now incorporated in the first cell (column 1, row 1). Please correct formatting as necessary.	Corrected heading format in Table 1.

Farnsworth Unit, Texas (FWU)

MONITORING, REPORTING, AND VERIFICATION PLAN

Perdure Petroleum, LLC



January, 2021

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Introduction

Perdure Petroleum, LLC (Perdure) operates the Farnsworth Unit (FWU) located in Ochiltree County, Texas for the primary purpose of enhanced oil recovery (EOR) using carbon dioxide (CO₂) with a subsidiary or ancillary purpose of geologic sequestration of CO₂ in a subsurface geologic formation. The discovery date of the field was October 26, 1955 and the FWU was unitized December 6, 1963 by Union Oil Company of California for the purpose of waterflooding with fresh water sourced from the Ogallala formation. The field structure is a lenticular bedding sand trending northwest to southeast with the average top of sand at 7990 feet, true vertical depth. Perdure has been operating the FWU since 2017. Perdure acquired the FWU from Chaparral Energy LLC, which initiated the CO₂-EOR project in December 2010. Perdure intends to continue CO₂-EOR operations until the end of the economic life of the CO₂-EOR program using various Class II injection wells as defined by Underground Injection Control (UIC) regulations and permitted under Texas Railroad Commission Statewide Rule 46. In this document, the term “gas” usually means a mixture of hydrocarbon light end components and the CO₂ component that can be produced as part of the EOR process.

Perdure has chosen to submit this Monitoring, Reporting, and Verification (MRV) plan to EPA for approval according to 40 CFR 98.440 (c)(1), Subpart RR of the Greenhouse Gas Reporting Program (GHGRP) for the purpose of qualifying for the tax credit in section 45Q of the federal Internal Revenue Code.

This MRV Plan contains ten sections:

Section 1 contains facility information.

Section 2 contains the project description including: a detailed description of the injection operation including the duration and volume of CO₂ to be injected; a detailed description of the geology and hydrogeology of the FWU located on the northwest shelf of the Anadarko basin and a detailed characterization of the injection reservoir and modeling techniques employed.

Section 3 contains the delineation of the maximum monitoring area (MMA) and the active monitoring area (AMA), both defined in 40 CFR 98.449, and as required by 40 CFR 98.448(a)(1), Subpart RR of the GHGRP.

Section 4 identifies the potential surface leakage pathways for CO₂ in the MMA and evaluates the likelihood, magnitude, and timing, of surface leakage of CO₂ through these pathways as required by 40 CFR 98.448(a)(2), Subpart RR of the GHGRP. This section also describes the strategy for detecting, verifying, and quantifying any surface leakage of CO₂ as required by 40 CFR 98.448(a)(3), Subpart RR of the GHGRP. Finally, this section also demonstrates that the risk of CO₂ leakage through the identified pathways is minimal.

Section 5 describes the strategy for establishing the expected baselines for monitoring CO₂ surface leakage as required by 40 CFR 98.448(a)(4), Subpart RR of the GHGRP.

Section 6 provides a summary of the considerations used to calculate site-specific variables for the mass balance equation as required by 40 CFR 98.448(a)(5), Subpart RR of the GHGRP.

Section 7 provides the estimated schedule for implementation of this MRV Plan as required by 40 CFR 98.448(a)(7).

Section 8 describes the quality assurance and quality control procedures that will be implemented for each technology applied in the leak detection and quantification process. This section also includes a discussion of the procedures for estimating missing data as detailed in 40 CFR 98.445.

Section 9 describes the records to be retained according to the requirements of 40 CFR 98.3(g) of Subpart A of the GHGRP and 40 CFR 98.447 of Subpart RR of the GRGRP.

Section 10 includes Appendices supporting the narrative of the MRV Plan.

1 Facility Information

1.1 Reporter number

The Farnsworth Unit CO₂ Flood reports under Greenhouse Gas Reporting Program Identification number 544683.

1.2 UIC permit class

For injection wells that are the subject of this MRV plan, the Texas Railroad Commission (TRRC) has issued Underground Injection Control (UIC) Class II enhanced recovery permits under its State Rule 46 (see Appendix 2). All wells in the FWU, including both injection and production wells, are regulated by TRRC, which has primacy to implement the UIC Class II program.

1.3 UIC injection well identification numbers

A list of the injection wells in the FWU is provided in Appendix 1. The details of the injection process are provided in Section 2.3.

2 Project Description

2.1 Project characteristics

2.1.1 Estimated years of CO₂ injection

It is currently projected that Perdure will inject CO₂ for an additional 12 years.

2.1.2 Estimated volume of CO₂ injected over lifetime of project

The chart to the left in Figure 2.4-7 in Section 2.4 - Reservoir Characterization Modeling shows the forecasted simulated cumulative CO₂ injection volume of approximately 180 billion standard cubic feet (Bscf) or 9.5 million metric tonnes (MMMT) through October 2032. For the period September 2020 through October 2032, an additional 52.5 Bscf or 2.77 MMMT will be stored in the FWU.

2.2 Environmental Setting of the MMA

2.2.1 Boundary of the MMA

Perdure has defined the boundary of the MMA as equivalent to the boundary of the FWU plus ½ mile beyond. A discussion of the methods used in delineating the MMA and the AMA are presented in Section 3.

2.2.2 Geology and hydrogeology

The geological discussions in Sections 2.2.2 and 4.3-4.4 are based on analysis of logs from over 140 wells, descriptions of cores from 8 wells including 3 recently cored that included sections from overlying seals as well as the shale underlying the main reservoirs, petrographic thin section descriptions and point counts as well as a variety of special analytical techniques including X-ray diffraction (XRD), which is the science of determining the atomic and molecular structure of rock crystals with an X-ray beam; scanning electron microscope (SEM) analysis; which uses a beam of electrons to define the surface of crystals; carbon isotope analysis to estimate the age of the sample; and a variety of mechanical tests. Two dimensional (2D) and three dimensional (3D) geophysical surveys were also used as part of this study. Details of recent geological investigations can be found in Gallagher (2014), Gragg (2016), Rasmussen et al (2019), Rose-Coss et al (2015), Trujillo (2018), Hobbs et al (2019), and Gragg et al (2018).

2.2.2.1 Tectonic Setting and Stratigraphy

The FWU is located on the northwest shelf of the Anadarko basin (Figure 2.2-1) and is one of many oil fields in the area that produce from a sequence of alternating sandstones and mudstones deposited during the late-Pennsylvanian Morrowan period. Oil production and CO₂ injection at FWU is restricted to the operationally-named Morrow B sandstone; the uppermost Morrow sandstone encountered below the Atokan Thirteen Finger limestone. The primary caprock intervals at FWU are comprised of the upper Morrow shale and the Thirteen Finger limestone (Figure 2.2-2). The Morrowan and Atokan intervals were deposited approximately 315-300 million years ago. Overlying stratigraphy includes Late Pennsylvanian through the middle Permian shales and limestones, with lesser amounts of dolomite, sandstone and evaporites.

The reservoir is approximately 60 feet thick through the field and lies at a depth of approximately 7600-7700 feet. The primary seal rocks of the Morrow shale and the Thirteen Finger Limestone comprise a package of approximately 180-200 feet thick in the field and are overlain by thousands of feet of Atokan and younger limestones and shales.

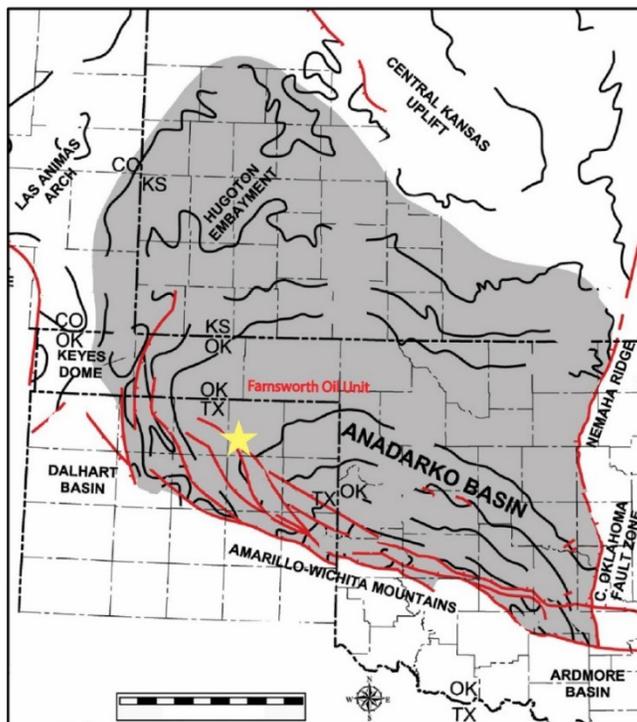


Figure 2.2-1- Location of the Farnsworth Unit (FWU) on the Northwest Shelf of the Anadarko Basin in West Texas. Red lines are approximate locations of faults that have been documented in the region.

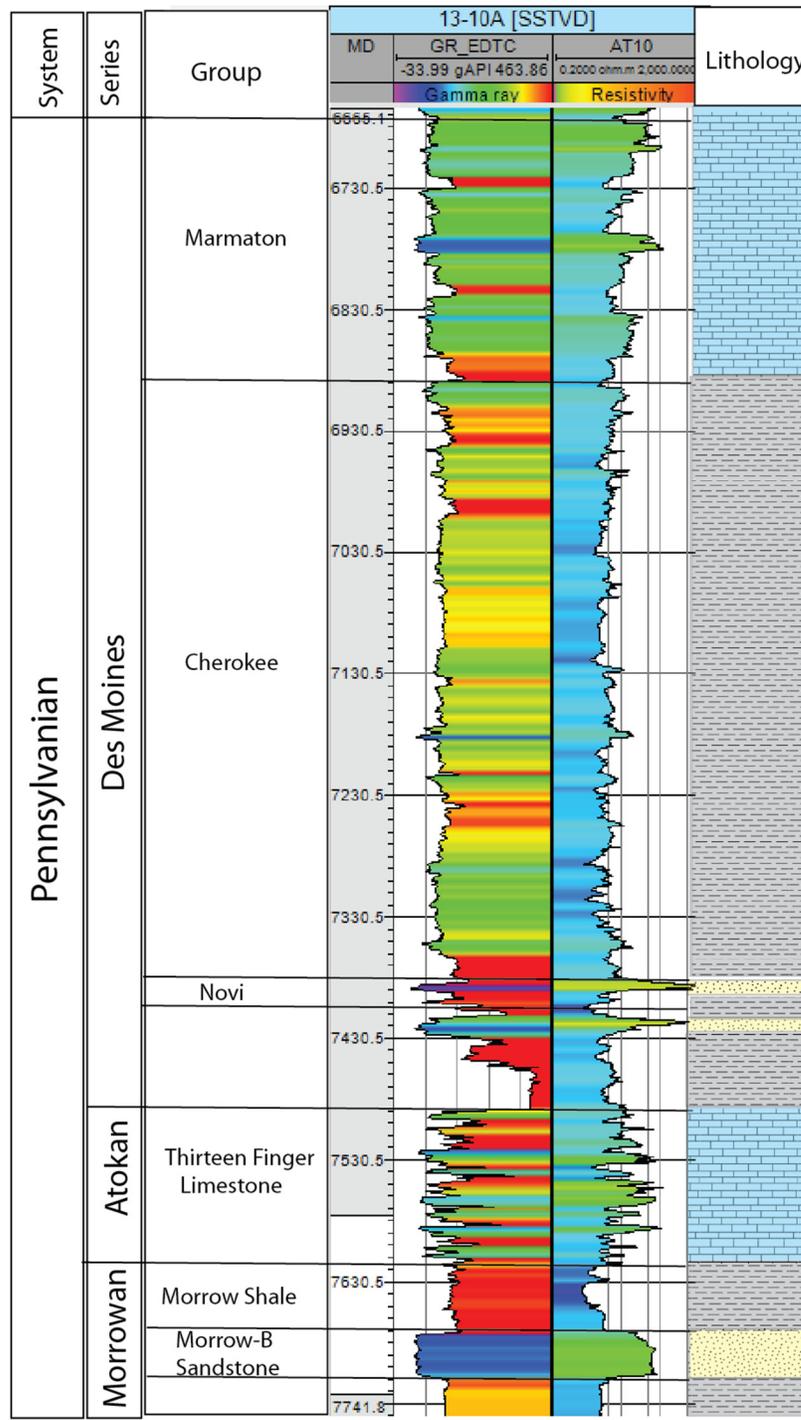


Figure 2.2-2- Stratigraphic section of the FWU.

Tectonic Setting

From FWU's location on the western edge of the basin, the Anadarko Basin plunges to the southeast where it reaches depths of over 40,000 feet (12,192 meters) adjacent to the Amarillo-Wichita Uplift (Perry, 1989). Maximum rates of subsidence occurred during

Morrowan to Atokan times (Evans, 1979; Perry, 1989; Higley, 2014). Positive features that might have influenced deposition within the region include the Ancestral Rockies to the north, the Central Kansas uplift to the northeast, and the Wichita-Amarillo uplift to the south (Evans, 1979; Munson, 1989). Of note is the fact that during Pennsylvanian time the FWU was located on the basin shelf in an area that was not affected greatly by tectonic deformation. Although faults have been reported previously in the northwest Anadarko Basin, we found no direct evidence for tectonic faults within the FWU (see Section 4).

Stratigraphy

Reservoir

Upper Morrowan sandstones in the Anadarko Basin margins have long been recognized as fluvial deposits (Swanson, 1979; Sonnenberg, 1985; Munson, 1989; Krystinik and Blakeney, 1990; Bowen et al., 1990; Al-Shaieb et al., 1995; Mckay and Noah, 1996; Puckette et al., 1996; Bowen and Weimer, 2003, 2004; Devries 2005; Puckette et al., 2008; Gallagher, 2014). At FWU, the Morrow B is a relatively coarse-grained subarkosic sandstone. The upper Morrowan facies in FWU, with sequences of basal conglomerate, coarse-grained sandstone, and fine-grained sandstone appear to be typical of incised valley deposits, as described by Wheeler et al. (1990), Krystinik and Blakeney (1990), Bowen et al. (1990), Blakeney et al. (1990), Sonnenberg et al. (1990) and Puckette et al. (2008). Typical reservoir porosity ranges from almost 0-25% with an average of ~15%, and permeability from 1-780 millidarcies (mD) with an average of ~35 mD (Rose-Coss, 2017)

Primary Seals

The Morrow B sandstones at FWU are encased above and below by shales. Contacts with shale both below and above the sandstone are sharp and irregular. The Morrow shale generally fines upwards in a series of thin beds (1-2 inches or 2.5-5 centimeters) that alternate between upper fine sands and fine to medium muds. Sand content decreases upwards through the section.

The Thirteen Finger limestone formation has two different lithofacies: diagenetic limestone (cementstone) and pyrite and fossil bearing fine to medium mudstone and coal. The two facies are intercalated with each other but tend to cluster in layers dominated more by one or the other. The number of limestone and mudstone beds varies from well to well; in one well 13-10A, 60-70 individual limestone beds were counted.

The entire Thirteen Finger interval is 130 feet (39.6 meters) thick, with approximately 40% of the thickness comprised of mudstone, 4% coal, and 46% is limestone. The cementstone is calcite rich, with some dolomite, and is completely diagenetic in origin and probably formed relatively soon following deposition. The organic-rich mudstone contains fibrous calcite "beef" fractures that are observed in the mudstone and coal lithology between cementstone "layers".

2.2.2.2 Hydrogeology

Information about Morrowan and Atokan formation water flow during oil operations has not been discovered in any oil or gas company published reports or academic research

studies in the Anadarko Basin. Groundwater flow rates in confined deep Anadarko layers at present are considered to be low to no flow (Nelson and Gianoutsos, 2014). Their arguments are based on (1) restricted recharge in the western basin, (2) density barriers to flow in the east, and (3) an overpressure pocket inhibiting flow in the deep basin. Jorgenson (1989) suggested flow could be west to east, driven by potential recharge to elevated units in the west and discharge at lower elevation outcrops in the east. The FWU CO₂ injection and production operations will not cause water to flow to outcrops of the Late Carboniferous (Pennsylvanian) time period that extend from Brownwood, Texas, to the Jacksboro/Bowie, Texas, area, which are hundreds of miles away (The Paleontology Portal).

The Carboniferous is a geologic period and system that cover 60 million years from the Devonian Period 358.9 million years ago, to the beginning of the Permian Period, 298.9 million years ago. As noted in the Section 2.2.2.1, the Morrowan and Atokan intervals of the FWU were deposited approximately 315-300 million years ago and are contained in the Carboniferous period.

2.3 Description of the Injection Process

Figure 2.3-1 depicts is a simplified flow diagram of the facilities and equipment within the boundaries of the FWU. CO₂ captured from the ethanol plant fermentation process is delivered via pipeline to the field for injection. The plant in Liberal KS is the only source of CO₂ to the field. The amount delivered is dependent on the production of CO₂ produced from the fermentation process. This amount will vary but should average 12 MMCFD. Once CO₂ enters the FWU there are three main processes involved in EOR operations. These processes are shown in Figure 2.3-1 and include:

1. CO₂ distribution and Injection. Purchased CO₂ is combined with recycled CO₂ from the FWU central tank battery and sent through the main CO₂ distribution system to various water alternating gas (WAG) injectors.
2. Produced Fluids Handling. Full well stream fluids are produced to the “all well test” site (AWT). The AWT site has two major purposes; 1) to individually test a well’s performance by separating and metering oil, gas and water, and 2) to separate all gas from liquid then send these two phases to the Central Tank Battery for final separation.
3. Produced Gas Processing. All phases from the AWTs are transferred to the central tank battery to separate the oil, gas and water using a series of vessels and storage tanks.

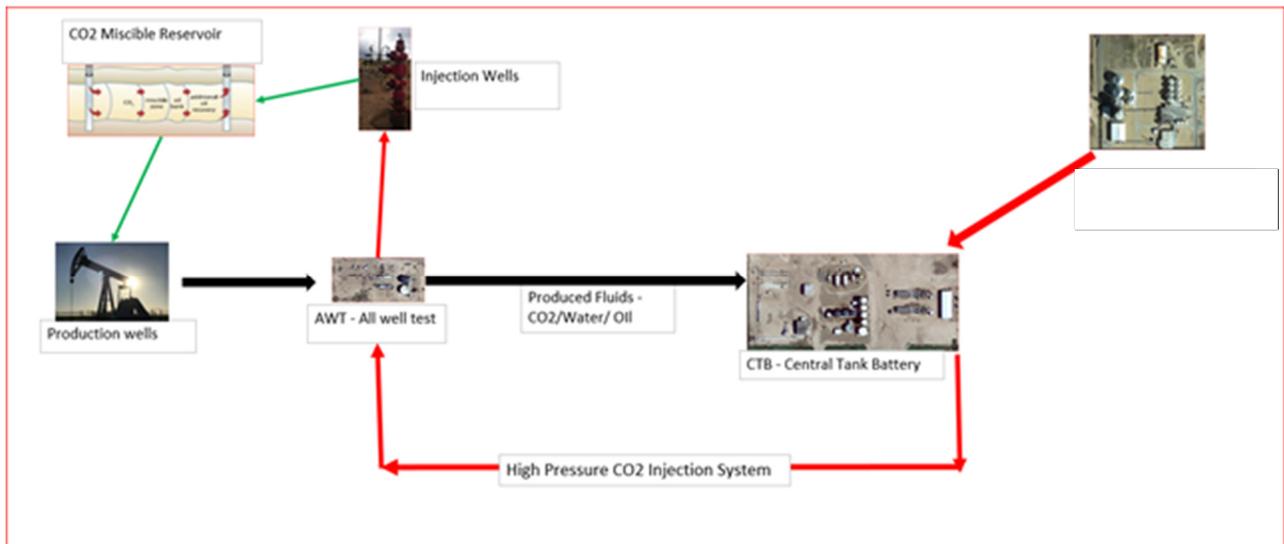


Figure 2.3-1 - Simplified flow diagram of the facilities and equipment within the boundaries of the Farnsworth Unit.

2.3.1 CO₂ Distribution and Injection

Perdure purchases CO₂ from Conestoga Energy Partners, the parent company of the Arkalon Ethanol plant located in Liberal Kansas. A custody transfer meter is located in the compression facility owned and operated by Perdure. The purchased CO₂ from the fermentation process is transported via a United States Department of Transportation (DOT) regulated pipeline to the FWU. A totalizer meter, for the purchased CO₂, is located in the field where instantaneous data is summed into a 24-hour flow rate which is recorded. A totalizer meter is a meter approved by American Gas Association (AGA) Report #3 to measure the flowrate of gases. The actual measurements taken are temperature, line pressure and differential pressure across the meter. Gas produced, recycled CO₂, from the wells is compressed and metered by a similar totalizer meter as the purchase CO₂ meter and is recorded daily.

Perdure currently has three active injection manifolds and approximately 17 active injection wells that the CO₂ is distributed through. When the MRV plan becomes active, the daily injection volume of the combined purchased CO₂ and recycled CO₂ will be approximately 24 MMCFD. Of this volume 12 MMCFD is purchased CO₂ and 12 MMCFD is recycled CO₂. This ratio of purchased CO₂ to recycled CO₂ is expected to change over time, with the percentage of recycled CO₂ increasing and purchased CO₂ decreasing. The current reservoir management plan projects that CO₂ purchases will remain constant at 12 MMCFD for 12 years and decline after 2033. (Per Reservoir Characterization and Modelling, the CO₂ purchases ceased at the end of 2033 which may or may not be true as ultimately production and the economic viability of the flood will dictate when purchased CO₂ is no longer required.) A reservoir management plan is an integrated process using various, surveillance techniques, economic evaluations, and accepted petroleum technical practices to efficiently operate enhanced oil recovery projects.

The three injection manifolds currently in the field distribute the CO₂ to the field. These manifolds have valves to switch to water when the time is called for. Depending on the

reservoir management plan the WAG cycle will be adjusted to maximize oil recovery and minimize CO₂ utilization in each injection pattern. At each injection well pad is a totalizer to measure the volumes injected every 24 hours. This data is collected daily by the field personnel and input into the data warehouse to be allocated for the pattern injection.

The two totalizer meters as described above will be used to determine the total volume injected used in section 7 for the mass balance equations necessary to determine annual and cumulative volumes of the stored CO₂.

2.3.2 Produced Fluids Handling

As injected CO₂ and water migrate through the reservoir, a mixture of oil, gas, and water (referred to as “produced fluids”) flows to the production wells. Gathering lines bring the produced fluids from each production well to the “all well test” (AWT) sites. Perdure has approximately 32 active production wells producing at any time. Each AWT has two separators. The first separator is used for testing individual wells to separate the gas, oil, and water produced from an individual well. This gas, oil and water is subsequently measured and recorded for the well. Each producing well is production tested every 30 to 60 days after the last production test, or after the well is returned to production. Depending on the reservoir management plan well testing can be more frequent to obtain data. The second separator is used to separate the gas from the oil/water mixture from the other wells producing into the AWT and the gas and liquids are displaced from the vessel in separate lines. Leaving the AWT sites are two lines transporting produced fluids. One for the liquid phase, a mixture of oil and water, and one for the gas phase.

When gas and liquid lines enter the CTB a series of vessels separate the oil, gas, and water to be accounted for and distributed for sales or reinjected. The liquid phase line has vessels to separate the oil from the water using density and residence time. The gas phase vessels collect any free liquids entrained with the gas. These free liquids are then combined back into the liquid phase line. All gas and water are reinjected, and the oil, which contains an estimated 2,930 ppm CO₂ (0.293%), is sold out of tanks. Annually, the oil from the stock tank is analyzed by a laboratory using ASTM crude oil analysis methods to determine the CO₂ content in the oil being sold.

After separation, the gas phase, which is approximately 89-93% CO₂, is mixed with reservoir volatile components, compressed, and distributed throughout the high-pressure distribution system using reciprocal compression and high-pressure horizontal pumps.

The water is transferred from the separation vessels to tanks for reinjection. After the water is conditioned it is either reinjected at the WAG skids or disposed of into permitted disposal wells. Although Perdure is not required to determine or report the amount of dissolved CO₂ in the water, analyses have shown the water typically contains <690 ppm (0.069%) CO₂.

FWU production has trace amounts of hydrogen sulfide (H₂S), which is toxic. There are approximately 8-10 workers on the ground in the FWU at any given time, and all field and contractor personnel are always required to wear H₂S detectors. The primary purpose of the H₂S detectors is protecting people from the risk of being harmed. The detection limit of

the H₂S detectors is quantified for readings in the range of 0-100 ppm and will sound an alarm above 10 ppm. The secondary purpose H₂S detectors would be to provide an indication of emissions of gas from a pipeline or surface equipment, that might go unnoticed by other observations or measurements. No gas volumes can be calculated based on the detector reading or alarm; only a H₂S leakage is detected and located. Once identified, further a further response will be initiated and CO₂ volumes will be quantified as discussed in sections 4.5, 4.6, 5.4 and 8.1.5 of this MRV plan.

2.3.3 Produced Gas Handling

Produced gas separated at the central tank battery (CTB) is stripped by a series of vessels of entrained and free water. The water content has been recorded to be < 20 pounds mass per MMCF, thus dehydration is not necessary. The gas is then sent to a centralized compression system to be compressed and placed in the high-pressure distribution system. This compression turns the CO₂ into a variable density liquid, which is then transported out via high pressure lines to the AWTs where a manifold splits this dense CO₂ to the wells that are on CO₂ injection at that time.

2.3.4 Facilities Locations

The locations of the “all well test” sites (AWT) are positioned in the field to access both injection distribution and production gathering. The central tank battery (CTB) is where the final separation and injection equipment is maintained and operated. The water injection station is where the horizontal pumps are located to reinject the produced brine.

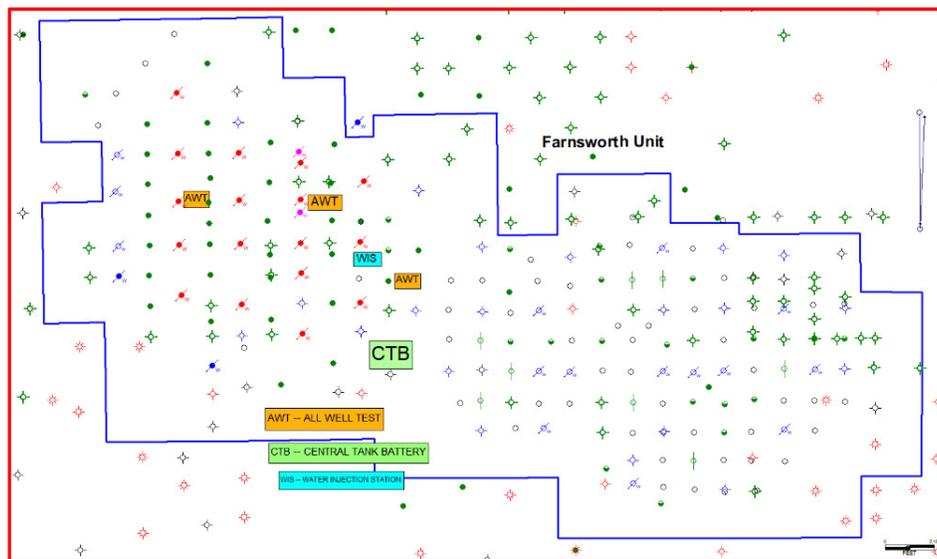


Figure 2.3-2 – Location of All Well Test (AWT) sites, Central Tank Battery (CTB) and Water Injection Station (WIS) in the FWU

2.3.5 Water Conditioning and Injection

Produced water collected at the central tank battery is collected in a series of vessels and tanks in a cascade system. This allows any entrained oil to further separate to the top of the tanks because of the density difference and is skimmed off and put back in the oil separation system. The clean water is then transferred to the water injection system where

it is boosted in pressure and sent out to the AWTs for distribution to all wells that are currently on water injection.

2.3.6 Well Operation and Permitting

The Texas Railroad Commission rules (Appendix 1) govern well location, construction, operation, maintenance, and closure for all wells in permitted units and wells. Perdure follows these rules and regulations to maintain safe and efficient operations. This includes complying with all current and updated information for mechanical integrity testing, well repairs for injection wells, drilling and completion permitting and reporting.

Briefly current rules require, among other provisions:

- That fluids be constrained in the strata in which they are encountered.
- That activities governed by the rule cannot result in the pollution of subsurface or surface water.
- That wells adhere to specified casing, cementing, drilling well control, and completion requirements designed to prevent fluids from moving from the strata they are encountered into strata with oil and gas, or into subsurface and surface waters.
- That wells file a completion report including basic electric log (e.g., a density, sonic, or resistivity (except dip meter) log run over the entire wellbore).
- That all wells be equipped with a Bradenhead gauge, measure the pressure between casing strings using the Bradenhead gauge, and follow procedures to report and address any instances where pressure on the Bradenhead is detected.
- And that all wells follow plugging procedures that require advance approval from the Director and allow consideration of the suitability of the cement based on the use of the well, the location and setting of plugs.

2.3.7 Number, Location and Depth of Injection Wells

Perdure's FWU injection wells are listed in Appendix 1. Injection is into the Upper Morrowan, a lenticular bedded sandstone trending northwest to southeast with the average top of sand at 7990 feet, true vertical depth. The Upper Morrowan is described in section 2.2.2.1 above.

2.4 Reservoir Characterization Modeling

2.4.1 Reservoir Model Description

The target reservoir Morrow B is a sandstone formation overlain by the Morrow shale and Thirteen Finger limestone, which serve as excellent seals for injected CO₂ (Ampomah et al., 2016a). The Morrow B sandstone reservoir is at a depth between 7550 feet and 7950 feet subsurface with an average dip of less than one degree (Figure 2.4-1). The productive limit of the FWU extends laterally to about 8300 acres. The maximum pay thickness is 54 feet with an average of 22 feet.

The FWU is approximately 4 mi by 7 mi and is usually divided into eastern and western portions because the two sides of this field have exhibited different reservoir behavior. The

eastern side was more prolific under primary production. However, the CO₂ –EOR study for FWU has concentrated on the west half of the field, which showed a better response to waterflood initiated in the 1960's and which is where the field operator is focusing their efforts (Ampomah et al., 2016b).

In the property modelling process, a hydraulic flow unit (HFU) methodology based on the Winland R35 method was used to describe and characterize heterogeneity within the Morrow B reservoir. The R35 parameter refers to the pore throat aperture radius when core samples are 35% saturated during a mercury injection porosimetry test. This captures pore throat size at which pore networks become interconnected and form continuous flow paths. Fifty-one (51) wells with core porosity and permeability measurements were used to define eight distinct porosity/permeability relationships (Figure 2.4-2). These eight relationships were based on depositional/diagenetic facies described from core and thin section analysis. The facies have differences, often subtle, that appear to greatly affect reservoir properties (Ross-Coss et al., 2016). There appears to be a strong relationship between the delineated hydraulic flow units and depositional and diagenetic trends that was not noted in early investigations into reservoir properties (Gallagher, 2014, Munson, 1989). After HFUs and porosity/permeability relationships were established, a Gaussian simulation method, cokriged with the facies model, was used to model porosity and net-to-gross ratio.

The geocellular structural model has a grid cell distribution of 1573*962*23 with a grid dimension of 25 feet × 25 feet. and includes the reservoir formation and several of the overlying seal formations. This model was upscaled to a reasonable size to decrease computational time for simulation purposes. The upscaled model, which uses only the western half of FWU, has a grid size of 176×163× 8 for a total of 229,504 cells that are approximately 100 feet by 100 feet on the top view perspective.

Figure 2.4-3 shows porosity and permeability distribution for the western half of FWU used in this study. Reservoir porosity ranges from 9.2% to 24% with a mean of 14.6% and shows a normal population distribution. Permeability ranges from 0.01 mD to 181 mD with an average value of 58 mD. The permeability histogram shows a log-normal population distribution.

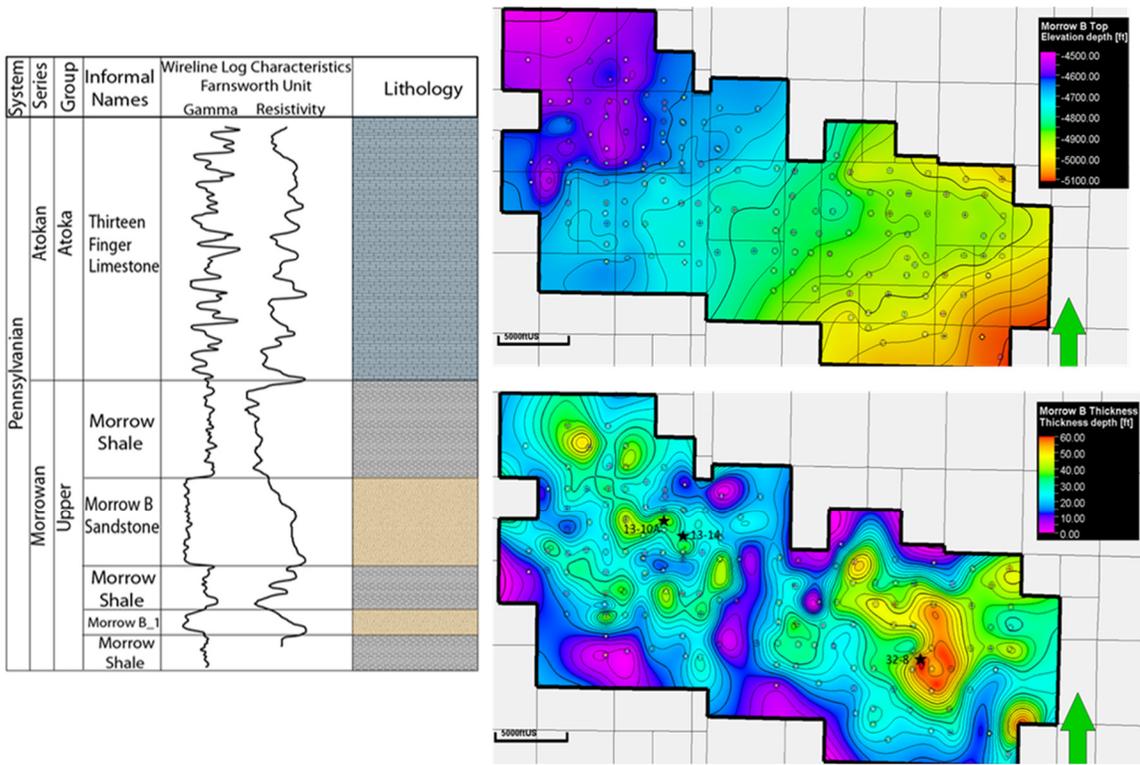


Figure 2.4-1- (Left) Type log of FWU caprock and reservoir. (Upper Right) Surface contour of Morrow B top. (Lower right) Thickness map of Morrow B sands (Gallagher 2014).

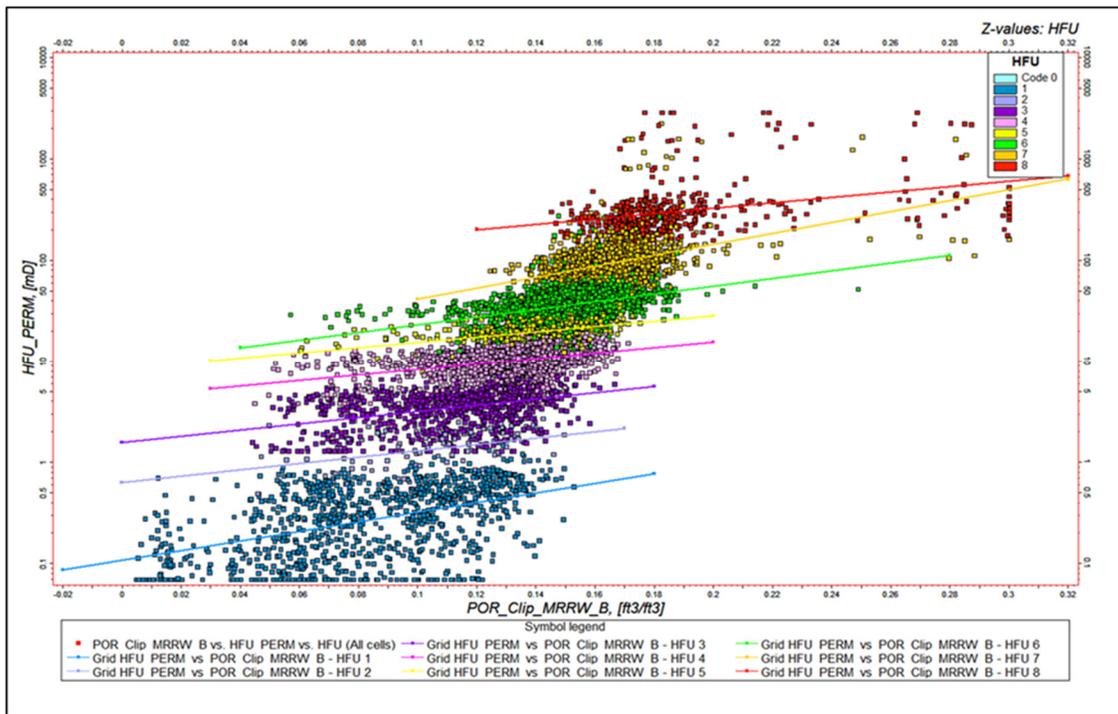


Figure 2.4-2 - Porosity versus permeability for the 51 cored wells, separated by pore throat size into hydraulic flow units.

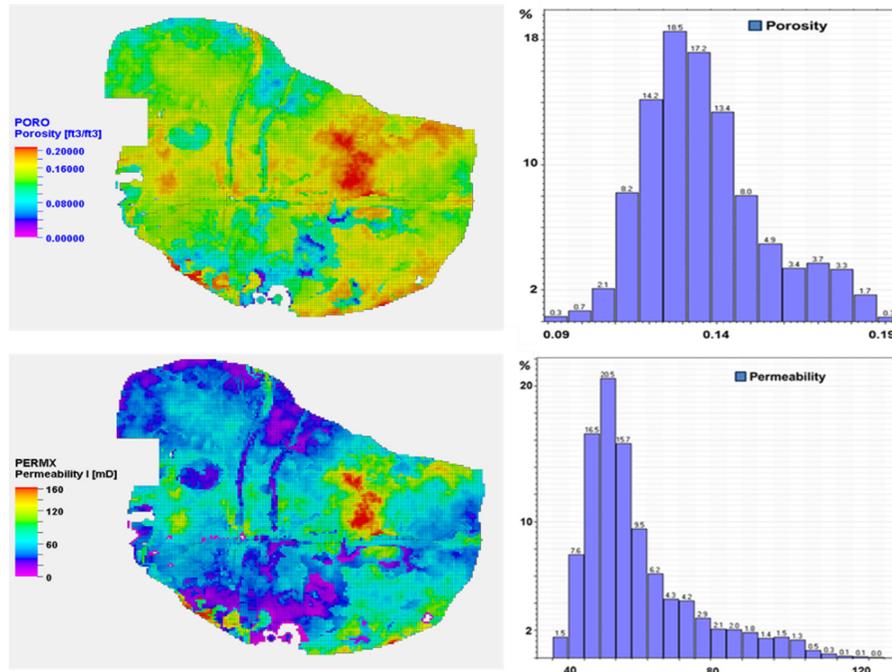


Figure 2.4-1- (Upper left) Porosity distribution using a Gaussian Simulation method for the west section of FWU used in the work. (Upper right) shows histogram illustrating a normal distribution of porosity with a mean of 14%. (Lower left) Permeability distribution constructed from porosity-permeability cross plots based on eight hydraulic flow units. (Lower right) Histogram illustrates a lognormal distribution of permeability.

2.4.2 Reservoir Fluid Modeling

The compositional fluid model was constructed from laboratory experiments tuned to an equation of state (Gunda et al., 2015). The process for the FWU involved comprehensive splitting and lumping of the C7+ fractions. The experimental data from PVT experiments including constant composition expansion (CCE), saturation pressure, differential liberation (DL), multi-stage separator tests and viscosity tests conducted on FWU fluid sample were used for the validation of the tuning process (Gunda et al., 2015). The mixing rules by Pedersen (Pedersen et al. 1989) were followed to split the C7+ fractions into two pseudocomponents using the average molecular weight, average specific gravity and the total mole percent. The isomers of C4 (butane) and C5 (pentane) were also lumped using the same methodology. A regression process was performed manually to achieve acceptable calibration to the laboratory data. The critical parameters for the two pseudocomponents were calculated based on Pedersen's approach (Pedersen 2002) using Calsep's PVTsim™ software package. The 3- parameter Peng Robinson equation of state (Peng and Robinson 1976) with Peneloux volume correction (Peneloux et al. 1982) was used to perform all the calculations. The viscosity modeled using the Lohrenz-Bray-Clark correlation (Lohrenz et al. 1964). After calibrating the fluid model to equation of state, a slim tube simulation experiment was conducted to obtain the minimum miscible pressure (MMP) for FWU. A one-dimensional 200 cell model was used for the experiment with a CO₂ injection rate of 1.2 pore volume. Figure 2.4-4 shows a plot of oil recovery vs. pressure illustrating the MMP of FWU computed from the simulation experiment. The MMP of 4009 psia realized from the simulation as compared to an MMP value 4200 psia derived from

laboratory experiments provided by the operator represents a less than 5% error (Gunda et al., 2015).

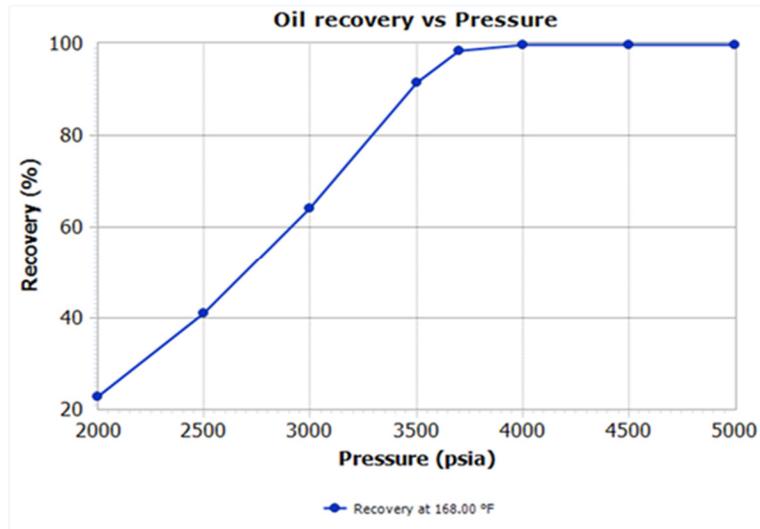


Figure 2.4-4. Oil recovery plot for 1D slim tube test

2.4.3 Assisted History Matching using Reduced Order Model

This section presents computer assisted history matching efforts for primary, secondary and tertiary recovery processes for FWU. Eclipse E300 (Schlumberger) was used throughout this study for all simulation runs. Most efforts were directed at matching secondary and tertiary processes by assigning higher weights in objective function formulation as compared to primary processes. Gas production field history was not available for primary recovery. The primary and secondary history processes lasted for 55 years until December 2010. The tertiary CO₂ flood was performed between December 2010 and August 2020. The parameters included in the objective function formulation were oil production, water production, water-cut, gas oil ratio (during waterflood), and injection rate. Pressure measurements including those made initially, prior to waterflood and at the end of waterflood were also used in the calibration process. Heath et al., (2015) conducted geomechanical analysis on FWU rock samples and determined a fracture pressure between 5400 to 5600 psia.

During primary recovery, there were a total of 60 production wells. As there were no recorded gas-oil or water-oil contacts, all grid blocks were assigned an initial oil saturation of 69% and 31% connate water saturation. With initial reservoir pressure of 2217.7 psia assigned to the datum depth of 4900 feet TVDSS, original average pressure in the model was 2150 psia. Oil originally in place (OOIP) for FWU west half in this model was about 71.4 MMstb with 23.8 MMscf of dissolved natural gas. During waterflood, there were 47 producer wells with 13 wells converted from producers to injector wells. An additional 6 water injector wells drilled during this period. The initial sensitivity analysis performed on primary and secondary recovery processes showed that well bottomhole pressure, oil-water contact (OWC), and bottomhole injection pressure were the most important parameters.

These uncertain variables were included in the history matching process to optimize the objective function at acceptable data uncertainty ranges.

From the history matching results it was deduced that OWC of an average value of 5000 feet TVDSS was appropriate to yield the best history match model. The bottomhole pressure had an optimum value of 4800 psia to improve history matching efforts. Sensitivity analysis showed global permeability was not particularly sensitive to the objective function. However, a few local permeabilities were furthered adjusted to improve the overall history matching. The overall RMS was about 10%, which was mostly contributed by gas-oil ratio match. This confirms some doubts the operator had on gas production history measurements during the primary and secondary recovery processes of the field. Figure 2.4-5 shows oil production and water cut profiles. Various waterflood patterns swept to residual oil saturation of about 27%, a successful flood. This is not unexpected given the relatively good mobility ratio of about 1.6 and high injection throughput of at least 1.7 displaceable pore volumes. From the simulation results, nearly 6 MMstb represents 10% of OOIP produced prior to the initiation of waterflood. A total of 25.65 MMstb of cumulative oil has been produced at the end of secondary from the west half of FWU, which represents nearly 40% of OOIP. During the tertiary history match, an initial simulation run showed a good calibration of compared to observed history until CO₂ breakthrough. Simulated gas production and CO₂ injection rates were unable to match measured volumes after the CO₂ breakthrough, which could be attributed to a potential change in wettability and interfacial tension. There is a possibility of the Morrow B transitioning into a mixed-wet wettability system. Corey parameters were adjusted to improve calibration of the CO₂ flood history match. An optimization approach was utilized to identify optimum values for Corey parameters. Figure 2.4-6 shows simulated results compared to historical oil production, gas production, CO₂ injection and water production profiles.

At the end of August 2020, according to simulation results, a total of 4.8 MMstb of oil has been produced from the west half of FWU since CO₂-WAG commenced (December 2010). About 93% of the purchased CO₂ remains as of August 2020.

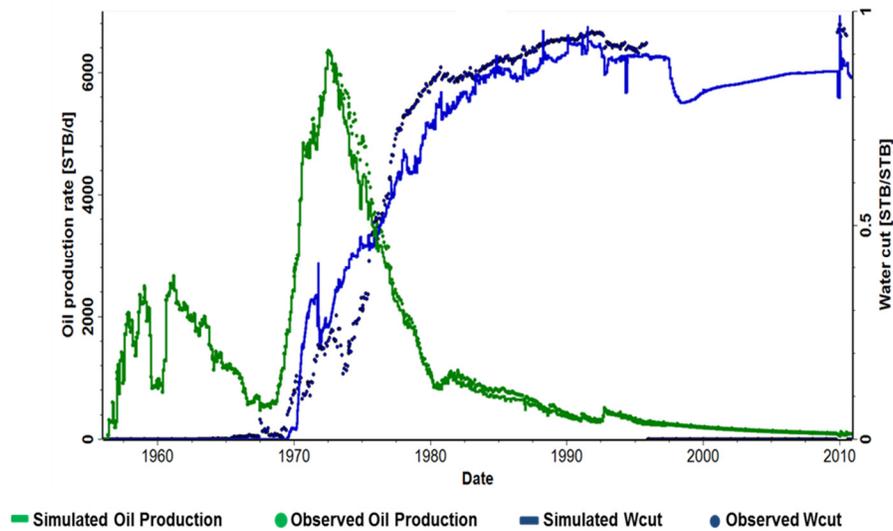


Figure 2.4-5- Calibration of simulated oil production rate and water cut vs. observed for primary and secondary history matching process.

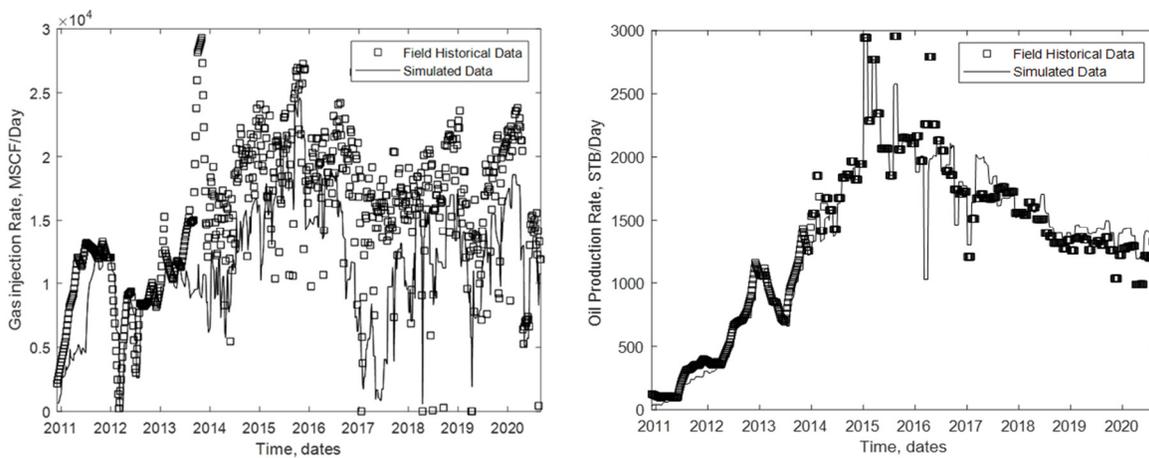


Figure 2.4-6- Calibration of simulated vs observed responses for tertiary recovery including CO₂ injection (left) and oil production rate (right).

2.4.4 CO₂ –EOR Performance Scenarios

Once an acceptable history match was reached, CO₂ flood performance could be predicted to optimize oil production and CO₂ storage. Several prediction cases based on different injection scenarios were run to maximize the potential of the projected flood. Per the current plan of the operator, five existing water injection wells will be converted to WAG injection wells and were included in the CO₂ prediction model. There is an anticipated constant CO₂ purchase of 12 MMscf/d and a flexible compressor capacity to recycle produced gas for reinjection purposes. A user-defined algorithm was developed in the numerical simulator to use purchased CO₂ in addition to produced gas (recycled) as a group injection rate target for the run scenarios. The model was performed for a 12-year period with bottomhole pressure and oil rate target constraints. Per §98.449 Definitions, the modelled area is projected to contain the free phase CO₂ plume at the end of year t + 5. The

injection profile shows the storage capacity of the Morrow B storage complex. Significant amount of produced CO₂ was recycled back into the injection stream (Figure 2.4-7). The compressor capacity will be expanded to compensate for high volume recycle volumes in the future.

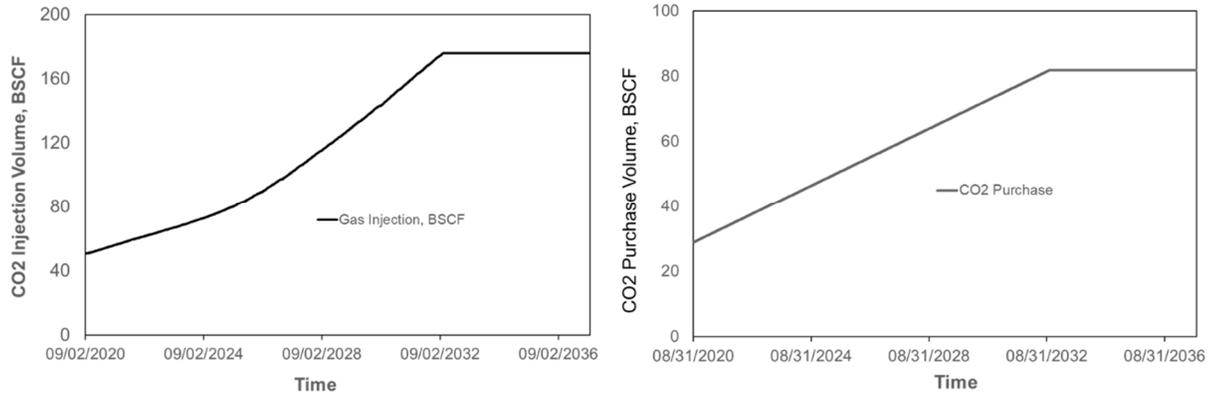


Figure 2.4-7 - Simulated Cumulative CO₂ injection Volume and CO₂ purchase volume for the Forecasting Scenario

3 Delineation of the monitoring areas

3.1 MMA

As defined in Subpart RR, the maximum monitoring area (MMA) is equal to or greater than the area expected to contain the free phase CO₂ plume until the CO₂ plume has stabilized plus an all-around buffer zone of at least one-half mile. The purchase volumes that are displayed in figure 2.4.7 and the mapped CO₂ composition results that are displayed in Section 3.1.1 indicate that all of the CO₂ will remain in modelled area is projected to contain the free phase CO₂ plume at the end of year t + 5; barring unforeseen future operational issues. Therefore, Perdure is defining the MMA as the boundary of the FWU plus an additional one-half mile buffer zone. This will allow for operational expansion throughout the FWU for the next 12 years, the anticipated life of the project.

3.1.1 Determination of free phase plume extent

Figure 3.1-1 shows the modeling simulation of the total CO₂ composition depicting the lateral extent of CO₂ in the injection zone. The injection area shows the significant high concentration of CO₂ which reiterates the containment within the injection zone and area. The simulation depicts the tertiary CO₂ flood that was performed between December 2010 and October 2032 with additional 5-year post-injection monitoring (Figure 3.1-2). The high green color shows almost zero CO₂ fraction which illustrates most of the CO₂ injected has not reach the model boundary even after a total of 22 years of potential CO₂ injection into the Morrow B formation.

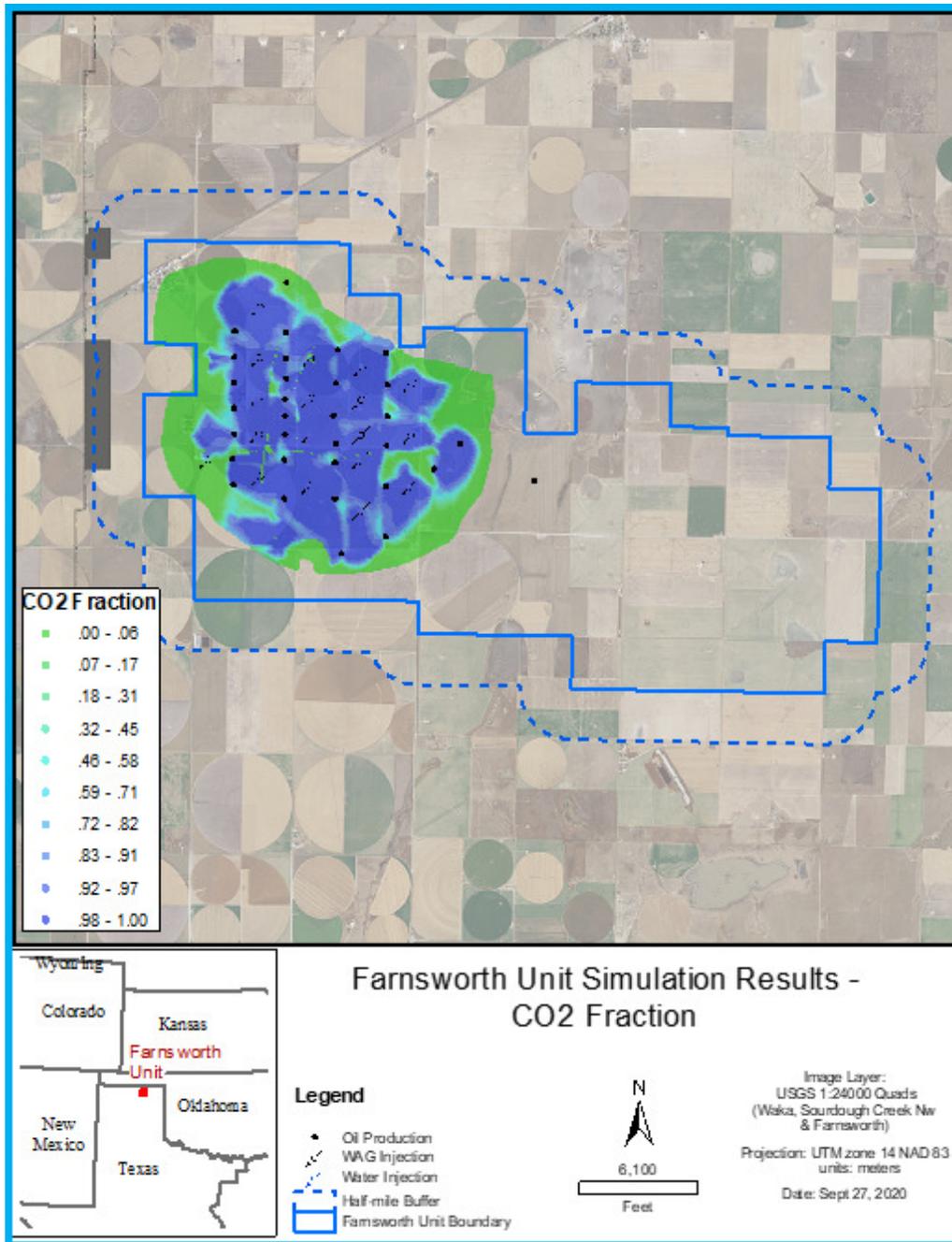


Figure 3.1-1: Model simulation of the tertiary CO₂ flood

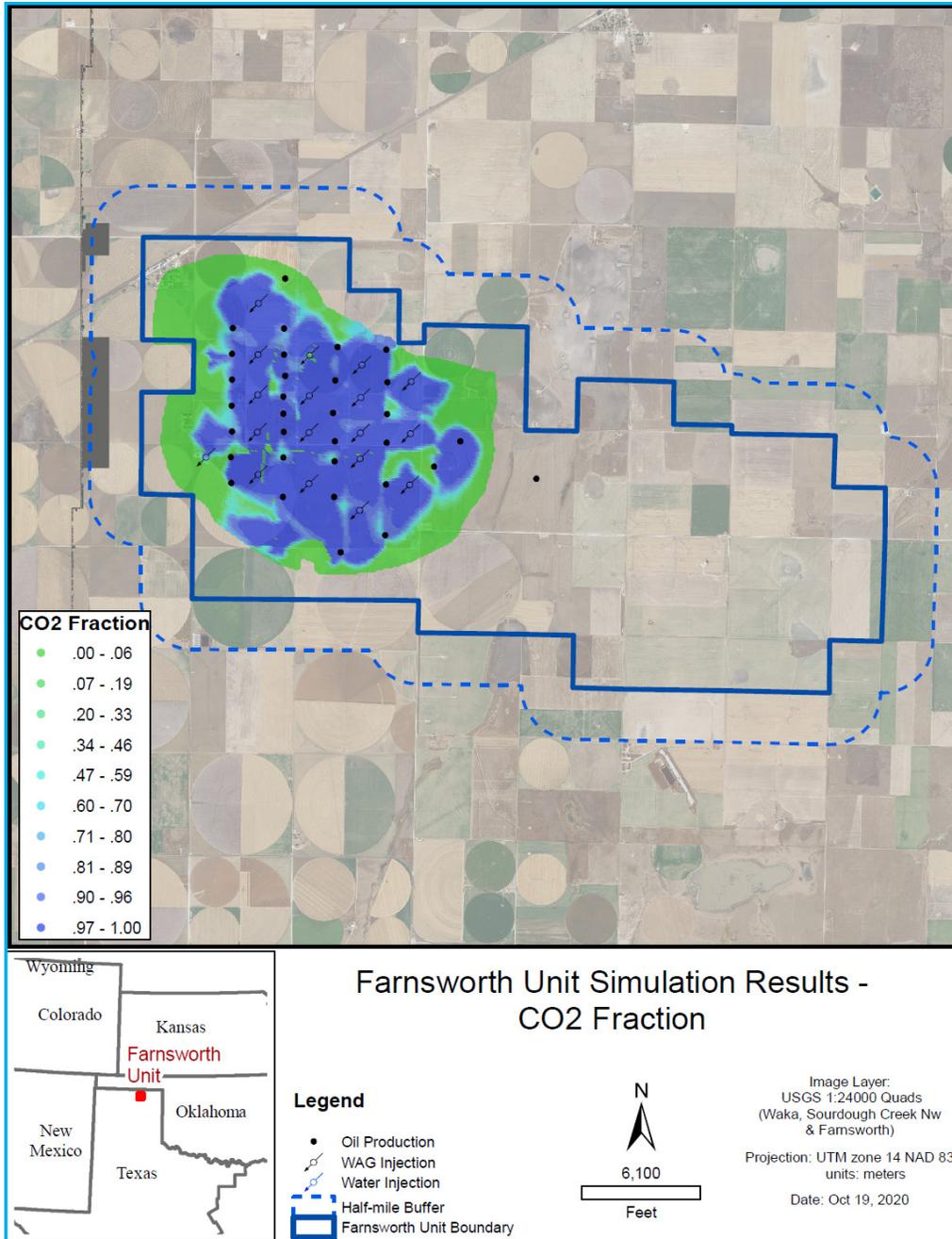


Figure 3.1-2 – CO₂ Plume Extent 5 years after Injection ceased.

3.1.2 Determination of buffer zone

Perdure intends to implement a buffer zone of one-half mile around the FWU, the minimum required by Subpart RR, because the site characterization of the FWU did not reveal any leakage pathways that would allow free-phase CO₂ to migrate laterally thereby warranting a buffer zone greater than one-half mile.

3.2 AMA

Currently, Perdure's operations are focused in the western portion of the FWU. However, it is anticipated as the project develops additional activity will occur in the eastern portion of the FWU; therefore, requiring active monitoring in that area. However, project development is driven by the market price of oil so Perdure is unable to provide a specific time in the future when the eastern portion of the FWU will be actively monitored. Therefore, for the purposes of this MRV plan, Perdure has chosen to include the entire FWU in the AMA.

4 Identification and Evaluation of Leakage Pathways

Since its discovery in 1955, its unitization in 1963, and the commencement of CO₂ EOR in 2010; the FWU has undergone extensive investigation and documentation as indicated in Section 2. From this body of work, Perdure has identified the following potential pathways of CO₂ leakage to the surface. This section will also address detection, verification, and quantification of leakage from each pathway.

4.1 Leakage from Surface Equipment

The surface equipment and pipelines utilize materials of construction and control processes that are standard in the oil and gas industry for CO₂ EOR projects. Ongoing field surveillance of pipelines, wellheads and other surface equipment via personnel instructed how to detect surface leaks and other equipment failure minimizes releases. In addition, requirements in the Texas Administrative Code (TAC) rules for the Texas Railroad Commission (TRRC) Oil and Gas Division to report and quantify leaks, both serve to minimize leakage of GHG from surface equipment. Operating and maintenance practices currently follow and will continue to follow demonstrated industry standards. As described in Section 6.4 below, should leakage from surface equipment occur it will be quantified according to the procedures in Subpart W of the GHGRP.

4.2 Leakage from Wells

Perdure has identified 61 abandoned wells, 32 injection wells (17 active), 58 production wells (32 active) and 2 monitoring wells within the MMA and assessed their potential for leakage of CO₂ to the surface as listed in Appendix 1.

4.2.1 Abandoned Wells

Figure 4.2-1 shows all wells plugged and abandoned in the FWU. Because the FWU was unitized in 1963, all plugging and abandonment activities of wells within the FWU have been conducted under the regulations of the TRRC for plugging wells. Perdure concludes that leakage of CO₂ to the surface through abandoned wells is unlikely. However, strategies for leak detection are in place that are discussed in Section 4.5 and the strategy to quantify the leak is discussed in Section 4.6.

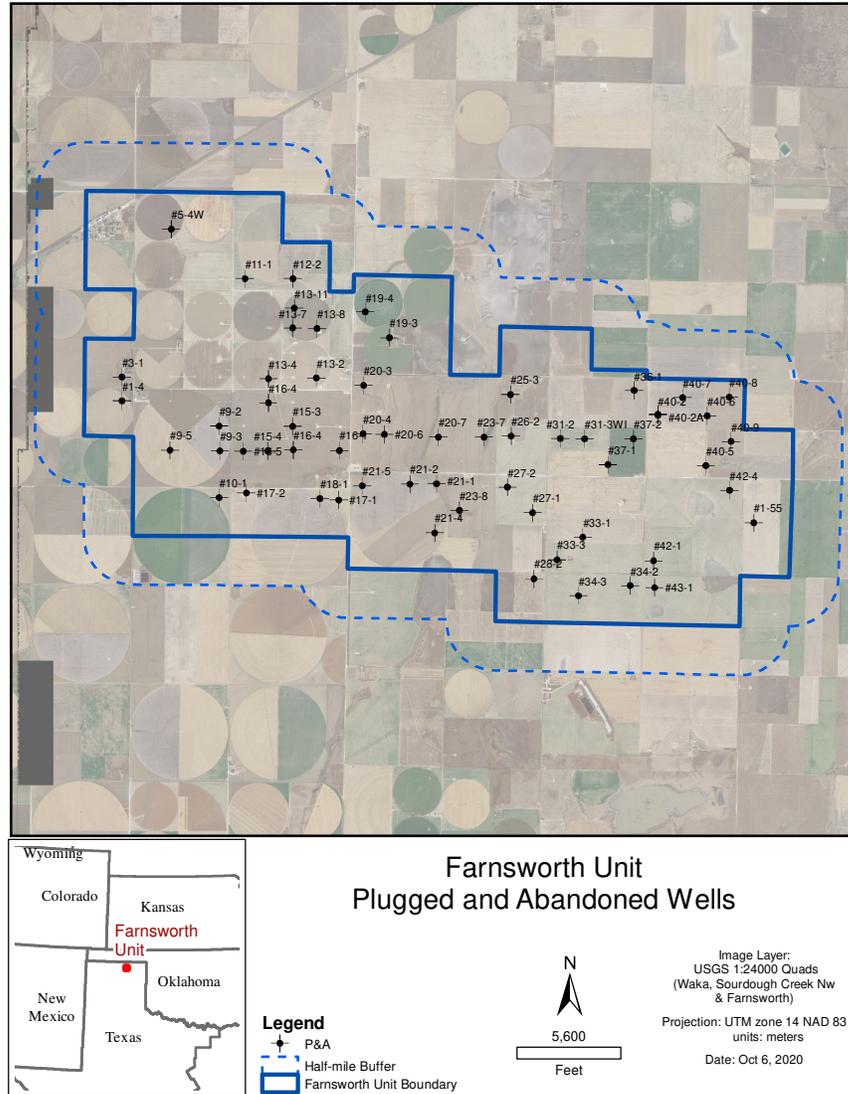


Figure 4.2-1: Plugged and Abandoned Wells in the FWU

4.2.2 Injection Wells

Mechanical integrity testing (MIT) is an essential requirement of the Underground Injection Control (UIC) program in demonstrating that injection wells themselves do not act as conduits for leakage into underground sources of drinking water (USDWs) and to the surface environment. Rule 46 and any special conditions pertaining to mechanical integrity testing the TRRC includes in the Class II permits issued to Perdure, ensure that active injection wells operate to be protective of subsurface and surface resources and the environment. Figure 4.2-2 and 4.2-3 shows the active and inactive, respectively, injection wells in the FWU. Perdure concludes that leakage of CO₂ to the surface through injection wells is unlikely.

4.2.3 Production Wells

Figure 4.2-2 4.2-3 shows the active and inactive, respectively, oil production wells in the FWU. However, as the project develops in the FWU additional production wells may be added and will be constructed according to the relevant rules of the TRRC. Additionally,

inactive wells may become active according to the rules of the TRRC. Perdure concludes that leakage of CO₂ to the surface through production wells is unlikely.

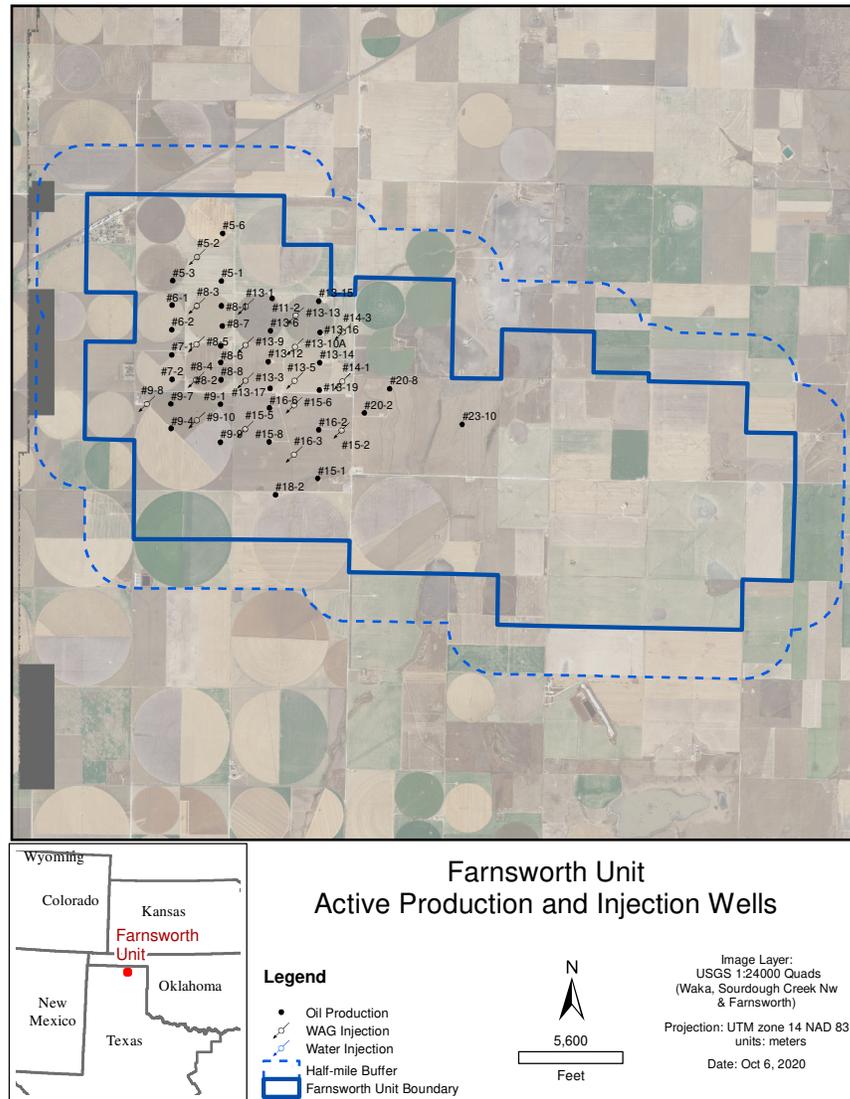


Figure 4.2-2: Active Production and Injection Wells in the FWU

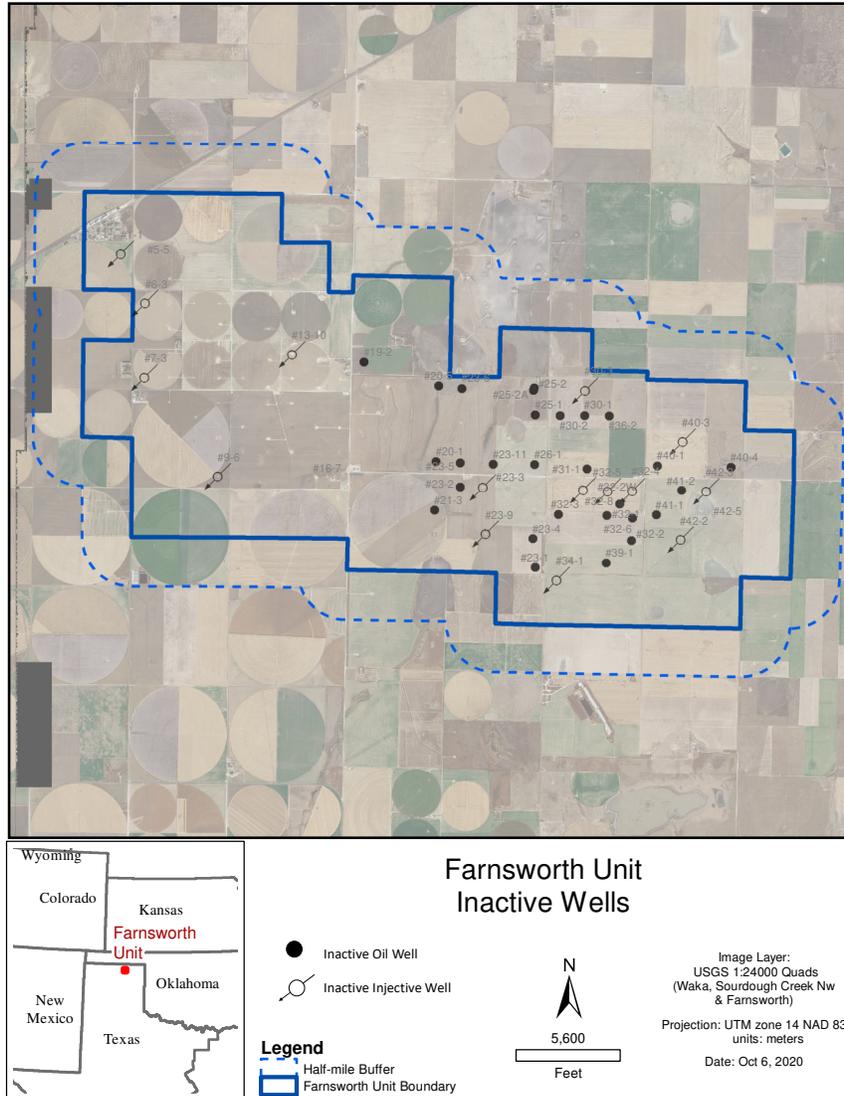


Figure 4.2-3: Inactive Production and Injection Wells in the FWU

4.2.4 Monitoring Well #13-10

The SWP has conducted monitoring of the Morrow B injection horizon and overlying seals in the area immediately adjacent to the new WAG injection well (#13-10A), through the use of a dedicated monitoring well (#13-10). This old WAG injection well (#13-10), drilled in 1971 to a total depth (TD) of 7770 feet, was repurposed for monitoring reservoir pressure and temperature, borehole temperature and microseismicity. To accomplish the task, the following equipment were permanently installed in the well:

- Downhole pressure and temperature gauges: Real time pressure and temperature monitoring of the reservoir
- Distributed Temperature Sensing (DTS): Real time monitoring of temperature along the wellbore for leakage detection.

- Sixteen level geophone array: Pseudo real time monitoring of passive and active (during injection and draw down cycles) microseismic activities within the FWU.
- Twenty surface seismometer stations: Monitor microseismic activities at the surface. Data is integrated with data from borehole geophone array to enhance event detection and location.

After the SWP has finished their Real time monitoring and their research efforts are completed Perdure may continue to observe and collect the data, but it will not be an ongoing part of the FWU MRV plan.

4.2.5 New Wells

As the project develops, new production wells and injection wells may be added to the FWU. All new wells will be constructed according to the relevant rules for the TRRC which ensure protection of subsurface and surface resources and the environment.

4.3 Leakage from Fractures, Faults and Bedding Plane Partings

Primary seals at FWU have been demonstrated to be mechanically very competent (see Section 2.2.2), thus the main concern of CO₂ migration at FWU is via seal bypass systems along fracture networks. The following several lines of analysis have been used to assess this risk in the area.

4.3.1 Presence of Hydrocarbons

The first and foremost argument against present day up-fault transmissibility is the 120 MMB of oil that was found trapped in the reservoir at the time of discovery (Munson, 1988). If significant escape pathways existed, oil would have drained from the reservoir prior to the current day.

4.3.2 Structural Analysis

The second argument against up-fault leakage are the results of an extensive field and regional analysis of core, 2D and 3D seismic data. 3D Reflection seismic data of the FWU was acquired in 2013 and reprocessed in 2017 to obtain a better image resolution. In-depth analysis of the reprocessed data gives us confidence that there are no significant faults or fractures in the field area. The Morrow B is only 60 feet thick in the area; below the resolution of the seismic signal to pick an exact top and base. Horizons identified as the Kansas City top, Thirteen Finger base, and as a reflector in the proximity of the Morrow B reservoir unit were picked in the 3D seismic data. Two horizons below the Morrow B, tentatively identified as the top of the Hunton limestone and top of the Sylvan shale, were also used in the structural analysis. A detailed isopach map of the Morrow B created from interpretation of 346 well logs were also used to crosscheck the seismic interpretation.

Reprocessed data (Hobbs et al.) shows a series of seismic horizons that dip gently and thicken slightly to the southeast (Figure 4.3-1), consistent with the location of FWU on the western edge of the Anadarko basin dictating that sedimentary packages should thicken and dip towards the center of the basin. The most prominent feature of the seismic data is an increase in the intensity of the reflectors in the central and western part of the field (Figure 4.3-2). Based on the bifurcation of reflectors and on their lateral morphological changes

they are interpreted as facies changes between carbonate or sandstone shelf deposits that transition laterally to shales. It is possible that such facies changes or channels could form preferential flow paths; however, these are relatively discontinuous, anastomosing, and irregular features that would not constitute a pathway to the surface. The structures visible in the seismic data can be interpreted as sedimentary/diagenetic features that include lateral facies changes, channel infills and karst collapse features.

In addition to the field-scale 3D seismic survey, over 70 mi of 2D seismic line in the region were used to constrain larger scale structural risk in the region. No faults were observed in any of the 2D lines.

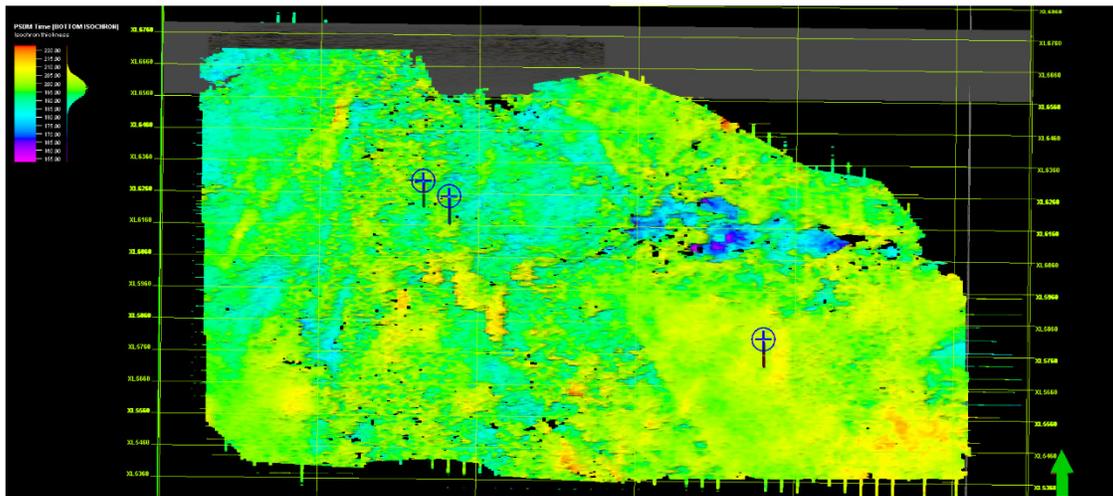
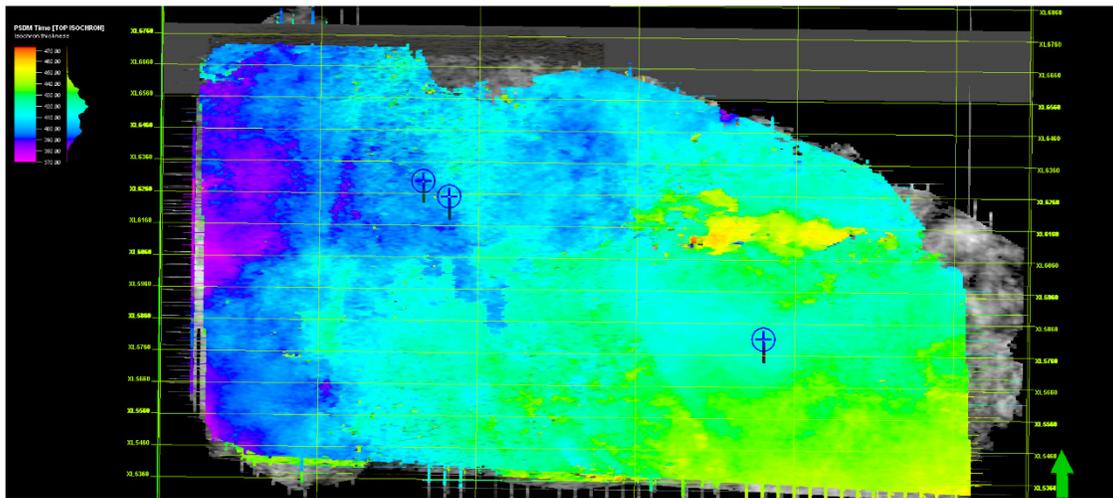
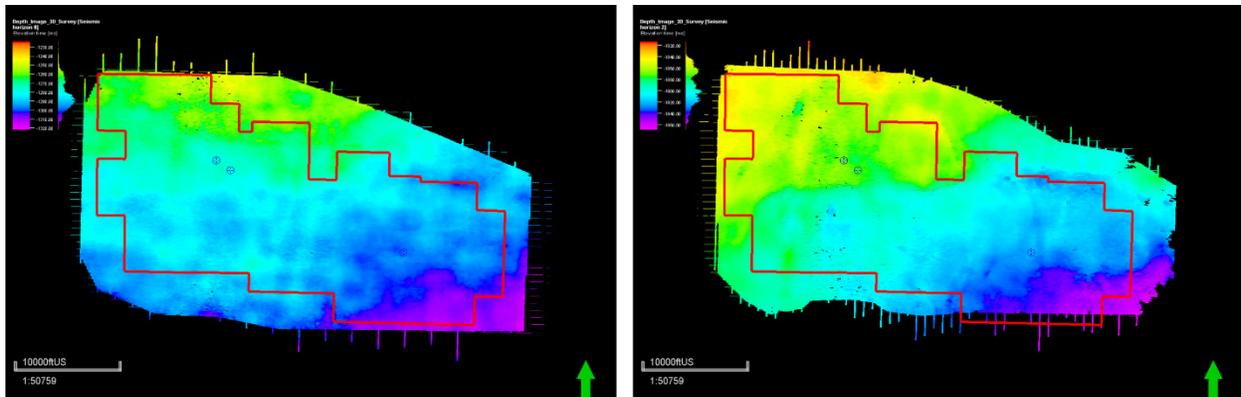


Figure 4.3-1 – a) depth (time) image of the Kansas City horizon (scale bar range – 1220-1320 milliseconds). b) depth (time) image of the Hunton base horizon (scale bar range – 1820-1960 milliseconds). c) Woodford base – Kansas City base isochron map (scale bar range – 470-370 milliseconds). d) Hunton base – Woodford base isochron map (scale bar range – 220-155 milliseconds).

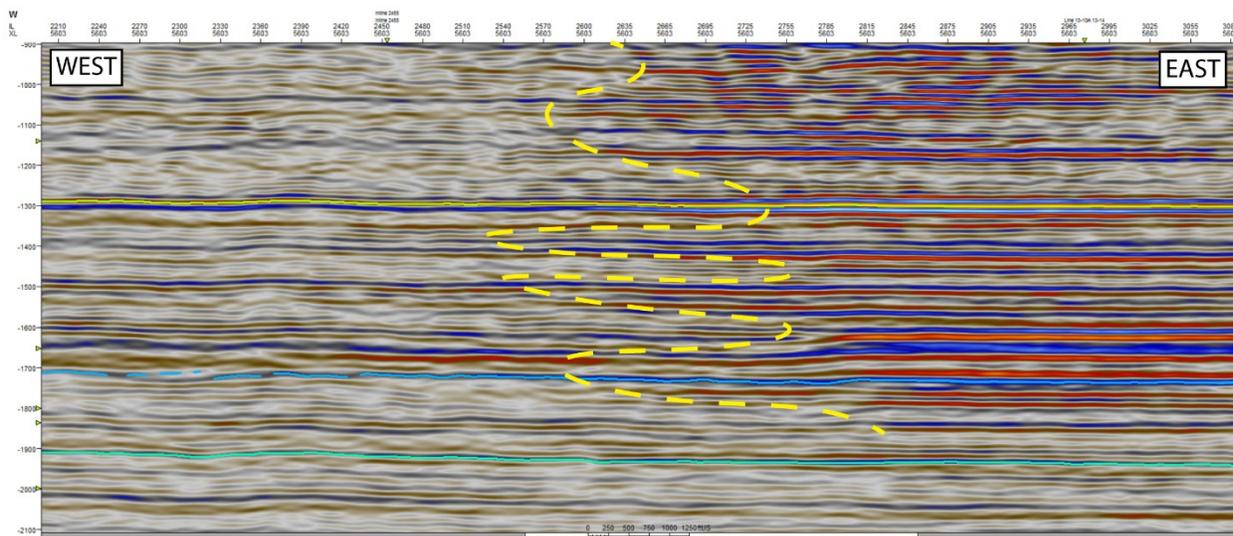
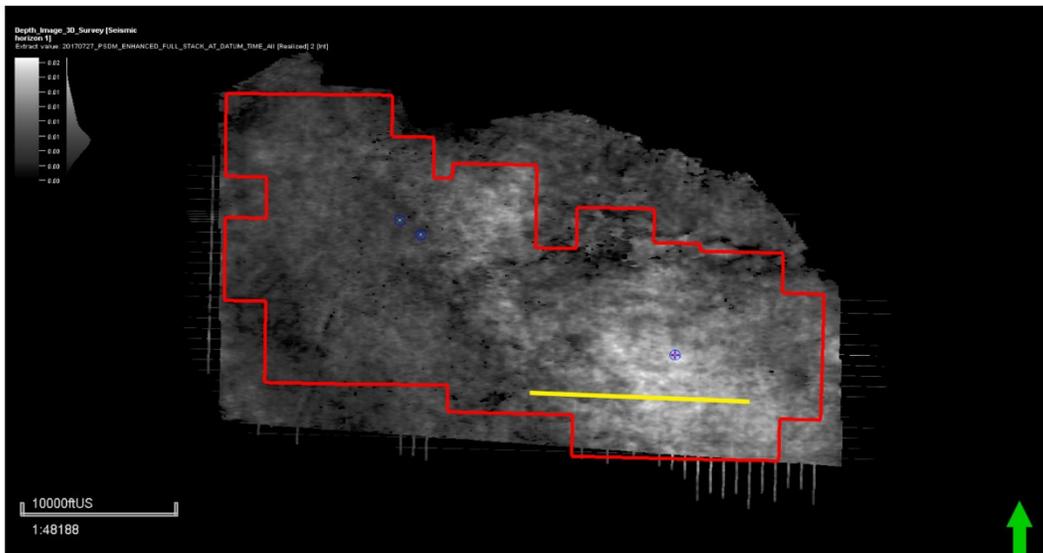


Figure 4.3-2 – a) amplitude intensity map of the base of the Woodford, yellow line shows location of the vertical seismic section. b) Lateral facies changes.

4.3.3 Fracture Analysis

Small aperture fractures were noted but not common in most of the reservoir cores we examined but most of these fractures appear to be drilling induced. Fractures in the Thirteen Finger limestone caprock were described using an industry-standard format for fracture class type, orientation, fracture dip, type of mineral fill, fracture porosity, fracture spacing, and intensity. Again, drilling induced fractures are most common. Natural mineral-filled fractures are quite rare, were formed during diagenesis at shallow depths, and are of Late Carboniferous age. Unless significantly damaged by large changes in reservoir pressure they are highly unlikely to provide migration pathways.

In the unlikely event CO₂ leakage occurs as a result of leakage through the faults and fractures it is unlikely that the leak would result in surface leakage. As with any CO₂ leakage, Perdure has strategies for leak detection in place that are discussed in Section 4.5 and the strategy to quantify the leak is discussed in Section 4.6.

4.4 Leakage Through Confining / Seal System

A variety of analytical methods were used for caprock (confining system) analysis. Petrologic examination included standard thin section petrography and backscattered electron microscopy. Petrophysical analytical methods include retort analysis, pulse-decay permeability measurement, pressure decay permeability analysis for tight rocks, and mercury injection porosimetry, which is also known as mercury injection capillary pressure (MICP). Geomechanical analysis involved a standard series of mechanical tests: Brazil tension, unconfined compression, triaxial compression, and multi-stress compression.

Results of the MICP analysis show that the mudstone lithologies in the Morrow Shale and Thirteen Finger Limestone can support CO₂ column heights of ~1,000 to 10,000 feet. At an order of magnitude over the thickness of the Morrow reservoir, this should prove an effective seal for CO₂ storage in the Morrow B injection horizon.

Failure analyses show that the Morrow B sands are weaker than overlying lithologies, so that any fracture initiation around the injection well would not be expected to propagate into the overlying sealing units. Mechanical properties of the overlying shale and limestones provide an interesting and effective combination of strength and elasticity. Limestone layers are strong but brittle, while the shale layers are weaker but sufficiently ductile to prevent extensive fracture propagation.

It is unlikely for hydrocarbon migration pathways that charged the Morrow reservoir to be potential CO₂ migration pathways via primary pore networks today. Any potential CO₂ migration would be most likely due to leakage from wellbores or bypass through fault and fracture networks, discussed in Sections 4.2 and 4.3.

In the unlikely event CO₂ leakage occurs as a result of leakage through the confining seal it is unlikely that the leak would result in surface leakage. As with any CO₂ leakage, Perdure has strategies for leak detection in place that are discussed in Section 4.5 and the strategy to quantify the leak is discussed in Section 4.6.

4.5 Strategy for Detection and Response of CO₂ Loss

As discussed above, the potential sources of leakage include fairly routine issues, such as problems with surface equipment (pumps, valves, etc.) or subsurface equipment (well bores), and unique events such as induced fractures. Table 1 summarizes some of these potential leakage scenarios, the monitoring activities designed to detect those leaks, Perdure's standard response, and other applicable regulatory programs requiring similar reporting.

The potential CO₂ losses discussed in the table are identified by type. Once the type is reported to a response manager the correct resources and personnel can be mobilized to

develop the optimal response procedure. The procedure will address and mitigate further CO₂ leakage.

Table 1 Response Plan for CO₂ Loss Known Potential Leakage Risks	Monitoring Methods and Frequency	Anticipated Response Plan
Tubing Leak	Monitor changes in annulus pressure; MIT for injectors	Workover crews respond within days
Casing Leak	Weekly field inspection; MIT for injectors; extra attention to high-risk wells	Workover crews respond within days
Wellhead Leak	Weekly field inspection	Workover crews respond within days
Loss of Bottom-hole pressure control	Blowout during well operations (weekly inspection but field personnel present daily)	Maintain well kill procedures
Unplanned wells drilled through Morrow	Weekly field inspection to prevent unapproved drilling; compliance with TRRC permitting for planned wells.	Assure compliance with TRRC regulations
Loss of seal in abandoned wells	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Re-enter and reseal abandoned wells
Pumps, valves, etc.	Weekly field inspection	Workover crews respond within days
Leakage along faults	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Shut in injectors near faults
Overfill beyond spill points	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Fluid management along lease lines
Leakage through induced fractures	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Comply with rules for keeping pressures below parting pressure
Leakage due to seismic event	Continuous monitoring of pressure in WAG skids; high pressure found in new wells as drilled	Shut in injectors near seismic event

4.6 Strategy for Quantifying CO₂ Losses

Major CO₂ losses are typically event driven and require a process to assess, address, track, and if applicable quantify potential CO₂ leakage to the surface. Perdure will reconcile the Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.

Given the uncertainty concerning the nature and characteristics of leaks that will be encountered, it is not clear the method for quantifying the volume of leaked CO₂ that would be most appropriate. In the event leakage occurs, Perdure will determine the most appropriate method for quantifying the volume leaked and will report the methodology used as required as part of the annual Subpart RR submission

Any volume of CO₂ detected leaking to surface will be quantified using acceptable emission factors such as those found in 40 CFR Part 98 Subpart W or engineering estimates of leak amounts based on measurements in the subsurface, Perdure's field experience, and other factors such as the frequency of inspection. As indicated in Sections 6.4, leaks will be documented, and the records of leakage events will be retained in the electronic

environmental documentation and reporting system. Repairs requiring a work order will be documented in the electronic equipment maintenance system.

Available studies of actual well leaks and natural analogs (e.g., naturally occurring CO₂ geysers) suggest that the amount released from routine leaks would be small as compared to the amount of CO₂ that would remain stored in the formation.

5 Strategy for Determining CO₂ Baselines for CO₂ Monitoring

Since conversion to a CO₂ EOR project in 2010, ongoing operational monitoring and several research projects at the FWU have provided data for establishing baselines of surface CO₂ leakage/emissions from the target injection zone for the CO₂, the Morrow B sandstone, and from surface equipment. The Site Characterization, Modeling, and Monitoring, Verification and Accounting (MVA) work conducted by the SWP provides the basis for established CO₂ baselines. Baseline groundwater monitoring conducted since 2013 indicates no leakage of CO₂ from underlying formations or wells into the local Ogallala aquifer. Soil flux monitoring also conducted since 2013 shows CO₂ flux ranging between 3 and 15 micromoles per second and square meter ($\mu\text{mol}/\text{m}^2/\text{sec}$) with variations generally attributed to seasonal changes and local crop growth patterns. Daily operational surface equipment inspection and periodic well surveillance monitoring are also conducted to ensure the integrity of infrastructure at the facility. Each of these is discussed in more detail below.

5.1 Site Characterization and Modeling

As described in Sections 2.2.2 and 2.4, the Morrow B sandstone is isolated both above and below by shale units of the Morrow. The primary seal consists of 180 – 200 ft of Morrow shale and Thirteen Finger Limestone which in turn is overlain by over a thousand feet of younger shale and limestone. These units provide a suitable seal to prevent the migration of CO₂ out of the injection reservoir. Additionally, no significant faults or fracture zones that cut across the seal units have been identified in the FWU, indicating that the most likely leakage pathway is from legacy wellbores that have been poorly completed/cemented.

Since 2013, several studies conducted by the SWP have evaluated the risk associated with leakage pathways through the seal units, including leakage of CO₂ to an overlying USDW or to the atmosphere through wellbores (Xiao et al, 2016, Xiao et al, 2017). The work of Ting et al (2017), in particular, looked at the potential geochemical impacts of CO₂-fluid interaction on typical cements used in regional wellbore completions, as well as the surrounding caprock. The diffusive flow of CO₂ and the mixing of brine fluids results in a reaction within the Portlandite wellbore cement, forming calcite. The calcite formation within the cement reduces the porosity of the cement, effectively sealing pathways. The calcium-silica-hydrate in the Portlandite, conversely, is not significantly degraded by the CO₂-fluids, suggesting that the wellbore maintains its integrity and structure. These self-sealing attributes of the wellbore cements of the FWU wells suggest that CO₂ injected into the Morrow B is not at risk of leakage to overlying units, USDWs or the atmosphere.

5.2 Groundwater Monitoring Wells

Since 2013, the Southwest Regional Partnership on Carbon Sequestration (SWP) has been regularly sampling and analyzing fluids from Ogallala aquifer groundwater wells in around the FWU (Figure 5.2-1). The SWP performs major ion and trace metal analyses to evaluate leakage of CO₂, brine and/or hydrocarbons from the Morrow B and shallower zones, and/or wellbores. To date, no indication of fluid leakage has been identified from any of the 14 groundwater monitoring wells in the area. Perdure is unlikely to continue monitoring USDW wells for CO₂ or brine contamination, as SWP studies (see section 5.1) have suggested minimal risk of groundwater contamination from CO₂ leakage from depth.

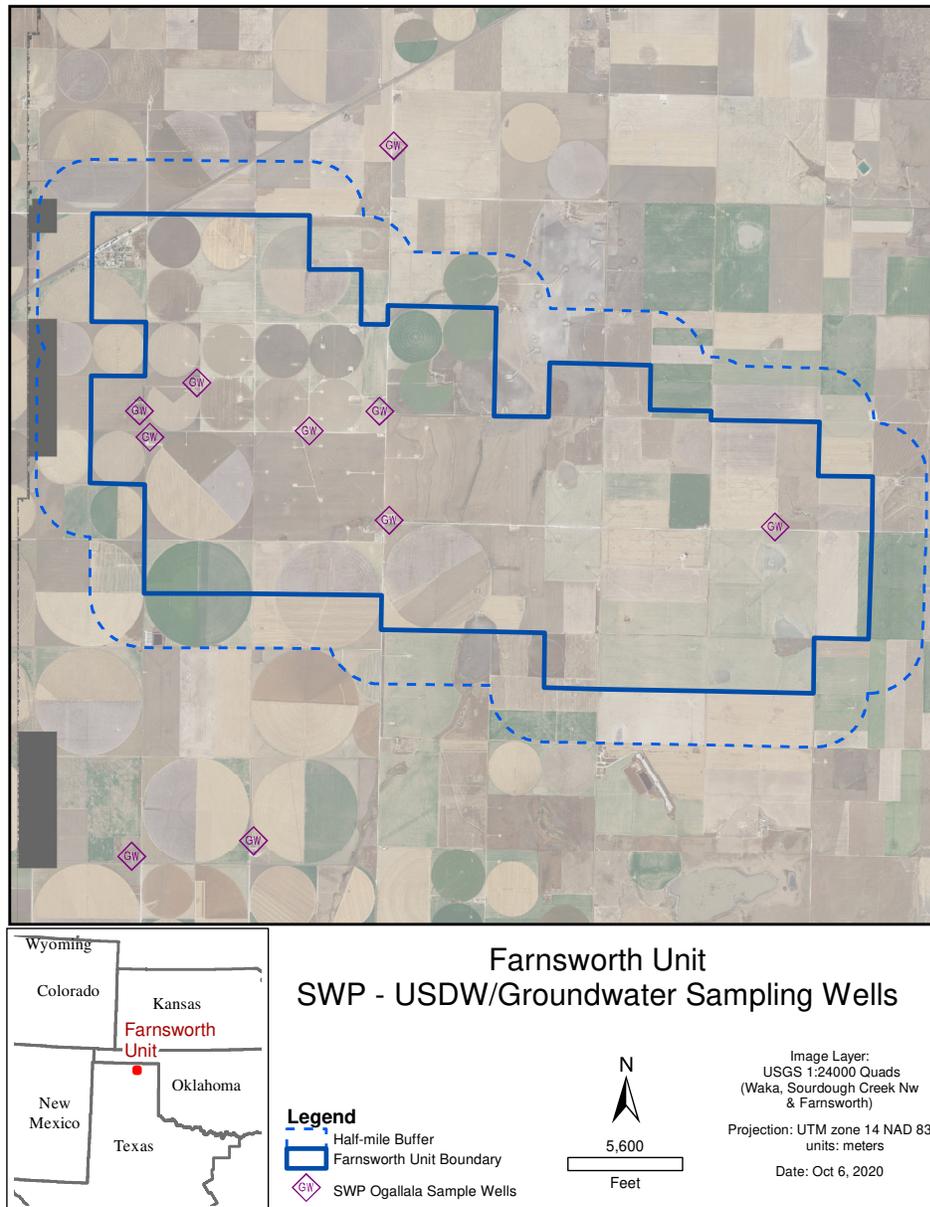


Figure 5.2-1: Ogallala groundwater monitoring wells

5.3 Soil CO₂ Monitoring

Since 2013, SWP has been conducting regular soil flux surveys within the western half of the FWU, to evaluate CO₂ leakage from the Morrow B. The SWP installed 94 PVC soil flux chamber collars around the 13-10A injection well (Figure 5.3-1); CO₂ soil flux was measured on a monthly basis, using a LiCor LI-8100 infrared gas analyzer, for a little over a year and then surveys were scaled back to once every 3 months. Soil flux values observed from the SWP surveys generally range between 3 and 15 μmol/m²/sec, with generally higher values in the summer due to plant respiration. To date, all CO₂ soil flux variations have been attributed to seasonal changes, and crop growth and rotation. The SWP soil flux collar network has identified no CO₂ leakage at the FWU, from any sources since monitoring activities began.

The data collected from the SWP has estimated that the atmospheric (approximately 3-meter elevation above the ground surface) baseline CO₂ concentration in the FWU area to be 390±10 ppmv (Parts Per Million by Volume), with CO₂ concentrations on the lower end of this range during the summer months and on the higher end of this range during the winter months. Any significant and consistent variance from this baseline will be investigated to determine the source of the CO₂ and if the CO₂ is determined to be leakage from the FWU then appropriate steps will be taken to measure and report the volumes, mitigate any leaks, and make any adjustments to the MRV plan that are required.

Atmospheric CO₂ values at the FWU have been determined by a SWP eddy tower installation. In winter 2019, the eddy system malfunctioned and has not been repaired due to COVID travel restrictions. However, the atmospheric CO₂ concentration data from the FWU eddy tower are in very good agreement with values obtained from the NOAA Global Monitoring Laboratory station in Moody, Texas (Station: WKT). Atmospheric CO₂ concentrations from the Moody, Texas station can be used for background CO₂ values in the FWU area.

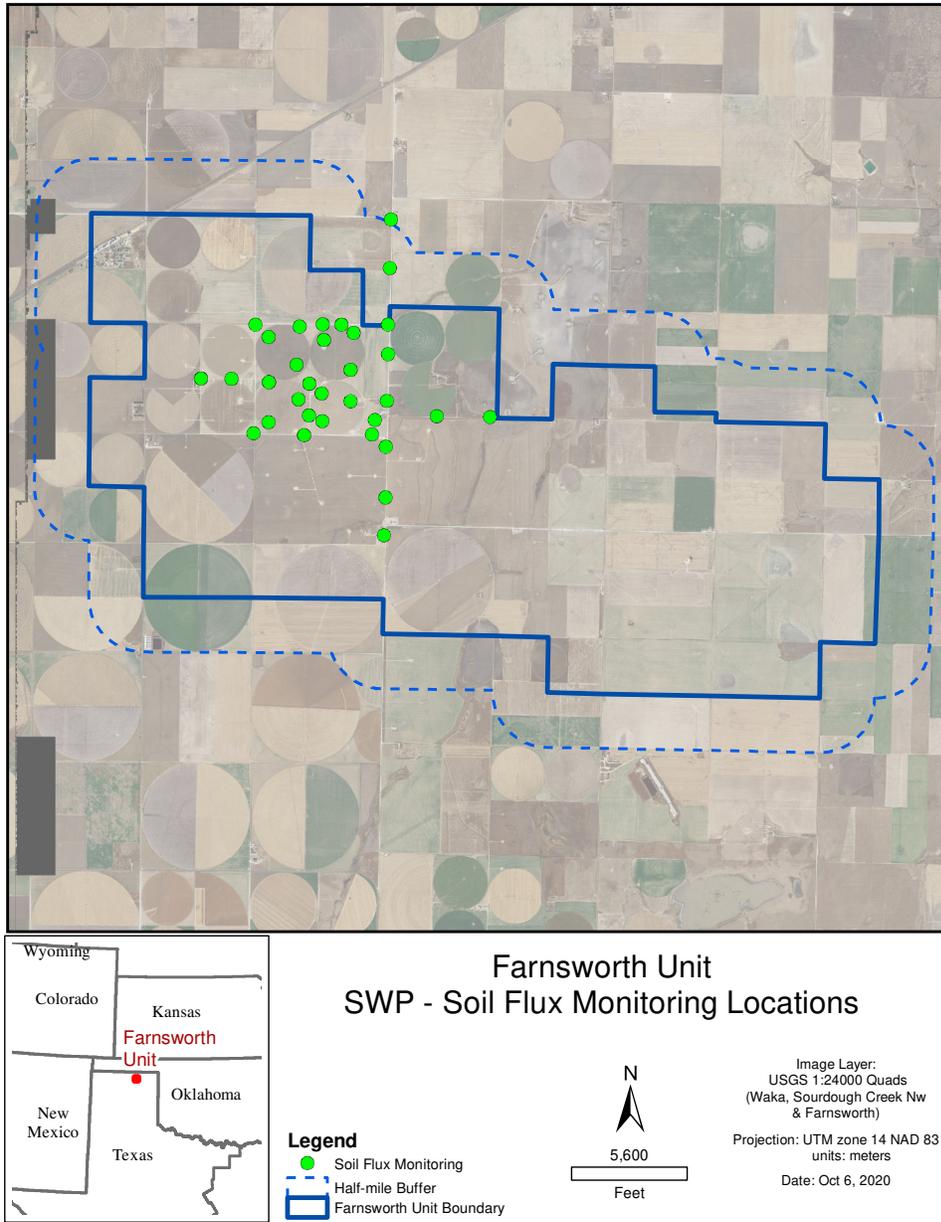


Figure 5.3 -1: Soil Flux

5.4 Visual Inspection

Perdure operational field personnel visually inspect surface equipment daily and report and act upon any event indicating leakage.

5.5 Well Surveillance

Perdure adheres to the requirements of Rule 46 for the TRRC governing fluid injection into productive reservoirs. Rule 46 includes requirements for monitoring, reporting, and testing of Class II injection wells. Furthermore, TRRC includes special conditions regarding monitoring, reporting, and testing in the individual permits for each injection well if they are deemed necessary.

Perdure also adheres to the requirements of Rule 20 for the TRRC governing the notification of a fires, breaks, leaks, or escapes. Rule 20 requires that all operators report leaks to TRRC including measured or estimated quantities of product leaked.

6 Site Specific Considerations for Determining the Mass of CO₂ Sequestered

Of the twelve RR equations in 98.443 of Subpart RR, the following are relevant to Perdure's operations.

6.1 Determining Mass of CO₂ Received

Perdure currently receives CO₂ to its FWU facility through their own pipeline from the Arkalon Ethanol plant in Liberal, Kansas. Perdure also recycles CO₂ from their production wells in the FWU.

$$CO_{2T,r} = \sum_{p=1}^4 (r_p - S_r) * D * C_{CO_2,p,r} \quad (\text{Equation RR-2})$$

where:

$CO_{2T,r}$ = Net annual mass of CO₂ received through flow meter r (metric tons).

r_p = Quarterly volumetric flow through a receiving flow meter r in quarter p at standard conditions (standard cubic meters).

S_r = Quarterly volumetric flow through a receiving flow meter r that is redelivered to another facility without being injected into your well in quarter p (standard cubic meters).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

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

p = Quarter of the year.

r = Receiving flow meter.

6.2 Determining Mass of CO₂ Injected

Perdure injects CO₂ into the injection wells listed in Appendix 1.

$$CO_{2,u} = \sum_{p=1}^4 r_{p,u} * D * C_{CO_2,p,u} \quad (\text{Equation RR-5})$$

where:

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

$Q_{p,u}$ = Quarterly volumetric flow rate measurement for flow meter u in quarter p at standard conditions (standard cubic meters per quarter).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

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

p = Quarter of the year.

u = Flow meter.

6.3 Determining Mass of CO₂ Produced from Oil Production Wells

Perdure also recycles CO₂ from its production wells which are part of its operations in the FWU. Therefore, the following equation is relevant to its operations.

$$CO_{2,w} = \sum_{p=1}^4 Q_{p,w} * D * C_{CO_2,p,w} \quad (\text{Equation RR-8})$$

Where:

$CO_{2,w}$ = Annual CO₂ mass produced (metric tons) through separator w.

$Q_{p,w}$ = Volumetric gas flow rate measurement for separator w in quarter p at standard conditions (standard cubic meters).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

$C_{CO_2,p,w}$ = CO₂ concentration measurement in flow for separator w in quarter p (vol. percent CO₂, expressed as a decimal fraction).

p = Quarter of the year.

w = Separator.

To aggregate production data, Perdure will sum the mass of all of the CO₂ separated at each gas-liquid separator in accordance with the procedure specified in Equation RR-9 below:

$$CO_{2P} = (1 + X) * \sum_{w=1}^W CO_{2,w} \quad (\text{Equation RR-9})$$

Where:

CO_{2P} = Total annual CO₂ mass produced (metric tons) through all separators in the reporting year.

$CO_{2,w}$ = Annual CO₂ mass produced (metric tons) through separator w in the reporting year.

X = Entrained CO₂ in produced oil or other fluid divided by the CO₂ separated through all separators in the reporting year (weight percent CO₂, expressed as a decimal fraction).

w = Separator.

6.4 Determining Mass of CO₂ Emitted by Surface Leakage

As required by 98.448 (d) of Subpart RR, Perdure will assess leakage from the relevant surface equipment listed in Sections 98.233 and 98.234 of Subpart W. According to 98.233 (r) (2) of Subpart W, the emissions factor listed in Table W-1A of Subpart W shall be used to estimate all streams of gases, including recycle CO₂ stream, for facilities that conduct EOR operations.

Perdure will calculate the total annual mass of CO₂ emitted from all leakage pathways in accordance with the procedure specified in Equation RR-10 below:

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

where:

CO_{2E} = Total annual CO₂ mass emitted by surface leakage (metric tons) in the reporting year.

$CO_{2,x}$ = Annual CO₂ mass emitted (metric tons) at leakage pathway x in the reporting year.

x = Leakage pathway.

6.5 Determining Mass of CO₂ Sequestered

The following Equation RR-11 pertains to facilities that are actively producing oil or natural gas.

$$CO_2 = CO_{2I} - CO_{2P} - CO_{2E} - CO_{2FI} - CO_{2FP} \quad \text{(Equation RR-11)}$$

Where:

CO_2 = Total annual CO₂ mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

CO_{2I} = Total annual CO₂ mass injected (metric tons) in the well or group of wells in the reporting year.

CO_{2P} = Total annual CO₂ mass produced (metric tons) in the reporting year.

CO_{2E} = Total annual CO₂ mass emitted (metric tons) by surface leakage in the reporting year.

CO_{2FI} = Total annual CO₂ mass emitted (metric tons) from equipment leaks and vented emissions of CO₂ 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 of the GHGRP.

CO_{2FP} = Total annual CO₂ mass emitted (metric tons) from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity, for which a calculation procedure is provided in subpart W of the GHGRP.

The following Equation RR-12 pertains to facilities that are not actively producing oil or natural gas. This equation may become relevant to Perdure's operation as it evolves in the future. However, this does not apply to Perdure's current operations.

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

CO_2 = Total annual CO₂ mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

CO_{2I} = Total annual CO₂ mass injected (metric tons) in the well or group of wells in the reporting year.

CO_{2E} = Total annual CO₂ mass emitted (metric tons) by surface leakage in the reporting year.

CO_{2FI} = Total annual CO₂ mass emitted (metric tons) from equipment leaks and vented emissions of CO₂ 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 of the GHGRP.

7 Estimated Schedule for implementation of MRV plan

Perdure expects to begin implementing the approved MRV plan when the new CO₂ capture facility is operational, January 1, 2022.

8 GHG Monitoring and Quality Assurance Program

Perdure will meet the monitoring and QA/QC requirements of 98.444 of Subpart RR including those of Subpart W for emissions from surface equipment as required by 98.444 (d).

8.1 GHG Monitoring

As required by 40 CFR 98.3(g)(5)(i), Perdure's 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 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.

8.1.1 General

Measurement of CO₂ Concentration – All measurements of CO₂ concentrations of any CO₂ quantity will be conducted according to an appropriate standard method published by a consensus-based standards organization or an industry standard practice such as the Gas Producers Association (GSA) standards.

Measurement of CO₂ Volume – All measurements of CO₂ volumes will be converted to the following standard industry temperature and pressure conditions for use in Equations RR-2, RR-5 and RR-8 of Subpart RR of the GHGRP: Standard cubic meters at a temperature of 60 degrees Fahrenheit and at an absolute pressure of 1 atmosphere. Perdure will adhere to the American Gas Association (AGA) Report #3 – (ORIFICE METERING OF NATURAL GAS AND OTHER RELATED HYDROCARBON FLUIDS)

8.1.2 CO₂ received.

Daily totalized volumetric flow meters are used to record CO₂ received via pipeline from the Arkalon ethanol plant in Liberal, Kansas. using a volumetric totalizer using accepted flow calculations for CO₂ according to the AGA Report #3.

8.1.3 CO₂ injected.

Daily CO₂ injection is recorded by combining the totals for the recycle compressor meter and the received CO₂ meter from Arkalon based on what's delivered on a 24-hour basis. This data is taken from the meter daily and stored in Perdure's data warehouse for records and reservoir management.

8.1.4 CO₂ produced.

The point of produced gas measurement is from a meter downstream of the compressors prior to being combined with purchase CO₂. The produced gas is sampled at least quarterly for the CO₂ content.

8.1.5 CO₂ emissions from equipment leaks and vented emissions of CO₂.

As required by 98.444 (d), Perdure will follow the monitoring and QA/QC requirements specified in Subpart W of the GHGRP for equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead and between the flow meter used to measure production quantity and the production wellhead.

As required by 98.448 (d) of Subpart RR, Perdure will assess leakage from the relevant surface equipment listed in Sections 98.233 and 98.234 of Subpart W. According to 98.233 (r) (2) of Subpart W, the emissions factor listed in Table W-1A of Subpart W shall be used to estimate all streams of gases, including recycle CO₂ stream, for facilities that conduct EOR operations. The default emission factors for production equipment are applied to the carbon capture utilization and storage (CCUS) injection operations reporting under Subpart RR.

8.1.6 Measurement devices.

As required by 40 CFR 98.444(e), Perdure 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) of 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, the American National Standards Institute (ANSI), the American Gas Association (AGA), the Gas Producers Association (GPA), the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API), and the North American Energy Standards Board (NAESB).
- All flow meters are National Institute of Standards and Technology (NIST) traceable.

8.2 QA/QC Procedures

Perdure will adhere to all QA/QC requirements in Subparts A, RR, and W of the GHGRP, 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.

8.3 Estimating Missing Data

Perdure will estimate any missing data according to the following procedures in 40 CFR 98.445 of Subpart RR of the GHGRP, as required.

- A quarterly flow rate of CO₂ received that is missing would be estimated using invoices or using a representative flow rate value from the nearest previous time period.
- A quarterly CO₂ concentration of a CO₂ stream received that is missing would be estimated using invoices or using a representative concentration value from the nearest previous time period.
- A quarterly quantity of CO₂ injected that is missing would be estimated using a representative quantity of CO₂ injected from the nearest previous period of time at a similar injection pressure.
- For any values associated with CO₂ emissions from equipment leaks and vented emissions of CO₂ from surface equipment at the facility that are reported in this subpart, missing data estimation procedures specified in subpart W of 40 CFR Part 98 would be followed.
- The quarterly quantity of CO₂ produced from subsurface geologic formations that is missing would be estimated using a representative quantity of CO₂ produced from the nearest previous period of time.

8.4 Revisions of the MRV Plan

Perdure will revise the MRV Plan as needed to reflect changes in production processes, monitoring instrumentation, and quality assurance procedures; or to improve procedures for the maintenance and repair of monitoring systems to reduce the frequency of monitoring equipment downtime.

9 Records Retention

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

- (1) A list of all units, operations, processes, and activities for which GHG emissions were calculated.
- (2) The data used to calculate the GHG emissions for each unit, operation, process, and activity. These data include:
 - (i) The GHG emissions calculations and methods used.
 - (ii) Analytical results for the development of site-specific emissions factors, if applicable.
 - (iii) The results of all required analyses.
 - (iv) Any facility operating data or process information used for the GHG emission calculations.
- (3) The annual GHG reports.
- (4) Missing data computations. For each missing data event, Perdure will retain a record of the cause of the event and the corrective actions taken to restore malfunctioning monitoring equipment.
- (5) A copy of the most recent revision of this MRV Plan.
- (6) 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.
- (7) Maintenance records for all continuous monitoring systems, flow meters, and other instrumentation used to provide data for the GHGs reported.
- (8) Quarterly records of CO₂ received, including mass flow rate of contents of container (mass or volumetric) at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- (9) Quarterly records of produced CO₂, including mass flow or volumetric flow at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- (10) Quarterly records of injected CO₂ including mass flow or volumetric flow at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.

- (11) Annual records of information used to calculate the CO₂ emitted by surface leakage from leakage pathways.
- (12) Annual records of information used to calculate the CO₂ emitted from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead.
- (13) Annual records of information used to calculate the CO₂ emitted from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity.
- (14) Any other records as specified for retention in this EPA-approved MRV plan.

10 Appendices

Appendix 1 - Perdure Wells

Table A1. 1 – Production wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#15-1	42357000600000	Oil Prod	Active	CO2	1	0
#8-2	42357004140000	Oil Prod	Active	CO2	1	0
#13-6	42357007960000	Oil Prod	Active	CO2	1	0
#9-1	42357009390000	Oil Prod	Active	CO2	1	0
#20-8	42357020580000	Oil Prod	Active	CO2	1	0
#7-1	42357020620000	Oil Prod	Active	CO2	1	0
#6-2	42357020630000	Oil Prod	Active	CO2	1	0
#8-1	42357020650000	Oil Prod	Active	CO2	1	0
#9-4	42357022130000	Oil Prod	Active	CO2	1	0
#23-10	42357300490000	Oil Prod	Active	CO2	1	0
#18-2	42357319870000	Oil Prod	Active	CO2	1	0
#8-6	42357330090000	Oil Prod	Active	CO2	1	0
#13-12	42357330130000	Oil Prod	Active	CO2	1	0
#9-9	42357330610000	Oil Prod	Active	CO2	1	0
#16-6	42357329830000	Oil Prod	Active	CO2	1	0
#15-8	42357330630000	Oil Prod	Active	CO2	1	0
#11-2	42357330000000	Oil Prod	Active	CO2	1	0
#13-14	42357331890000	Oil Prod	Active	CO2	1	0
#13-15	42357333730000	Oil Prod	Active	CO2	1	0
#13-16	42357331930000	Oil Prod	Active	CO2	1	0

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#13-17	42357333990000	Oil Prod	Active	CO2	1	0
#13 -19	42357333740000	Oil Prod	Active	CO2	1	0
#16-2	42357000770002	Oil Prod	Active	CO2	1	0
#20-2	42357811240000	Oil Prod	Active	CO2	1	0
#5-1	42357810720000	Oil Prod	Active	CO2	1	0
#5-3	42357810740001	Oil Prod	Active	CO2	1	0
#5-6	42357334110000	Oil Prod	Active	CO2	1	0
#6-1	42357020640001	Oil Prod	Active	CO2	1	0
#7-2	42357810800000	Oil Prod	Active	CO2	1	0
#8-7	42357334050000	Oil Prod	Active	CO2	1	0
#8-8	42357334130000	Oil Prod	Active	CO2	1	0
#9-7	42357810910000	Oil Prod	Active	CO2	1	0
#30-1	42357002490000	Oil Prod	Inactive	CO2	0	0
#30-2	42357002510000	Oil Prod	Inactive	CO2	0	0
#20-1	42357004700000	Oil Prod	Inactive	CO2	0	0
#40-4	42357005140000	Oil Prod	Inactive	CO2	0	0
#23-2	42357007760000	Oil Prod	Inactive	CO2	0	0
#19-2	42357806010000	Oil Prod	Inactive	CO2	0	0
#41-1	42357009990000	Oil Prod	Inactive	CO2	0	0
#20-32	42357020390000	Oil Prod	Inactive	CO2	0	0
#23-6	42357811400000	Oil Prod	Inactive	CO2	0	0
#21-3	42357020670000	Oil Prod	Inactive	CO2	0	0
#41-2	42357021920000	Oil Prod	Inactive	CO2	0	0
#32-3	42357022060000	Oil Prod	Inactive	CO2	0	0
#36-2	42357023350000	Oil Prod	Inactive	CO2	0	0
#31-1	42357023370000	Oil Prod	Inactive	CO2	0	0
#32-1	42357023450000	Oil Prod	Inactive	CO2	0	0
#23-5	42357023680000	Oil Prod	Inactive	CO2	0	0
#25-2A	42357300990000	Oil Prod	Inactive	CO2	0	0
#23-11	42357313550000	Oil Prod	Inactive	CO2	0	0
#32-6	42357319890000	Oil Prod	Inactive	CO2	0	0
#40-1	42357811720000	Oil Prod	Inactive	CO2	0	0
#25-1	42357811450000	Oil Prod	Inactive	CO2	0	0
#26-1	42357811480000	Oil Prod	Inactive	CO2	0	0
#32-8	42357334100000	Oil Prod	Inactive	CO2	0	0
#39-1	42357811710000	Oil Prod	Inactive	CO2	0	0
#43-2	42357008020000	Oil Prod	Inactive	CO2	0	0
J ORTHA E 1	42357005100002	Oil Prod	Inactive	CO2	0	0
#42-1	42357000040000	Oil Prod	P&A	CO2	0	0
#4-1	42357001560000	Oil Prod	P&A	CO2	0	0
#16-4	42357004760000	Oil Prod	P&A	CO2	0	0

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#23-8	42357007790000	Oil Prod	P&A	CO2	0	0
#3-1	42357009340000	Oil Prod	P&A	CO2	0	0
#9-3	42357009400000	Oil Prod	P&A	CO2	0	0
#17-1	42357003410000	Oil Prod	P&A	CO2	0	0
#19-4	42357806030000	Oil Prod	P&A	CO2	0	0
#15-4	42357023340000	Oil Prod	P&A	CO2	0	0
#31-2	42357023360000	Oil Prod	P&A	CO2	0	0
#40-2	42357023480000	Oil Prod	P&A	CO2	0	0
#13-8	42357023490000	Oil Prod	P&A	CO2	0	0
#13-2	42357023500000	Oil Prod	P&A	CO2	0	0
#13-4	42357023510000	Oil Prod	P&A	CO2	0	0
#13-7	42357023520000	Oil Prod	P&A	CO2	0	0
#9-2	42357023530000	Oil Prod	P&A	CO2	0	0
#17-1	42357003410000	Oil Prod	P&A	CO2	0	0
#19-4	42357806030000	Oil Prod	P&A	CO2	0	0
#15-4	42357023340000	Oil Prod	P&A	CO2	0	0
#31-2	42357023360000	Oil Prod	P&A	CO2	0	0
#40-2	42357023480000	Oil Prod	P&A	CO2	0	0
#13-8	42357023490000	Oil Prod	P&A	CO2	0	0
#13-2	42357023500000	Oil Prod	P&A	CO2	0	0
#13-4	42357023510000	Oil Prod	P&A	CO2	0	0
#13-7	42357023520000	Oil Prod	P&A	CO2	0	0
#37-1	42357811680000	Oil Prod	P&A	CO2	0	0
BOESE 1	42357003010000	Oil Prod	P&A	CO2	0	0

Table A1.2 – Water Alternating Gas (WAG) Injection Wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#13-1 (INJ)	42357007950000	WAG Inj	Active	CO2	0	1
#13-3 (INJ)	42357007940000	WAG Inj	Active	CO2	0	1
#13-5 (INJ)	42357007990000	WAG Inj	Active	CO2	0	1
#13-9 (INJ)	42357811020000	WAG Inj	Active	CO2	0	1
#13-10A (INJ)	42357331790000	WAG Inj	Active	CO2	0	1
#13-13 (INJ)	42357333320000	WAG Inj	Active	CO2	0	1
#14-1 (INJ)	42357020410000	WAG Inj	Active	CO2	0	1
#15-2 (INJ)	42357811100000	WAG Inj	Active	CO2	0	1
#15-5 (INJ)	42357020300000	WAG Inj	Active	CO2	0	1
#15-6 (INJ)	42357301210000	WAG Inj	Active	CO2	0	1
#16-3 (INJ)	42357004720000	WAG Inj	Active	CO2	0	1
#5-2 (INJ)	42357023310000	WAG Inj	Active	CO2	0	1

#8-3 (INJ)	42357810840000	WAG Inj	Active	CO2	0	1
#8-4 (INJ)	42357003990000	WAG Inj	Active	CO2	0	1
#8-5 (INJ)	42357301160000	WAG Inj	Active	CO2	0	1
#9-10 (INJ)	42357330770000	WAG Inj	Active	CO2	0	1
#9-8 (INJ)	42357301860000	WAG Inj	Active	CO2	0	1
#11-1 (INJ)	42357020350000	WAG Inj	Inactive	CO2	0	0
#13-10 (INJ)	42357301030000	Monitor	Inactive	None	0	0

Table A1.3 – Water Source Wells (WSW)

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#1 (WSW)	42357810690000	WSW	Active	CO2	0	0
#2 (WSW)	42357810700000	WSW	Active	CO2	1	0

Table A1.4 – Water Injection Wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#23-9 (INJ)	42357020380000	Wtr Inj	Inactive	CO2	0	0
#30-3 (INJ)	42357020470000	Wtr Inj	Inactive	CO2	0	0
#32-2 (INJ)	42357811590000	Wtr Inj	Inactive	CO2	0	0
#32-4 (INJ)	42357811610000	Wtr Inj	Inactive	CO2	0	0
#32-5 (INJ)	42357317680001	Wtr Inj	Inactive	CO2	0	0
#34-1 (INJ)	42357020500000	Wtr Inj	Inactive	CO2	0	0
#40-3 (INJ)	42357811740000	Wtr Inj	Inactive	CO2	0	0
#42-2 (INJ)	42357811820000	Wtr Inj	Inactive	CO2	0	0
#42-3 (INJ)	42357020330001	Wtr Inj	Inactive	CO2	0	0
#6-3 (INJ)	42357303410000	Wtr Inj	Inactive	CO2	0	0
#7-3 (INJ)	42357302540000	Wtr Inj	Inactive	CO2	0	0
#9-6 (INJ)	42357020340000	Wtr Inj	Inactive	CO2	0	0
#10-1 (INJ)	42357009380000	Wtr Inj	Inactive	CO2	0	0
#14-2 (INJ)	42357002670001	Wtr Inj	Inactive	CO2	0	0
#16-5 (INJ)	42357020370000	Wtr Inj	P&A	CO2	0	0
#19-3 (INJ)	42357806020000	Wtr Inj	P&A	CO2	0	0
#20-5 (INJ)	42357252290000	Wtr Inj	P&A	CO2	0	0
#20-6 (INJ)	42357020360000	Wtr Inj	P&A	CO2	0	0
#20-7 (INJ)	42357020450000	Wtr Inj	P&A	CO2	0	0
#21-1 (INJ)	42357020310000	Wtr Inj	P&A	CO2	0	0
#21-2 (INJ)	42357020270000	Wtr Inj	P&A	CO2	0	0
#21-4 (INJ)	42357020280000	Wtr Inj	P&A	CO2	0	0
#25-3 (INJ)	42357020460000	Wtr Inj	P&A	CO2	0	0
#26-2 (INJ)	42357020420000	Wtr Inj	P&A	CO2	0	0
#31-3 (INJ)	42357020480000	Wtr Inj	P&A	CO2	0	0
#33-1 (INJ)	42357000290000	Wtr Inj	P&A	CO2	0	0
#33-3 (INJ)	42357021340000	Wtr Inj	P&A	CO2	0	0
#34-2 (INJ)	42357008730000	Wtr Inj	P&A	CO2	0	0
#36-1 (INJ)	42357020490000	Wtr Inj	P&A	CO2	0	0
#37-2 (INJ)	42357811690000	Wtr Inj	P&A	CO2	0	0
#40-7 (INJ)	42357811780000	Wtr Inj	P&A	CO2	0	0
#42-4 (INJ)	42357010010000	Wtr Inj	P&A	CO2	0	0
#14-3 (INJ)	42357020660000	Wtr Inj	P&A	CO2	0	0
#15-3 (INJ)	42357006060000	Wtr Inj	P&A	CO2	0	0
#16-1 (INJ)	42357020400000	Wtr Inj	P&A	CO2	0	0
#23-7 (INJ)	42357020430000	Wtr Inj	P&A	CO2	0	0
#40-9 (INJ)	42357020570000	Wtr Inj	P&A	CO2	0	0

Appendix 2 - Referenced Regulations

U.S. Code > Title 26. INTERNAL REVENUE CODE > Subtitle A. Income Taxes > Chapter 1. NORMAL TAXES AND SURTAXES > Subchapter A. Determination of Tax Liability > Part IV. CREDITS AGAINST TAX > Subpart D. Business Related Credits > [Section 45Q - Credit for carbon oxide sequestration](#)

Texas Administrative Code (TAC) > Title 16 - Economic Regulation > Part 1 – Railroad Commission of Texas > [Chapter 3 – Oil and Gas Division](#)

Rules

- §3.1 Organization Report; Retention of Records; Notice Requirements
- §3.2 Commission Access to Properties
- §3.3 Identification of Properties, Wells, and Tanks
- §3.4 Oil and Geothermal Lease Numbers and Gas Well ID Numbers Required on All Forms
- §3.5 Application to Drill, Deepen, Reenter, or Plug Back
- §3.6 Application for Multiple Completion
- §3.7 Strata to Be Sealed Off
- §3.8 Water Protection
- §3.9 Disposal Wells
- §3.10 Restriction of Production of Oil and Gas from Different Strata
- §3.11 Inclination and Directional Surveys Required
- §3.12 Directional Survey Company Report
- §3.13 Casing, Cementing, Drilling, Well Control, and Completion Requirements
- §3.14 Plugging
- §3.15 Surface Equipment Removal Requirements and Inactive Wells
- §3.16 Log and Completion or Plugging Report
- §3.17 Pressure on Bradenhead
- §3.18 Mud Circulation Required
- §3.19 Density of Mud-Fluid
- §3.20 Notification of Fire Breaks, Leaks, or Blow-outs
- §3.21 Fire Prevention and Swabbing
- §3.22 Protection of Birds
- §3.23 Vacuum Pumps
- §3.24 Check Valves Required
- §3.25 Use of Common Storage
- §3.26 Separating Devices, Tanks, and Surface Commingling of Oil
- §3.27 Gas to be Measured and Surface Commingling of Gas
- §3.28 Potential and Deliverability of Gas Wells to be Ascertained and Reported
- §3.29 Hydraulic Fracturing Chemical Disclosure Requirements
- §3.30 Memorandum of Understanding between the Railroad Commission of Texas (RRC) and the Texas Commission on Environmental Quality (TCEQ)
- §3.31 Gas Reservoirs and Gas Well Allowable
- §3.32 Gas Well Gas and Casinghead Gas Shall Be Utilized for Legal Purposes

§3.33	Geothermal Resource Production Test Forms Required
§3.34	Gas To Be Produced and Purchased Ratably
§3.35	Procedures for Identification and Control of Wellbores in Which Certain Logging Tools Have Been Abandoned
§3.36	Oil, Gas, or Geothermal Resource Operation in Hydrogen Sulfide Areas
§3.37	Statewide Spacing Rule
§3.38	Well Densities
§3.39	Proration and Drilling Units: Contiguity of Acreage and Exception Thereto
§3.40	Assignment of Acreage to Pooled Development and Proration Units
§3.41	Application for New Oil or Gas Field Designation and/or Allowable
§3.42	Oil Discovery Allowable
§3.43	Application for Temporary Field Rules
§3.45	Oil Allowables
§3.46	Fluid Injection into Productive Reservoirs
§3.47	Allowable Transfers for Saltwater Injection Wells
§3.48	Capacity Oil Allowables for Secondary or Tertiary Recovery Projects
§3.49	Gas-Oil Ratio
§3.50	Enhanced Oil Recovery Projects--Approval and Certification for Tax Incentive
§3.51	Oil Potential Test Forms Required
§3.52	Oil Well Allowable Production
§3.53	Annual Well Tests and Well Status Reports Required
§3.54	Gas Reports Required
§3.55	Reports on Gas Wells Commingling Liquid Hydrocarbons before Metering
§3.56	Scrubber Oil and Skim Hydrocarbons
§3.57	Reclaiming Tank Bottoms, Other Hydrocarbon Wastes, and Other Waste Materials
§3.58	Certificate of Compliance and Transportation Authority; Operator Reports
§3.59	Oil and Gas Transporter's Reports
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§3.63	Carbon Black Plant Permits Required
§3.70	Pipeline Permits Required
§3.71	Pipeline Tariffs
§3.72	Obtaining Pipeline Connections
§3.73	Pipeline Connection; Cancellation of Certificate of Compliance; Severance
§3.76	Commission Approval of Plats for Mineral Development
§3.78	Fees and Financial Security Requirements
§3.79	Definitions
§3.80	Commission Oil and Gas Forms, Applications, and Filing Requirements
§3.81	Brine Mining Injection Wells
§3.83	Tax Exemption for Two-Year Inactive Wells and Three-Year Inactive Wells

- §3.84 Gas Shortage Emergency Response
- §3.85 Manifest to Accompany Each Transport of Liquid Hydrocarbons by Vehicle
- §3.86 Horizontal Drainhole Wells
- §3.91 Cleanup of Soil Contaminated by a Crude Oil Spill
- §3.93 Water Quality Certification Definitions
- §3.95 Underground Storage of Liquid or Liquefied Hydrocarbons in Salt Formations
- §3.96 Underground Storage of Gas in Productive or Depleted Reservoirs
- §3.97 Underground Storage of Gas in Salt Formations
- §3.98 Standards for Management of Hazardous Oil and Gas Waste
- §3.99 Cathodic Protection Wells
- §3.100 Seismic Holes and Core Holes
- §3.101 Certification for Severance Tax Exemption or Reduction for Gas Produced From High-Cost Gas Wells
- §3.102 Tax Reduction for Incremental Production
- §3.103 Certification for Severance Tax Exemption for Casinghead Gas Previously Vented or Flared
- §3.106 Sour Gas Pipeline Facility Construction Permit
- §3.107 Penalty Guidelines for Oil and Gas Violations

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Appendix 4 - Abbreviations and Acronyms

2D – 2 dimensional
3D – 3 dimensional
AGA – American Gas Association
AMA – Active Monitoring Area
ANSI – American National Standards Institute
API – American Petroleum Institute
ASTM - American Society for Testing and Materials
Bscf – billion standard cubic feet
B/D – barrels per day
bopd – barrels of oil per day
C4 – butane
C5 – pentane
C7 – heptane
C7+ - standard heptane plus
CCE – constant composition expansion
CCUS – carbon capture utilization and storage
cf – cubic feet
CH₄ – methane
CO₂ – carbon dioxide
EOR – Enhanced Oil Recovery
EOS – Equation of State
EPA – US Environmental Protection Agency
ESD – Emergency Shutdown Device
FWU – Farnsworth Unit
GHG – Greenhouse Gas
GHGRP – Greenhouse Gas Reporting Program
GPA – Gas Producers Association
H₂S – hydrogen sulfide
mD – millidarcy(ies)
MICP – mercury injection capillary pressure
MIT – mechanical integrity test
MMA – maximum monitoring area
MMB – million barrels
MMP – minimum miscible pressure
MMscf – million standard cubic feet
MMstb – million stock tank barrels
MRV – Monitoring, Reporting, and Verification
MMMT – Million metric tonnes
MT -- Metric tonne
NIST - National Institute of Standards and Technology
NAESB – North American Energy Standards Board
OOIP – Original Oil-In-Place

OWC – oil water contact
PPM – Parts Per Million
psia – pounds per square inch absolute
PVT – pressure, volume, temperature
QA/QC – quality assurance/quality control
RMS – root mean square
SEM – scanning electron microscope
SWP - Southwest Regional Partnership on Carbon Sequestration
TAC – Texas Administrative Code
TD – total depth
TRRC – Texas Railroad Commission
TSD – Technical Support Document
TVDSS – True Vertical Depth Subsea
UIC – Underground Injection Control
USDW – Underground Source of Drinking Water
WAG – Water Alternating Gas (Gas is recycled CO₂ and purchase CO₂)
XRD – x-ray diffraction

Appendix 5 - Conversion Factors

Perdure reports CO₂ at standard conditions of temperature and pressure as defined in the State of Texas in the Texas Administrative Code for the Oil and Gas Division, Rule 3.79 as follows:

Cubic foot of gas or standard cubic foot of gas--The volume of gas contained in one cubic foot of space at a standard pressure base and at a standard temperature base. The standard pressure base shall be 14.65 pounds per square inch absolute, and the standard temperature base shall be 60 degrees Fahrenheit.

To calculate CO₂ mass from CO₂ volume, EPA recommends using the database of thermodynamic properties developed by the National Institute of Standards and Technology (NIST). This online database is available at:

<https://webbook.nist.gov/chemistry/fluid/>

It provides density of CO₂ using the Span and Wagner equation of state (EOS) at a wide range of temperature and pressures.

At State of Texas standard conditions, the Span and Wagner EOS gives a density of CO₂ of 0.002641684 lb-moles per cubic foot. Converting the CO₂ density in units of metric tonnes per cubic foot:

$$Density_{CO_2} \left(\frac{MT}{ft^3} \right) = Density_{CO_2} \left(\frac{lb - moles}{ft^3} \right) \times MW_{CO_2} \times \frac{1 MT}{2204.62 lbs}$$

Where:

$$Density_{CO_2} = \text{Density of CO}_2 \text{ in metric tonnes (MT) per cubic foot}$$

$$Density_{CO_2} = 0.002641684$$

$$MW_{CO_2} = 44.0095$$

$$Density_{CO_2} = 5.2734 \times 10^{-5} \frac{MT}{ft^3} \text{ or } 5.2734 \times 10^{-2} \frac{MT}{Mcf}$$

The conversion factor 5.2734×10^{-2} MT/Mcf is used to convert CO₂ volumes in standard cubic feet to CO₂ mass in metric tonnes.

**Request for Additional Information: Farnsworth Unit (FWU)
December 16, 2020**

Instructions: Please enter responses into this table. Any long responses, references, or supplemental information may be attached to the end of the table as an appendix. Supplemental information may also be provided in a resubmitted MRV plan.

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
1.	1.1	5	The MRV Plan states that the Reporter Number is TBD. Is the Farnsworth Unit CO2 Flood already a reporter under GHGRP, GHGRP ID: 544683?	Added GHGRP ID: 544683 to the revised document.
2.	Multiple	6, 11	There are several acronyms and/or abbreviations used that are undefined. It may be helpful to define them on first use. These include, for example, XRD, SEM, Ma, and DOT, among others.	Explained XRD, SEM, Ma, and DOT terms in the revised document.
3.	2.2.2	6	Throughout the document, certain units are expressed or spelled in different ways. In just one paragraph, for example, feet, ft, and ' are used to represent feet. Consistency may be helpful.	Changed ft to feet in the revised document. Removed ft from list of acronyms.

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
4.	2.2.2.2	9-10	<p>“There is currently a lack of research on the state of groundwater flow in the deeper formations in the Anadarko Basin.”</p> <p>“The FWU CO₂ injection and production operations will not cause water to flow to outcrops of the Late Carboniferous (Pennsylvanian) time period that extend from Brownwood, Texas, to the Jacksboro/Bowie, Texas, area, which are hundreds of miles away (The Paleontology Portal).”</p> <p>The first statement in the paragraph for section 2.2.2.2, “There is a current lack of research...”, is at odds with the certainty in the final sentence in the paragraph which asserts, “...operations will not cause water to flow...”. Please clarify the availability of information regarding groundwater flow and how this informed the conclusions in the MRV plan. Additionally, some context/background on the Carboniferous outcrops would be useful.</p>	<p>“Lack of research” was clarified in revised document to include the following.</p> <p>Information about Morrowan and Atokan formation water flow during oil operations has not been discovered in any oil or gas company published reports or academic research studies in the Anadarko Basin.</p> <p>The Carboniferous is a geologic period and system that cover 60 million years from the Devonian Period 358.9 million years ago, to the beginning of the Permian Period, 298.9 million years ago. As noted in the Section 2.2.2.1, the Morrowan and Atokan intervals of the FWU were deposited approximately 315-300 million years ago and are contained in the Carboniferous period.</p>
5.	2.3	10	<p>“CO₂ liberated from the ethanol plant is delivered via pipeline to the field for injection.”</p> <p>Figure 2.3-1: “Arkalon Ethanol Plant fresh CO₂”</p> <p>Is the word “captured” more accurate than “liberated” in this context? Additionally, please specify what is meant by “fresh” CO₂ – this term should be defined.</p>	<p>Changed “liberated” to captured in the revised document.</p> <p>Relabel figure to “Arkalon Ethanol Plant – Fermentation CO₂”</p>
6.	2.3 Slight wording changes	10-12	<p>It is not clear what takes place at the “all well test sites” (AWT) and the central tank battery (CTB). It would be helpful if the activities/operations at these two sets of operations/facilities were more clearly defined and distinguished.</p>	<p>Slight wording changes</p>
7.	2.3.1 See added language	11	<p>Please specify what “totalizer meter” is, what it measures, and where measurements are made in the FWU.</p>	<p>See added language</p>

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
8.	2.3.1	11	<p>“The CO2 is transported via a DOT regulated pipeline to the FWU and a totalizer meter for the purchase fresh CO2 is located in the field where data for 24-hour flow rates are recorded. Gas produced from the wells is compressed and metered by a similar flow totalizer meter as the purchase CO2 recorded daily.”</p> <p>These statements are unclear, potentially due to typos. Should the word “purchase” in two places be “purchased”? Also, in the phrase “purchase CO2 recorded daily”, should the word “is” appear after CO2? Please clarify.</p>	<p>Changed to “The purchased CO₂ from the fermentation process is transported via a United States Department of Transportation (DOT) regulated pipeline to the FWU. A totalizer meter, for the purchased CO₂, is located in the field where instantaneous data is summed into a 24-hour flow rate and recorded” in the revised document.</p>
9.	2.3.1 See added language	11	<p>“The daily injection volume of the purchase and recycle will be 24 MMCFD. Of this volume 12 MMCFD is purchase CO2 and 12 MMCFD is recycle. This ratio of fresh CO2 to the recycled CO2 is expected to change over time, with the percentage of recycled CO2 increasing and purchases decreasing. The current reservoir management plan projects that purchases will decline after 2033.”</p> <p>These statements are unclear. Are the 12 MMCFD purchased and 12 MMCFD recycled <u>current</u> flows or will this be the case sometime in the future? Will purchases cease or decline after 2033? Section 2.1.1 states that CO₂ will be injected for an additional 12 years (presumably from 2020). Also, the text states that these values change over time, so the rates should be tied to a particular point in time. Please clarify the injection plan.</p>	<p>Changed to “When the MRV plan becomes active, the daily injection volume of the combined purchased CO₂ and recycled CO₂ will be 24 MMCFD. Of this volume 12 MMCFD is purchased CO₂ and 12 MMCFD is recycled CO₂. This ratio of purchased CO₂ to recycled CO₂ is expected to change over time, with the percentage of recycled CO₂ increasing and purchased CO₂ decreasing. The current reservoir management plan projects that CO₂ purchases will remain constant at 12 MMCFD for 12 years and decline after 2033. (Per Reservoir Characterization and Modelling, the CO₂ purchases ceased at the end of 2033.)” in the revised document.</p> <p>See added language</p>
10.	2.3.2	11	<p>“Each well is tested every thirty days, if possible, and try not to exceed 60 days.”</p> <p>This sentence is unclear.</p>	<p>Changed to “Each well is production tested every thirty to sixty days after the last production test or returned to production.” In the revised document.</p>

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
11.	2.3.2 See added language.	12	<p>“All gas and water are reinjected, and the oil, which contains 2,930 ppm CO2 (0.293%), is sold out of tanks.”</p> <p>How is the value of 2,930 ppm determined or measured? Does this correspond to the value of X in Equation RR-9? See also item 32.</p>	<p>Added, “Annually, the oil from the stock tank is analyzed by a laboratory using ASTM crude oil analysis methods” to the revised document.</p> <p>It is the final CO2 that is not separated from the crude oil and is part of X in Equation RR-9.</p>
12.	2.3.2 See added language	12	<p>“FWU production has trace amounts of hydrogen sulfide (H2S), which is toxic. There are approximately 8-10 workers on the ground in the FWU at any given time, and all field and contractor personnel are always required to wear H2S detectors.”</p> <p>The plan mentions that personal H2S monitors will be used to detect leakage, but there is no further discussion of how emissions detected from H2S detectors will be quantified or estimated. Given that there are “trace” amounts of H2S entrained in the produced fluids, how will detection be observed, and leaked volumes measured or estimated? Is there an estimate for the H2S composition of the gas? What is the detection limit of the H2S monitors?</p>	<p>Added clarification, “The primary purpose of the H2S detectors is protecting people from the risk of being harmed. The detection limit of the H2S detectors is quantified for readings in the range of 0-100 ppm and will sound an alarm above 10 ppm. The secondary purpose H2S detectors would be to provide an indication of emissions of gas from a pipeline or surface equipment, that might go unnoticed by other observations or measurements. No gas volumes can be calculated based on the detector reading or alarm; only a H2S leakage is detected and located. Once identified, further detection and quantification will proceed as discussed in sections 4.5, 4.6, 5.4 and 8.1.5 of this MRV plan.”</p>
13.	2.3.3	12	<p>“The water content has been recorded to be < 20# MMCF, thus dehydration is not necessary.”</p> <p>This is not clear, especially “< 20# MMCF”. Please correct or elaborate as necessary.</p>	<p>Changed “#”, the unit of mass chiefly used in the USA, to “pounds mass” in the revised document.</p>
14.	2.4.1	15	<p>“The upscaled model, which uses only the western half of FWU, has a grid size of 176×163× 8 for a total of 229,504 cells that are 100 ft on a side.”</p> <p>Should the end of the sentence read “100 ft on each side”?</p>	<p>Changed “cells that are 100 ft on a side.” to “cells that are approximately 100 feet by 100 feet on their top view perspective” in the revised document.</p>

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
15.	2.4.3	18	<p>“This confirms some doubts operator had on gas production history measurements during the primary and secondary recovery processes of the field.”</p> <p>Should the word “the” be included after “some doubts” in this sentence?</p>	Added “the” in revised document.
16.	2.4.4 See added language	19-20	<p>“Currently the operator plans to convert existing five water injectors to WAG wells in addition to existing 20 WAG wells.”</p> <p>This sentence is unclear, please revise.</p>	<p>Revised in document.</p> <p>“Per the current plan of the operator, five existing water injection wells will be converted to WAG wells and were included in the CO2 prediction model.”</p>
17.	2.4.4 See added language	20	<p>“Additional 5 years was run to ascertain the movement of CO2 post-injection period.”</p> <p>This sentence is unclear. Is this in reference to the model?</p>	<p>Revised in document.</p> <p>“Per §98.449 Definitions, the modelled area is projected to contain the free phase CO2 plume at the end of year t + 5</p>
18.	3.1 See added language	20	<p>“The modeling described in Section 2.4 indicates that the majority of the CO2 will remain in the reservoir.”</p> <p>This statement is unclear and conclusory. Does this mean that some portion of the CO2 will leak out of the reservoir? There is nothing in Section 2.4 that discussed CO2 in the reservoir, except that “About 93% of the purchased CO2 remains as of August 2020.” This refers to past performance, while the referenced sentence refers to future performance. Please clarify what “majority” means, and over what time frame this is meant to apply. Furthermore, please explain how the modeling supports the conclusions drawn.</p>	<p>Unclear and conclusory statement revised and explained in revised document.</p> <p>“The purchase volumes that are displayed in figure 2.4.7 and the mapped CO2 composition results that are displayed in Section 3.1.1 indicate that all of the CO2 will remain in modelled area is projected to contain the free phase CO2 plume at the end of year t + 5; barring unforeseen future operational issues.”</p>

No.	MRV Plan		EPA Questions	Responses
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19.	4	23	§ 98.448 states that the MRV plan should identify “potential surface leakage pathways for CO2 in the maximum monitoring area and the likelihood, magnitude, and timing, of surface leakage of CO2 through these pathways.” Also, it states that the plan should describe a “... strategy for detecting and quantifying any surface leakage of CO2.” As applied to several elements as described in items 20-31 below, more information is necessary to satisfy these requirements. Some of the explanation for Section 4 may be included in the narrative for Section 5. In those cases, references to that discussion would help.	Added section 4.5 to discuss leak detection strategy and section 4.6 to discuss quantifying the leakage.
20.	4	23	Can more information be provided on the number of wells in the FWU, including production wells, injection wells, monitoring wells, P&A'd wells and any other identified inactive wells?	Specific total well counts have been added to section 4.2
21.	4.1	23	Can more explanation be provided on the strategy for detecting and quantifying any surface leakage of CO2 from surface equipment?	See section 4.1 revisions regarding surface equipment leaks. Strategy is patrolling, preventative maintenance and proper materials.
22.	4.2	23-25	Even though the plan states that the leakage from wells is unlikely, can more explanation be provided on the strategy for detecting and quantifying any leakage of CO2 from wells, however unlikely, should it occur? If leakage does occur, how would such leakage be detected and quantified? This applies to all well categories.	Referenced section 4.5 and 4.6
23.	4.2.3	26	There is no indication of the well types in the legend of Figure 4.2-3. Please address.	Added well symbol legend to Figure 4.2-3

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
24.	4.2.4 See change	26-27	What role, if any, will the existing monitoring wells serve in this MRV plan? The plan describes what equipment was installed in these wells previously, and how they were used for research purposes, but later states that the long-term usage of these wells will be reduced or may cease. Thus, their role in this MRV plan for possibly monitoring for and quantifying potential leakage is unclear. Please clarify.	See change "After the SWP has finished their Real time monitoring and their research efforts are completed Perdure may continue to observe and collect the data, but it will not be an ongoing part of the FWU MRV plan."
25.	4.3.2	28	<p>"Other notable features have been interpreted as We conclude that the structures visible in the seismic data can be interpreted as sedimentary/diagenetic features that include lateral facies changes, channel infills and karst collapse features."</p> <p>It appears that text was lost after "have been interpreted as..." or some other editorial work is needed here. Please address.</p>	Deleted "Other notable features have been interpreted as We conclude that" from revised document
26.	4.3 See added comment	28-30	Even though the plan states that the leakage from fractures, faults and bedding plane partings is unlikely, can more explanation be provided on the strategy for detecting and quantifying any leakage of CO2 from such features, however unlikely, should it occur? If leakage does occur, how would such leakage be detected and quantified?	See added comment "In the unlikely event CO ₂ leakage occurs as a result of leakage through the faults and fractures it is unlikely that the leak would result in surface leakage. As with any CO ₂ leakage, we will quantify the volumes according to the procedures in Subpart W of the GHGRP described in Section 6.4."
27.	4.4 See added comment	31	Even though the plan states that the leakage through confining/seal systems is unlikely, can more explanation be provided on the strategy for detecting and quantifying any leakage of CO2 through confining/seal systems, however unlikely, should it occur? If leakage does occur, how would such leakage be detected and quantified?	See added comment "In the unlikely event CO ₂ leakage occurs as a result of leakage through the confining seal it is unlikely that the leak would result in surface leakage. As with any CO ₂ leakage, we will quantify the volumes according to the procedures in Subpart W of the GHGRP described in Section 6.4."

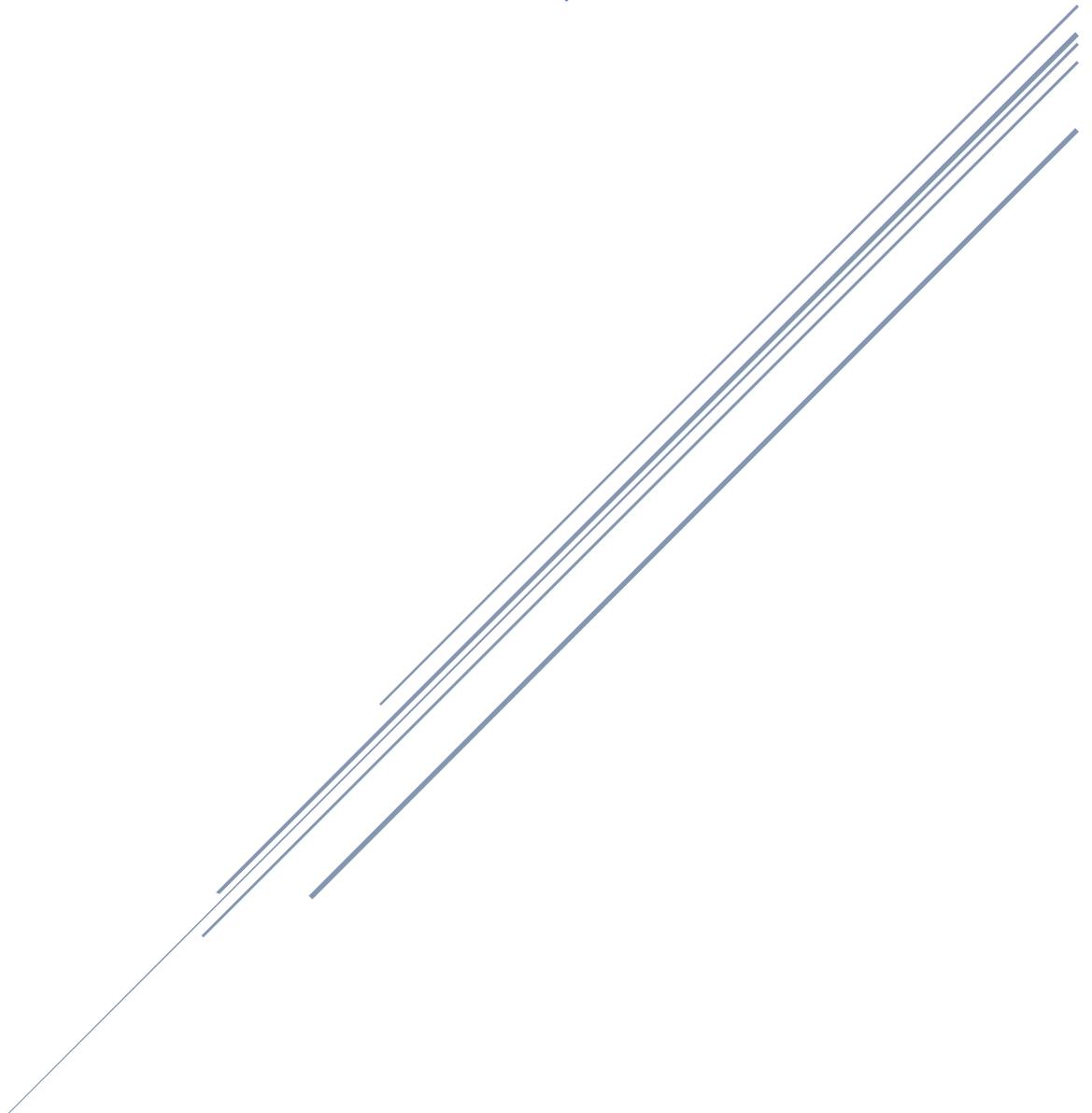
No.	MRV Plan		EPA Questions	Responses
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28.	5	31-35	Please provide additional information regarding the strategy for establishing the expected baselines for monitoring CO2 surface leakage. For example, how is the baseline used to determine potential surface leakage?	Section 5 has been rewritten to present material in a more logical order. Beginning with site characterization and modeling focused on the target injection zone and seal (confining zone), then upward to the groundwater monitoring of the Ogallala aquifer, then to shallow soil flux monitoring, then finally monitoring of surface equipment and well surveillance. Site characterization and modeling indicates low risk for leakage from the target zone and ground water monitoring to date indicates no evidence of fluid leakage from the target zone therefore, justifying the discontinuation of ground water monitoring. Soil flux monitoring background data collected to date reveal a range of CO2 flux attributed to seasonal changes and local crop growth patterns. Any ongoing soil flux monitoring data significantly and consistently above this range will trigger investigation and action if deemed necessary. Any indication of leakage from surface equipment or from injection wells as evidenced by failed mechanical integrity tests will trigger investigation and remedial action as appropriate.
29.	5.2 this has been moved to 5.5	31	“Rule 46 includes requirement for monitoring, reporting, and testing of Class II injection wells.” Should “requirement” be “requirements”?	Changed requirement to requirements in revised document.
30.	5.3 & 5.4 Ground water monitoring is now in 5.2; soil flux monitoring is now in 5.3	32-33	What role, if any, will the existing groundwater monitoring wells and soil CO2 monitoring serve in this MRV plan to monitor for possible leakage? The plan describes what has been performed in the past, and how these activities were used for research purposes, but later states that the future usage of these monitoring approaches “may” continue to be used. Thus, their role in this MRV plan is unclear. Please clarify.	The operator is unlikely to continue monitoring USDW wells for CO2 or brine contamination, as SWP studies have suggested minimal risk of groundwater contamination from CO2 leakage from depth.

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
31.	5.5 this has been moved to 5.2	34-35	What role, if any, will the previous site characterization and modeling work serve in this MRV plan for establishing a baseline for monitoring for possible leakage? The plan describes what has been performed in the past, and states that this work demonstrates that the likelihood of leakage is small, but does not describe how this will be used to establish a baseline to determine if leakage does occur, however unlikely. Thus, their role in this MRV plan is unclear. Please clarify.	In the revised Section 5, site characterization and modeling are presented as providing the basis for establishing CO2 baseline data and the justification for discontinuing groundwater monitoring (Section 5.2).
32.	6.3 & 8.1.4 See added comment	36 & 39	Equation RR-9 of Subpart RR requires reporting of the amount of CO2 entrained in the produced oil. This is represented by X in Equation RR-9. No mention is made in Section 8.1.4 on how the value for X will be determined, or how the CO2 entrained in the oil is represented. As stated in No. 11 above, the oil is said to contain 2,930 ppm CO2 (0.293%), but it does not state how this value is determined or measured, or how it corresponds to the value of X in Equation RR-9. Please address.	Covered in item No. 11 above. See added comment
33.	8.1.1	39	“Perdure will adhere to the American Gas Association (AGA) Report #3 – Orifice Metering” Please complete/correct the punctuation of this sentence.	Corrected to “Perdure will adhere to the American Gas Association (AGA) Report #3 – (ORIFICE METERING OF NATURAL GAS AND OTHER REIATED HYDROCARBON FLUIDS)” in the revised document.

Farnsworth Unit, Texas (FWU)

MONITORING, REPORTING, AND VERIFICATION PLAN

Perdure Petroleum, LLC



November, 2020

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Introduction

Perdure Petroleum, LLC (Perdure) operates the Farnsworth Unit (FWU) located in Ochiltree County, Texas for the primary purpose of enhanced oil recovery (EOR) using carbon dioxide (CO₂) with a subsidiary or ancillary purpose of geologic sequestration of CO₂ in a subsurface geologic formation. The discovery date of the field was October 26, 1955 and the FWU was unitized December 6, 1963 by Union Oil Company of California for the purpose of waterflooding with fresh water sourced from the Ogallala formation. The field structure is a lenticular bedding sand trending northwest to southeast with the average top of sand at 7990 feet, true vertical depth. Perdure has been operating the FWU since 2017. Perdure acquired the FWU from Chaparral Energy LLC, which initiated the CO₂-EOR project in December 2010. Perdure intends to continue CO₂-EOR operations until the end of the economic life of the CO₂-EOR program using various Class II injection wells as defined by Underground Injection Control (UIC) regulations and permitted under Texas Railroad Commission Statewide Rule 46. In this document, the term “gas” usually means a mixture of hydrocarbon light end components and the CO₂ component that can be produced as part of the EOR process.

Perdure has chosen to submit this Monitoring, Reporting, and Verification (MRV) plan to EPA for approval according to 40 CFR 98.440 (c)(1), Subpart RR of the Greenhouse Gas Reporting Program (GHGRP) for the purpose of qualifying for the tax credit in section 45Q of the federal Internal Revenue Code.

This MRV Plan contains ten sections:

Section 1 contains facility information.

Section 2 contains the project description including: a detailed description of the injection operation including the duration and volume of CO₂ to be injected; a detailed description of the geology and hydrogeology of the FWU located on the northwest shelf of the Anadarko basin and a detailed characterization of the injection reservoir and modeling techniques employed.

Section 3 contains the delineation of the maximum monitoring area (MMA) and the active monitoring area (AMA), both defined in 40 CFR 98.449, and as required by 40 CFR 98.448(a)(1), Subpart RR of the GHGRP.

Section 4 identifies the potential surface leakage pathways for CO₂ in the MMA and evaluates the likelihood, magnitude, and timing, of surface leakage of CO₂ through these pathways as required by 40 CFR 98.448(a)(2), Subpart RR of the GHGRP. This section also describes the strategy for detecting, verifying, and quantifying any surface leakage of CO₂ as required by 40 CFR 98.448(a)(3), Subpart RR of the GHGRP. Finally, this section also demonstrates that the risk of CO₂ leakage through the identified pathways is minimal.

Section 5 describes the strategy for establishing the expected baselines for monitoring CO₂ surface leakage as required by 40 CFR 98.448(a)(4), Subpart RR of the GHGRP.

Section 6 provides a summary of the considerations used to calculate site-specific variables for the mass balance equation as required by 40 CFR 98.448(a)(5), Subpart RR of the GHGRP.

Section 7 provides the estimated schedule for implementation of this MRV Plan as required by 40 CFR 98.448(a)(7).

Section 8 describes the quality assurance and quality control procedures that will be implemented for each technology applied in the leak detection and quantification process. This section also includes a discussion of the procedures for estimating missing data as detailed in 40 CFR 98.445.

Section 9 describes the records to be retained according to the requirements of 40 CFR 98.3(g) of Subpart A of the GHGRP and 40 CFR 98.447 of Subpart RR of the GRGRP.

Section 10 includes Appendices supporting the narrative of the MRV Plan.

1 Facility Information

1.1 Reporter number
TBD

1.2 UIC permit class
For injection wells that are the subject of this MRV plan, the Texas Railroad Commission (TRRC) has issued Underground Injection Control (UIC) Class II enhanced recovery permits under its State Rule 46 (see Appendix 2). All wells in the FWU, including both injection and production wells, are regulated by TRRC, which has primacy to implement the UIC Class II program.

1.3 UIC injection well identification numbers
A list of the injection wells in the FWU is provided in Appendix 1. The details of the injection process are provided in Section 2.3.

2 Project Description

2.1 Project characteristics

2.1.1 Estimated years of CO₂ injection

It is currently projected that Perdure will inject CO₂ for an additional 12 years.

2.1.2 Estimated volume of CO₂ injected over lifetime of project

The chart to the left in Figure 2.4-7 in Section 2.4 - Reservoir Characterization Modeling shows the forecasted simulated cumulative CO₂ injection volume of approximately 180 billion standard cubic feet (Bscf) or 9.5 million metric tonnes (MMMT) through October 2032. For the period September 2020 through October 2032, an additional 52.5 Bscf or 2.77 MMT will be stored in the FWU.

2.2 Environmental Setting of the MMA

2.2.1 Boundary of the MMA

Perdure has defined the boundary of the MMA as equivalent to the boundary of the FWU plus ½ mile beyond. A discussion of the methods used in delineating the MMA and the AMA are presented in Section 3.

2.2.2 Geology and hydrogeology

The geological discussions in Sections 2.2.2 and 4.3-4.4 are based on analysis of logs from over 140 wells, descriptions of cores from 8 wells including 3 recently cored that included sections from overlying seals as well as the shale underlying the main reservoirs, petrographic thin section descriptions and point counts as well as a variety of special analytical techniques including XRD and SEM analysis, carbon isotope analysis, and a variety of mechanical tests. 2D and 3D geophysical surveys were also used as part of this study. Details of recent geological investigations can be found in Gallagher (2014), Gragg (2016), Rasmussen et al (2019), Rose-Coss et al (2015), Trujillo (2018), Hobbs et al (2019), and Gragg et al (2018).

2.2.2.1 Tectonic Setting and Stratigraphy

The FWU is located on the northwest shelf of the Anadarko basin (Figure 2.2-1) and is one of many oil fields in the area that produce from a sequence of alternating sandstones and mudstones deposited during the late-Pennsylvanian Morrowan period. Oil production and CO₂ injection at FWU is restricted to the operationally-named Morrow B sandstone; the uppermost Morrow sandstone encountered below the Atokan Thirteen Finger limestone. The primary caprock intervals at FWU are comprised of the upper Morrow shale and the Thirteen Finger limestone (Figure 2.2-2). The Morrowan and Atokan intervals were deposited approximately 315-300 Ma. Overlying stratigraphy includes Late Pennsylvanian through the middle Permian shales and limestones, with lesser amounts of dolomite, sandstone and evaporites. The reservoir is approximately 60 feet thick through the field and lies at a depth of approximately 7600-7700 ft. The primary seal rocks of the Morrow shale and the Thirteen Finger Limestone comprise a package of approximately 180-200' thickness in the field and are overlain by thousands of feet of Atokan and younger limestones and shales.

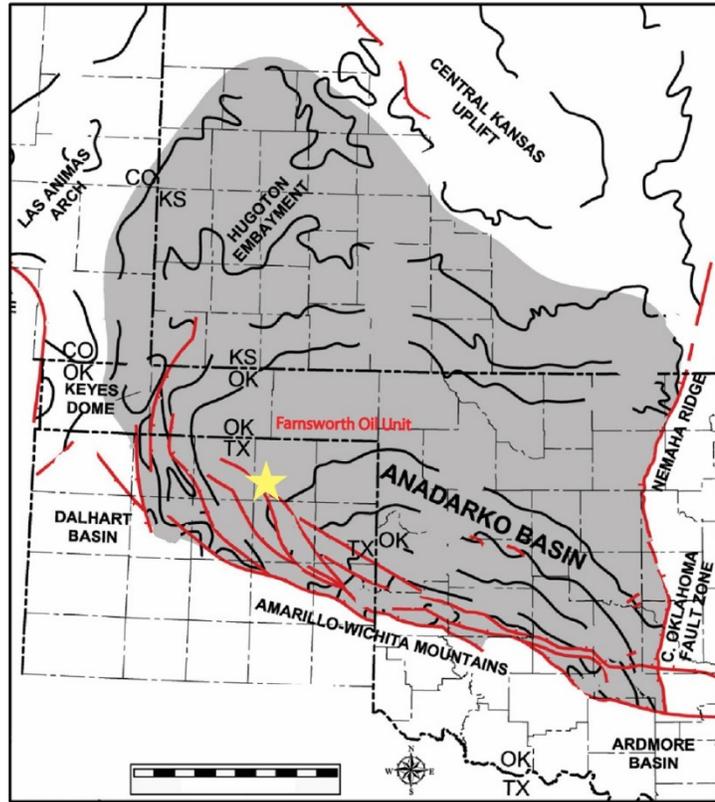


Figure 2.2-1- Location of the Farnsworth Unit (FWU) on the Northwest Shelf of the Anadarko Basin in West Texas. Red lines are approximate locations of faults that have been documented in the region.

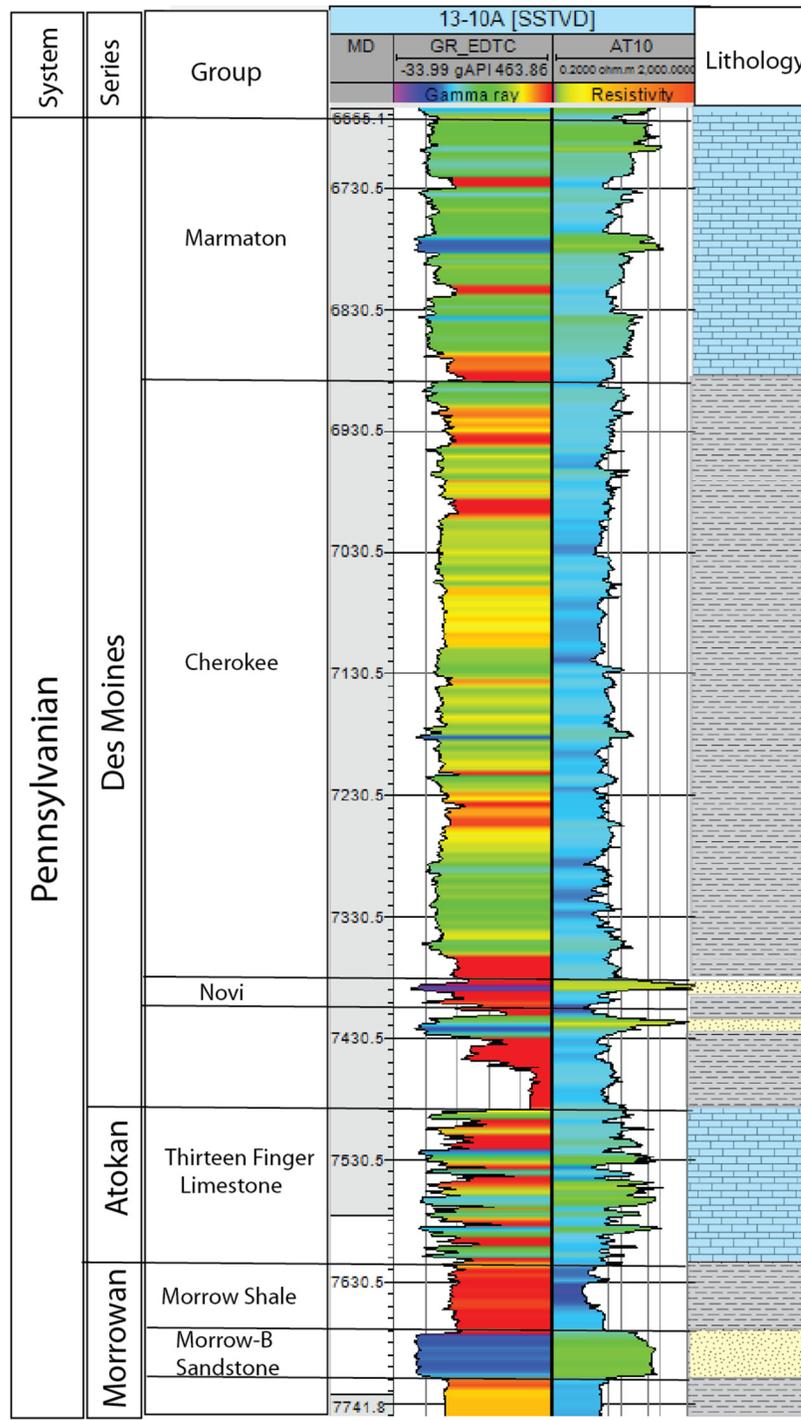


Figure 2.2-2- Stratigraphic section of the FWU.

Tectonic Setting

From FWU's location on the western edge of the basin, the Anadarko Basin plunges to the southeast where it reaches depths of over 40,000 ft (12,192 m) adjacent to the Amarillo-Wichita Uplift (Perry, 1989). Maximum rates of subsidence occurred during Morrowan to

Atokan times (Evans, 1979; Perry, 1989; Higley, 2014). Positive features that might have influenced deposition within the region include the Ancestral Rockies to the north, the Central Kansas uplift to the northeast, and the Wichita-Amarillo uplift to the south (Evans, 1979; Munson, 1989). Of note is the fact that during Pennsylvanian time the FWU was located on the basin shelf in an area that was not affected greatly by tectonic deformation. Although faults have been reported previously in the northwest Anadarko Basin, we found no direct evidence for tectonic faults within the FWU (see Section 4).

Stratigraphy

Reservoir

Upper Morrowan sandstones in the Anadarko Basin margins have long been recognized as fluvial deposits (Swanson, 1979; Sonnenberg, 1985; Munson, 1989; Krystinik and Blakeney, 1990; Bowen et al., 1990; Al-Shaieb et al., 1995; Mckay and Noah, 1996; Puckette et al., 1996; Bowen and Weimer, 2003, 2004; Devries 2005; Puckette et al., 2008; Gallagher, 2014). At FWU, the Morrow B is a relatively coarse-grained subarkosic sandstone. The upper Morrowan facies in FWU, with sequences of basal conglomerate, coarse-grained sandstone, and fine-grained sandstone appear to be typical of incised valley deposits, as described by Wheeler et al. (1990), Krystinik and Blakeney (1990), Bowen et al. (1990), Blakeney et al. (1990), Sonnenberg et al. (1990) and Puckette et al. (2008). Typical reservoir porosity ranges from almost 0-25% with an average of ~15%, and permeability from 1-780 mD with an average of ~35 mD (Rose-Coss, 2017)

Primary Seals

The Morrow B sandstones at FWU are encased above and below by shales. Contacts with shale both below and above the sandstone are sharp and irregular. The Morrow shale generally fines upwards in a series of thin beds (1-2 inches or 2.5-5 cm) that alternate between upper fine sands and fine to medium muds. Sand content decreases upwards through the section.

The Thirteen Finger limestone formation has two different lithofacies: diagenetic limestone (cementstone) and pyrite and fossil bearing fine to medium mudstone and coal. The two facies are intercalated with each other but tend to cluster in layers dominated more by one or the other. The number of limestone and mudstone beds varies from well to well; in one well 13-10A, 60-70 individual limestone beds were counted.

The entire Thirteen Finger interval is 130 ft (39.6 m) thick, with approximately 40% of the thickness comprised of mudstone, 4% coal, and 46% is limestone. The cementstone is calcite rich, with some dolomite, and is completely diagenetic in origin and probably formed relatively soon following deposition. The organic-rich mudstone contains fibrous calcite "beef" fractures that are observed in the mudstone and coal lithology between cementstone "layers".

2.2.2.2 Hydrogeology

There is currently a lack of research on the state of groundwater flow in the deeper formations in the Anadarko Basin. Groundwater flow rates in confined deep Anadarko

layers at present are considered to be low to no flow (Nelson and Gianoutsos, 2014). Their arguments are based on (1) restricted recharge in the western basin, (2) density barriers to flow in the east, and (3) an overpressure pocket inhibiting flow in the deep basin. Jorgenson (1989) suggested flow could be west to east, driven by potential recharge to elevated units in the west and discharge at lower elevation outcrops in the east. The FWU CO₂ injection and production operations will not cause water to flow to outcrops of the Late Carboniferous (Pennsylvanian) time period that extend from Brownwood, Texas, to the Jacksboro/Bowie, Texas, area, which are hundreds of miles away (The Paleontology Portal).

2.3 Description of the Injection Process

Figure 2.3-1 depicts a simplified flow diagram of the facilities and equipment within the boundaries of the FWU. CO₂ liberated from the ethanol plant is delivered via pipeline to the field for injection. The plant in Liberal KS is the only source of CO₂ to the field. The amount delivered is dependent on the production of CO₂ produced from the fermentation process. This amount will vary but should average 12 MMCFD. Once CO₂ enters the FWU there are three main processes involved in EOR operations. These processes are shown in Figure 2.3-1 and include:

1. CO₂ distribution and Injection. Purchased CO₂ is combined with recycled CO₂ from the FWU central tank battery and sent through the main CO₂ distribution system to various water alternating gas (WAG) injectors.
2. Produced Fluids Handling. Full well stream fluids are produced to the all well test sites (AWT). Vessels at these sites separate the phases so that the oil, gas and water can be measured for individual well test production. All of the produced gas and fluids are combined and sent to the central tank battery (CTB)
3. Produced Gas Processing. All phases from the AWTs are transferred to the central tank battery to separate the oil, gas and water using a series of vessels and storage tanks.

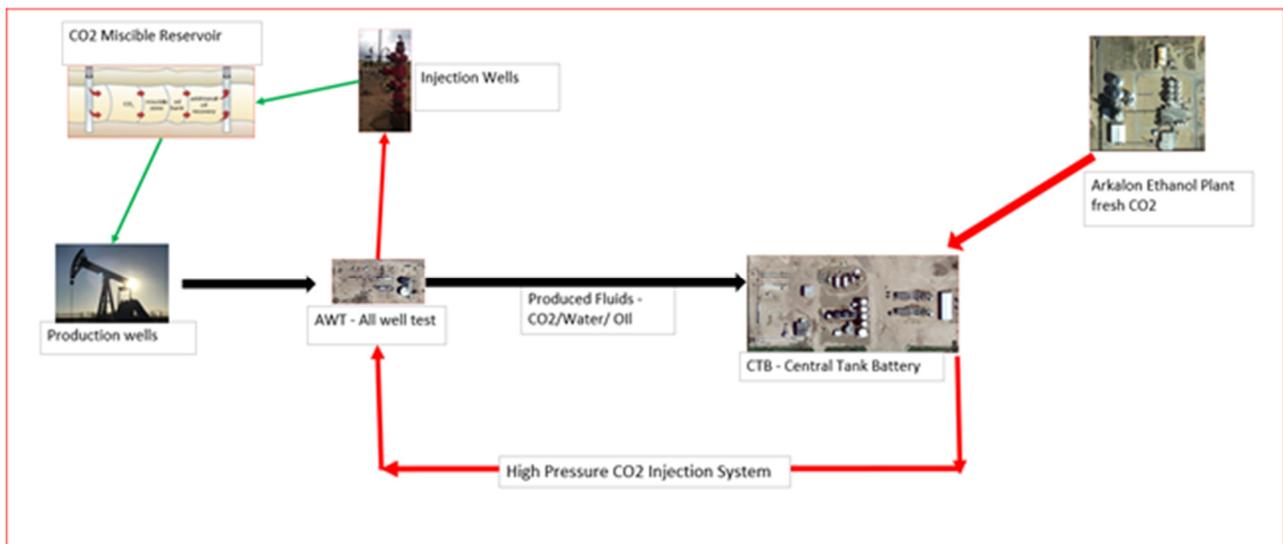


Figure 2.3-1 - Simplified flow diagram of the facilities and equipment within the boundaries of the Farnsworth Unit.

2.3.1 CO₂ Distribution and Injection

Perdure purchases CO₂ from Conestoga Energy Partners, the parent company of the Arkalon Ethanol plant located in Liberal Kansas. A custody transfer meter is located in the compression facility owned and operated by Perdure. The CO₂ is transported via a DOT regulated pipeline to the FWU and a totalizer meter for the purchase fresh CO₂ is located in the field where data for 24-hour flow rates are recorded. Gas produced from the wells is compressed and metered by a similar flow totalizer meter as the purchase CO₂ recorded daily.

Perdure currently has three active injection manifolds and approximately 17 active injection wells that the CO₂ is distributed through. The daily injection volume of the purchase and recycle will be 24 MMCFD. Of this volume 12 MMCFD is purchase CO₂ and 12 MMCFD is recycle. This ratio of fresh CO₂ to the recycled CO₂ is expected to change over time, with the percentage of recycled CO₂ increasing and purchases decreasing. The current reservoir management plan projects that purchases will decline after 2033. A reservoir management plan is an integrated process using various, surveillance techniques, economic evaluations, and accepted petroleum technical practices to efficiently operate enhanced oil recovery projects.

The three injection manifolds currently in the field distribute the CO₂ to the field. These manifolds have valves to switch to water when the time is called for. Depending on the reservoir management plan the WAG cycle will be adjusted to maximize oil recovery and minimize CO₂ utilization in each injection pattern. At each injection well pad is a totalizer to measure the volumes injected every 24 hours. This data is collected daily by the field personnel and input into the data warehouse to be allocated for the pattern injection.

The two totalizer meters as described above will be used to determine the total volume injected used in section 7 for the mass balance equations necessary to determine annual and cumulative volumes of the stored CO₂.

2.3.2 Produced Fluids Handling

As injected CO₂ and water migrate through the reservoir, a mixture of oil, gas, and water (referred to as “produced fluids”) flows to the production wells. Gathering lines bring the produced fluids from each production well to the all well test (AWT) sites. Perdure has approximately 32 active production wells producing at any time. Each AWT has two (2) separators. The first separator is used for well testing to separate the gas, oil, and water. This vessel is used to measure the production rates of oil, water and gas from individual wells. Each well is tested every thirty days, if possible, and try not to exceed 60 days. Depending on the reservoir management plan well testing can be more frequent to obtain data. The second separator is used separate the gas from the oil/water mixture and each is displaced from the vessel in separate lines. Leaving the AWT sites are two lines transporting produced fluids. One for the liquid phase, a mixture of oil and water, and one for the gas phase.

When gas and liquid lines enter the CTB a series of vessels separate the oil, gas and water to be accounted for and distributed for sales or reinjected. The liquid phase line has vessels to

separate the oil from the water using density and residence time. The gas phase vessels collect any free liquids entrained with the gas. These free liquids are then combined back into the liquid phase line. All gas and water are reinjected, and the oil, which contains 2,930 ppm CO₂ (0.293%), is sold out of tanks.

After separation, the gas phase, which is approximately 89-93% CO₂, is mixed with reservoir volatile components, compressed and distributed throughout the high-pressure distribution system using reciprocal compression and high-pressure horizontal pumps.

The water is transferred from the separation vessels to tanks for reinjection. After the water is conditioned it is either reinjected at the WAG skids or disposed of into permitted disposal wells. Although Perdure is not required to determine or report the amount of dissolved CO₂ in the water, analyses have shown the water typically contains <690 ppm (0.069%) CO₂.

FWU production has trace amounts of hydrogen sulfide (H₂S), which is toxic. There are approximately 8-10 workers on the ground in the FWU at any given time, and all field and contractor personnel are always required to wear H₂S detectors. The primary purpose of the H₂S detectors is protecting people from the risk of being harmed; and a secondary purpose would be to provide an indication of miniscule emissions of gas from a pipeline or surface equipment, which could not be noticed by other observations or measurements, as discussed in sections 5 and 8.

2.3.3 Produced Gas Handling

Produced gas separated at the central tank battery (CTB) is stripped by a series of vessels of entrained and free water. The water content has been recorded to be < 20# MMCF, thus dehydration is not necessary. The gas is then sent to a centralized compression system to be compressed and placed in the high-pressure distribution system. This compression turns the CO₂ into a variable density liquid, which is then transported out via high pressure line to the AWTs where a manifold splits this dense CO₂ to the wells that are on CO₂ injection at that time.

2.3.4 Facilities Locations

The locations of the all well test sites (AWT) are positioned in the field to access both injection distribution and production gathering. The central tank battery (CTB) is where the final separation and injection equipment is maintained and operated. The water injection station is where the horizontal pumps are located to reinject the produced brine.

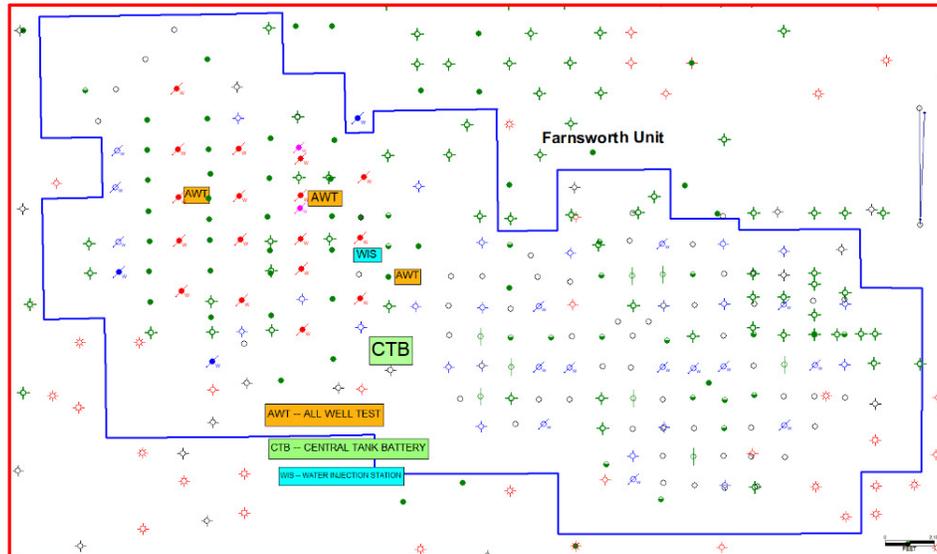


Figure 2.3-2 – Location of All Well Test (AWT) sites, Central Tank Battery (CTB) and Water Injection Station (WIS) in the FWU

2.3.5 Water Conditioning and Injection

Produced water collected at the central tank battery is collected in a series of vessels and tanks in a cascade system. This allows any entrained oil to further separate to the top of the tanks because of the density difference and is skimmed off and put back in the oil separation system. The clean water is then transferred to the water injection system where it is boosted in pressure and sent out to the AWTs for distribution to all wells that are currently on water injection.

2.3.6 Well Operation and Permitting

The Texas Railroad Commission rules (Appendix 1) govern well location, construction, operation, maintenance, and closure for all wells in permitted units and wells. Perdure follows these rules and regulations to maintain safe and efficient operations. This includes complying with all current and updated information for mechanical integrity testing, well repairs for injection wells, drilling and completion permitting and reporting.

Briefly current rules require, among other provisions:

- That fluids be constrained in the strata in which they are encountered;
- That activities governed by the rule cannot result in the pollution of subsurface or surface water;
- That wells adhere to specified casing, cementing, drilling well control, and completion requirements designed to prevent fluids from moving from the strata they are encountered into strata with oil and gas, or into subsurface and surface waters;
- That wells file a completion report including basic electric log (e.g., a density, sonic, or resistivity (except dip meter) log run over the entire wellbore);

- That all wells be equipped with a Bradenhead gauge, measure the pressure between casing strings using the Bradenhead gauge, and follow procedures to report and address any instances where pressure on the Bradenhead is detected;
- And that all wells follow plugging procedures that require advance approval from the Director and allow consideration of the suitability of the cement based on the use of the well, the location and setting of plugs.

2.3.7 Number, Location and Depth of Injection Wells

Perdure's FWU injection wells are listed in Appendix 1. Injection is into the Upper Morrowan, a lenticular bedded sandstone trending northwest to southeast with the average top of sand at 7990 feet, true vertical depth. The Upper Morrowan is described in section 2.2.2.1 above.

2.4 Reservoir Characterization Modeling

2.4.1 Reservoir Model Description

The target reservoir Morrow B is a sandstone formation overlain by the Morrow shale and Thirteen Finger limestone, which serve as excellent seals for injected CO₂ (Ampomah et al., 2016a). The Morrow B sandstone reservoir is at a depth between 7550 ft and 7950 ft subsurface with an average dip of less than one degree (Figure 2.4-1). The productive limit of the FWU extends laterally to about 8300 acres. The maximum pay thickness is 54 ft with an average of 22 ft.

The FWU is approximately 4 mi by 7 mi and is usually divided into eastern and western portions because the two sides of this field have exhibited different reservoir behavior. The eastern side was more prolific under primary production. However, the CO₂ –EOR study for FWU has concentrated on the west half of the field, which showed a better response to waterflood initiated in the 1960's and which is where the field operator is focusing their efforts (Ampomah et al., 2016b).

In the property modelling process, a hydraulic flow unit (HFU) methodology based on the Winland R35 method was used to describe and characterize heterogeneity within the Morrow B reservoir. The R35 parameter refers to the pore throat aperture radius when core samples are 35% saturated during a mercury porosimetry test. This captures pore throat size at which pore networks become interconnected and form continuous flow paths. Fifty-one (51) wells with core porosity and permeability measurements were used to define eight distinct porosity/permeability relationships (Figure 2.4-2). These eight relationships were based on depositional/diagenetic facies described from core and thin section analysis. The facies have differences, often subtle, that appear to greatly affect reservoir properties (Ross-Coss et al., 2016). There appears to be a strong relationship between the delineated hydraulic flow units and depositional and diagenetic trends that was not noted in early investigations into reservoir properties (Gallagher, 2014, Munson, 1989). After HFUs and porosity/permeability relationships were established, a Gaussian simulation method, cokriged with the facies model, was used to model porosity and net-to-gross ratio.

The geocellular structural model has a grid cell distribution of 1573*962*23 with a grid dimension of 25 ft × 25 ft. and includes the reservoir formation and several of the overlying seal formations. This model was upscaled to a reasonable size to decrease computational time for simulation purposes. The upscaled model, which uses only the western half of FWU, has a grid size of 176×163× 8 for a total of 229,504 cells that are 100 ft on a side.

Figure 2.4-3 shows porosity and permeability distribution for the western half of FWU used in this study. Reservoir porosity ranges from 9.2% to 24% with a mean of 14.6% and shows a normal population distribution. Permeability ranges from 0.01 mD to 181 mD with an average value of 58 mD. The permeability histogram shows a log-normal population distribution.

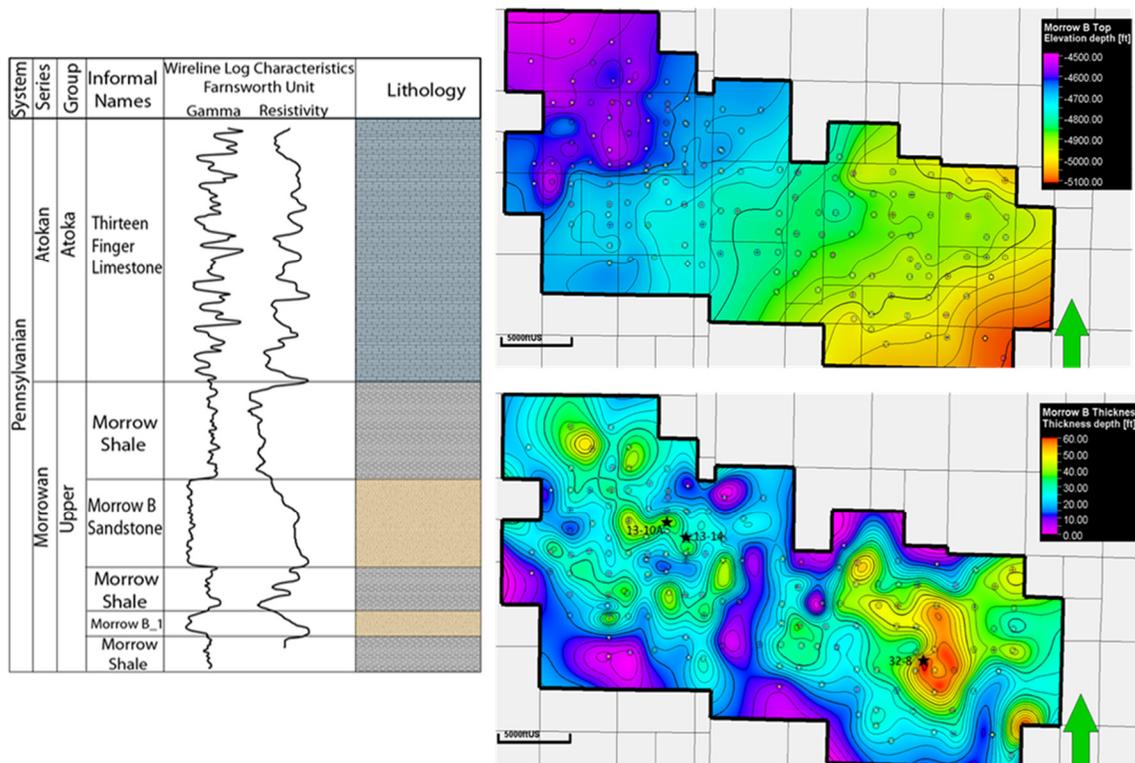


Figure 2.4-1- (Left) Type log of FWU caprock and reservoir. (Upper Right) Surface contour of Morrow B top. (Lower right) Thickness map of Morrow B sands (Gallagher 2014).

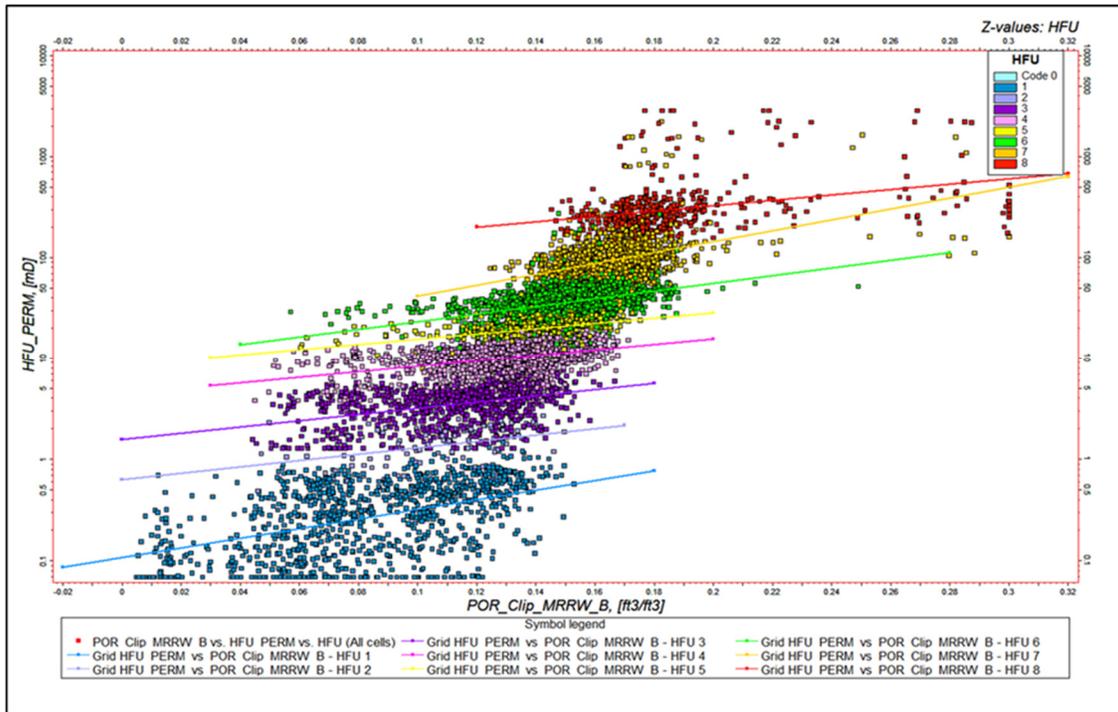


Figure 2.4-2 - Porosity versus permeability for the 51 cored wells, separated by pore throat size into hydraulic flow units.

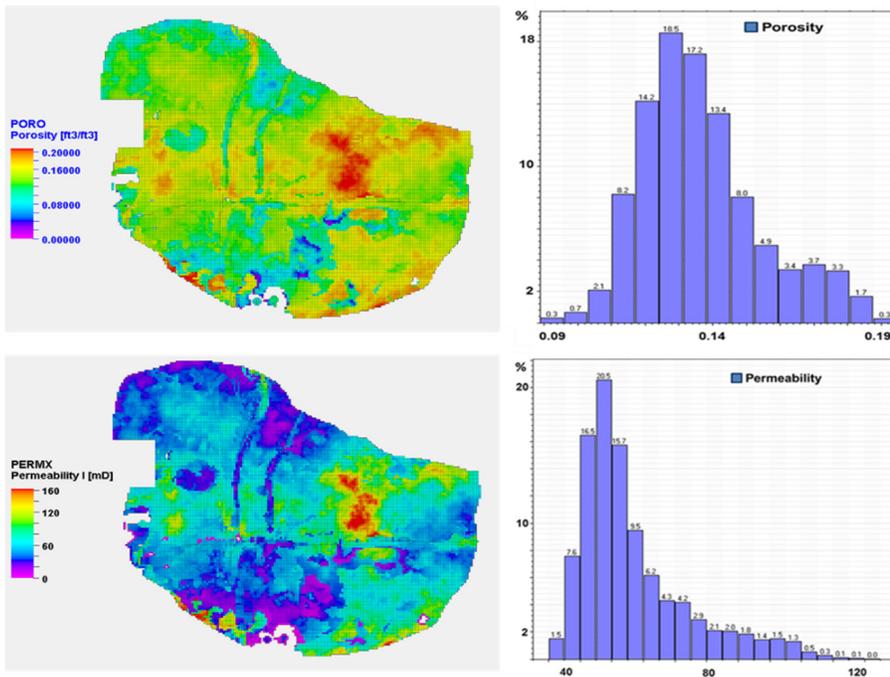


Figure 2.4-1- (Upper left) Porosity distribution using a Gaussian Simulation method for the west section of FWU used in the work. (Upper right) shows histogram illustrating a normal distribution of porosity with a mean of 14%. (Lower left) Permeability distribution constructed from porosity-permeability cross plots based on eight hydraulic flow units. (Lower right) Histogram illustrates a lognormal distribution of permeability.

2.4.2 Reservoir Fluid Modeling

The compositional fluid model was constructed from laboratory experiments tuned to an equation of state (Gunda et al., 2015). The process for the FWU involved comprehensive splitting and lumping of the C7+ fractions. The experimental data from PVT experiments including constant composition expansion (CCE), saturation pressure, differential liberation (DL), multi-stage separator tests and viscosity tests conducted on FWU fluid sample were used for the validation of the tuning process (Gunda et al., 2015). The mixing rules by Pedersen (Pedersen et al. 1989) were followed to split the C7+ fractions into two pseudocomponents using the average molecular weight, average specific gravity and the total mole percent. The isomers of C4 (butane) and C5 (pentane) were also lumped using the same methodology. A regression process was performed manually to achieve acceptable calibration to the laboratory data. The critical parameters for the two pseudocomponents were calculated based on Pedersen's approach (Pedersen 2002) using Calsep's PVTsim™ software package. The 3- parameter Peng Robinson equation of state (Peng and Robinson 1976) with Peneloux volume correction (Peneloux et al. 1982) was used to perform all the calculations. The viscosity modeled using the Lohrenz-Bray-Clark correlation (Lohrenz et al. 1964). After calibrating the fluid model to equation of state, a slim tube simulation experiment was conducted to obtain the minimum miscible pressure (MMP) for FWU. A one-dimensional 200 cell model was used for the experiment with a CO₂ injection rate of 1.2 pore volume. Figure 2.4-4 shows a plot of oil recovery vs. pressure illustrating the MMP of FWU computed from the simulation experiment. The MMP of 4009 psia realized from the simulation as compared to an MMP value 4200 psia derived from laboratory experiments provided by the operator represents a less than 5% error (Gunda et al., 2015).

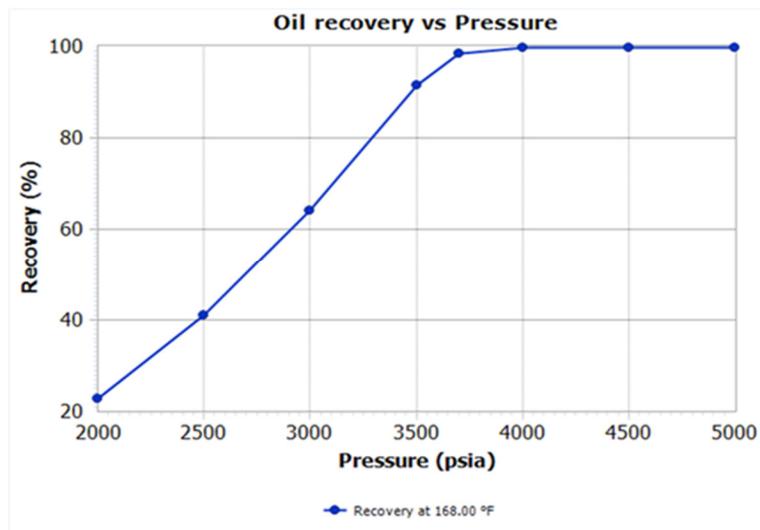


Figure 2.4-4. Oil recovery plot for 1D slim tube test

2.4.3 Assisted History Matching using Reduced Order Model

This section presents computer assisted history matching efforts for primary, secondary and tertiary recovery processes for FWU. Eclipse E300 (Schlumberger) was used throughout this

study for all simulation runs. Most efforts were directed at matching secondary and tertiary processes by assigning higher weights in objective function formulation as compared to primary processes. Gas production field history was not available for primary recovery. The primary and secondary history processes lasted for 55 years until December 2010. The tertiary CO₂ flood was performed between December 2010 and August 2020. The parameters included in the objective function formulation were oil production, water production, water-cut, gas oil ratio (during waterflood), and injection rate. Pressure measurements including those made initially, prior to waterflood and at the end of waterflood were also used in the calibration process. Heath et al., (2015) conducted geomechanical analysis on FWU rock samples and determined a fracture pressure between 5400 to 5600 psia.

During primary recovery, there were a total of 60 production wells. As there were no recorded gas-oil or water-oil contacts, all grid blocks were assigned an initial oil saturation of 69% and 31% connate water saturation. With initial reservoir pressure of 2217.7 psia assigned to the datum depth of 4900 ft TVDSS, original average pressure in the model was 2150 psia. Oil originally in place (OOIP) for FWU west half in this model was about 71.4 MMstb with 23.8 MMscf of dissolved natural gas. During waterflood, there were 47 producer wells with 13 wells converted from producers to injector wells. An additional 6 water injector wells drilled during this period. The initial sensitivity analysis performed on primary and secondary recovery processes showed that well bottomhole pressure, oil-water contact (OWC), and bottomhole injection pressure were the most important parameters. These uncertain variables were included in the history matching process to optimize the objective function at acceptable data uncertainty ranges.

From the history matching results it was deduced that OWC of an average value of 5000 ft TVDSS was appropriate to yield the best history match model. The bottomhole pressure had an optimum value of 4800 psia to improve history matching efforts. Sensitivity analysis showed global permeability was not particularly sensitive to the objective function. However, a few local permeabilities were furthered adjusted to improve the overall history matching. The overall RMS was about 10%, which was mostly contributed by gas-oil ratio match. This confirms some doubts operator had on gas production history measurements during the primary and secondary recovery processes of the field. Figure 2.4-5 shows oil production and water cut profiles. Various waterflood patterns swept to residual oil saturation of about 27%, a successful flood. This is not unexpected given the relatively good mobility ratio of about 1.6 and high injection throughput of at least 1.7 displaceable pore volumes. From the simulation results, nearly 6 MMstb represents 10% of OOIP produced prior to the initiation of waterflood. A total of 25.65 MMstb of cumulative oil has been produced at the end of secondary from the west half of FWU, which represents nearly 40% of OOIP. During the tertiary history match, an initial simulation run showed a good calibration of compared to observed history until CO₂ breakthrough. Simulated gas production and CO₂ injection rates were unable to match measured volumes after the CO₂ breakthrough, which could be attributed to a potential change in wettability and interfacial tension. There is a possibility of the Morrow B transitioning into a mixed-wet wettability system. Corey parameters were adjusted to improve calibration of the CO₂ flood history

match. An optimization approach was utilized to identify optimum values for Corey parameters. Figure 2.4-6 shows simulated results compared to historical oil production, gas production, CO₂ injection and water production profiles.

At the end of August 2020, according to simulation results, a total of 4.8 MMstb of oil has been produced from the west half of FWU since CO₂-WAG commenced (December 2010). About 93% of the purchased CO₂ remains as of August 2020.

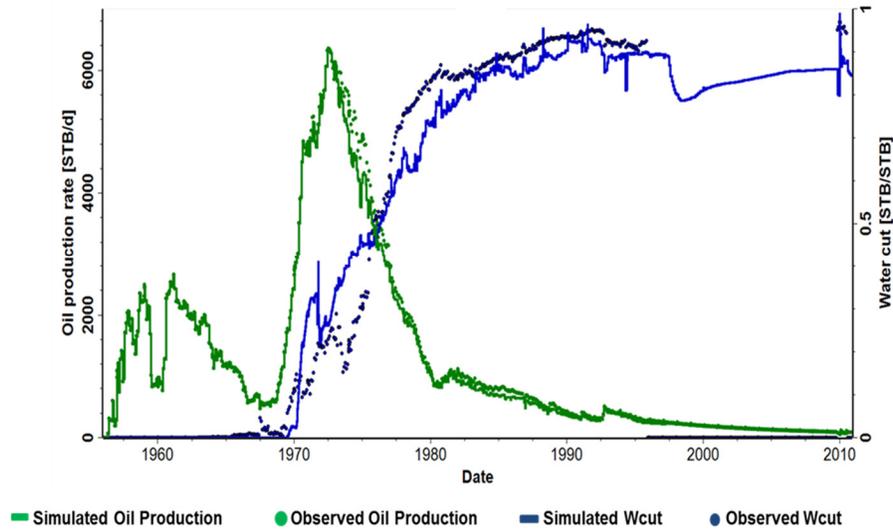


Figure 2.4-5- Calibration of simulated oil production rate and water cut vs. observed for primary and secondary history matching process.

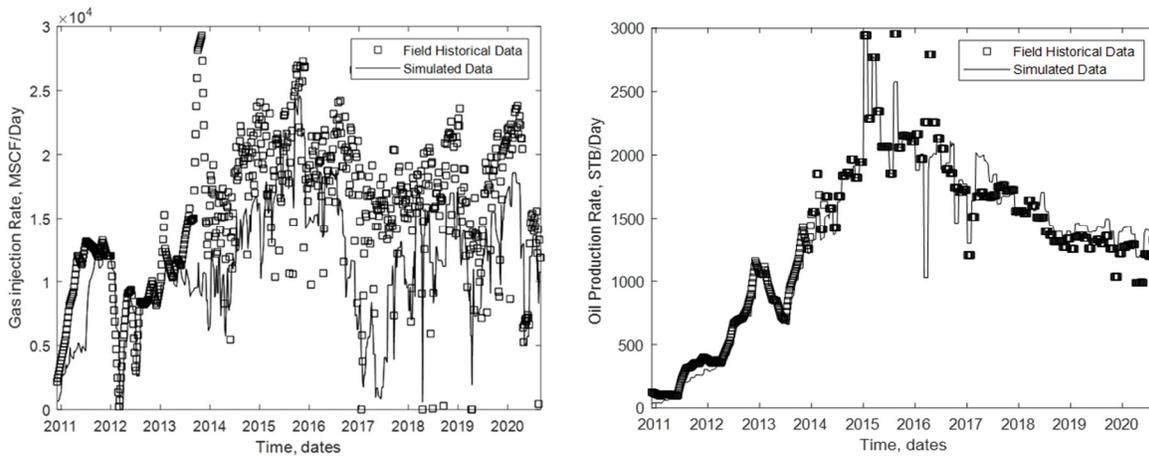


Figure 2.4-6- Calibration of simulated vs observed responses for tertiary recovery including CO₂ injection (left) and oil production rate (right).

2.4.4 CO₂ –EOR Performance Scenarios

Once an acceptable history match was reached, CO₂ flood performance could be predicted to optimize oil production and CO₂ storage. Several prediction cases based on different injection scenarios were run to maximize the potential of the projected flood. Currently the operator plans to convert existing five water injectors to WAG wells in addition to existing

20 WAG wells. There is an anticipated constant CO₂ purchase of 12 MMscf/d and a flexible compressor capacity to recycle produced gas for reinjection purposes. A user-defined algorithm was developed in the numerical simulator to use purchased CO₂ in addition to produced gas (recycled) as a group injection rate target for the run scenarios. The model was performed for a 12-year period with bottomhole pressure and oil rate target constraints. Additional 5 years was run to ascertain the movement of CO₂ post-injection period. The injection profile shows the storage capacity of the Morrow B storage complex. Significant amount of produced CO₂ was recycled back into the injection stream (Figure 2.4-7). The compressor capacity will be expanded to compensate for high volume recycle volumes in the future.

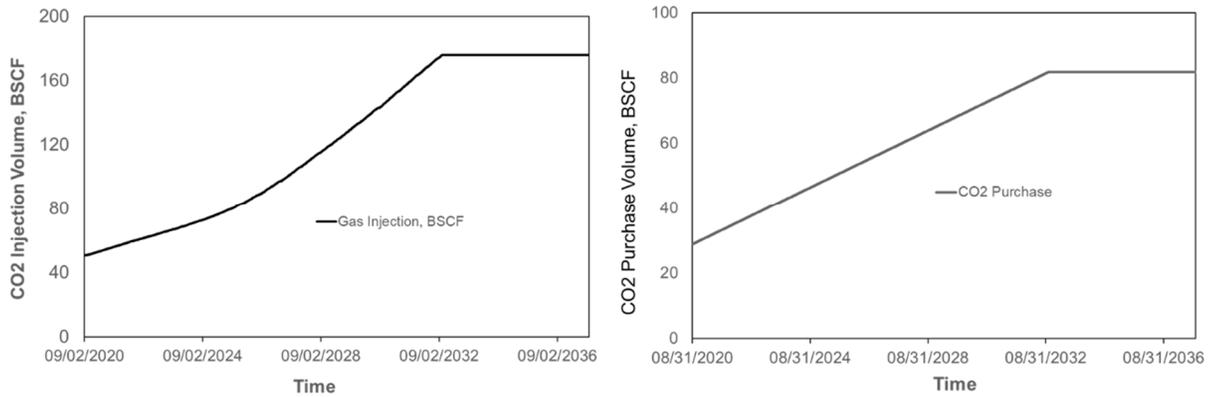


Figure 2.4-7 - Simulated Cumulative CO₂ injection Volume and CO₂ purchase volume for the Forecasting Scenario

3 Delineation of the monitoring areas

3.1 MMA

As defined in Subpart RR, the maximum monitoring area (MMA) is equal to or greater than the area expected to contain the free phase CO₂ plume until the CO₂ plume has stabilized plus an all-around buffer zone of at least one-half mile. The modeling described in Section 2.4 indicates that the majority of the CO₂ will remain in the reservoir. Therefore, Perdure is defining the MMA as the boundary of the FWU plus an additional one-half mile buffer zone. This will allow for operational expansion throughout the FWU for the next 12 years, the anticipated life of the project.

3.1.1 Determination of free phase plume extent

Figure 3.1-1 shows the modeling simulation of the total CO₂ composition depicting the lateral extent of CO₂ in the injection zone. The injection area shows the significant high concentration of CO₂ which reiterates the containment within the injection zone and area. The simulation depicts the tertiary CO₂ flood that was performed between December 2010 and October 2032 with additional 5-year post-injection monitoring (Figure 3.1-2). The high green color shows almost zero CO₂ fraction which illustrates most of the CO₂ injected has not reach the model boundary even after a total of 22 years of potential CO₂ injection into the Morrow B formation.

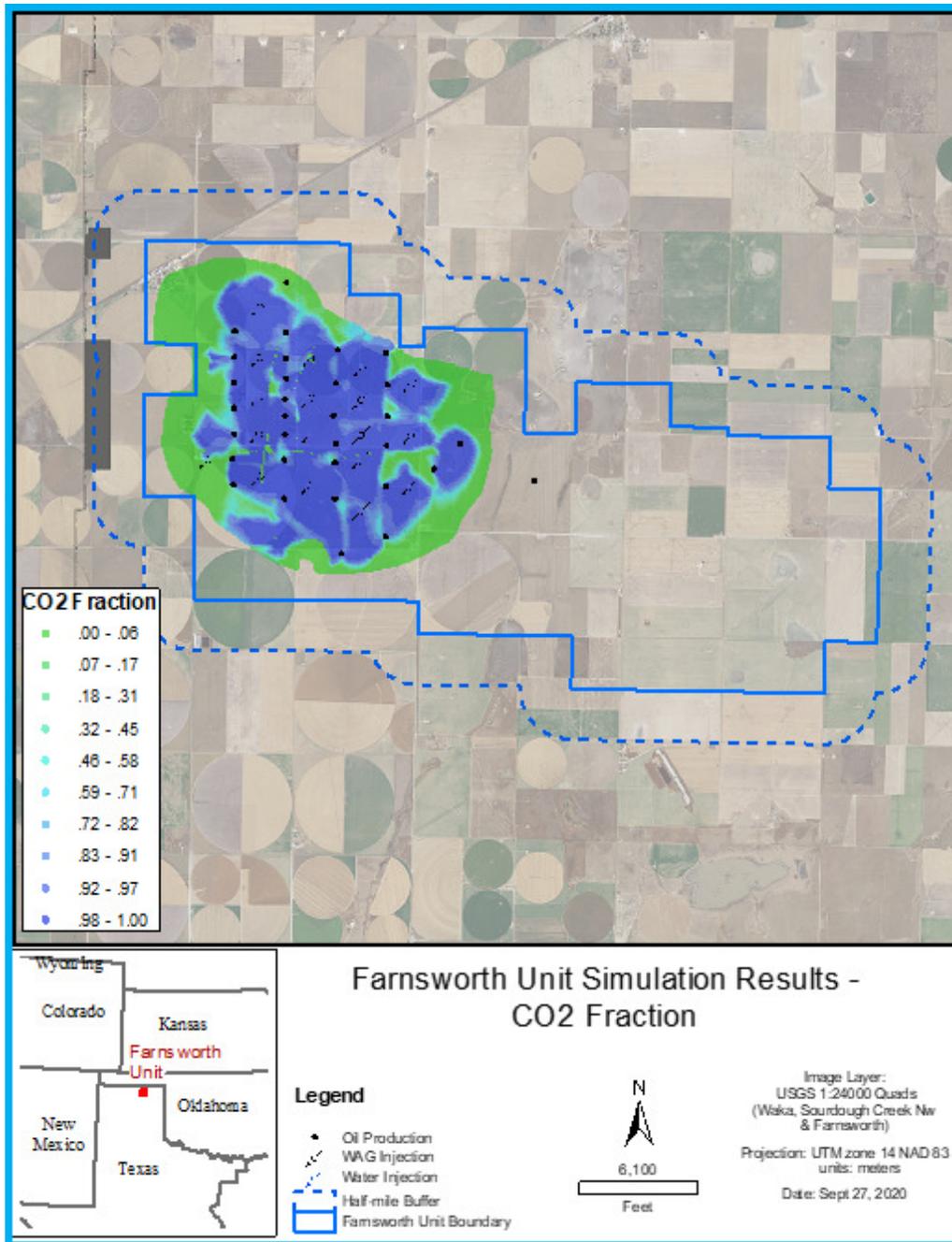


Figure 3.1-1: Model simulation of the tertiary CO₂ flood

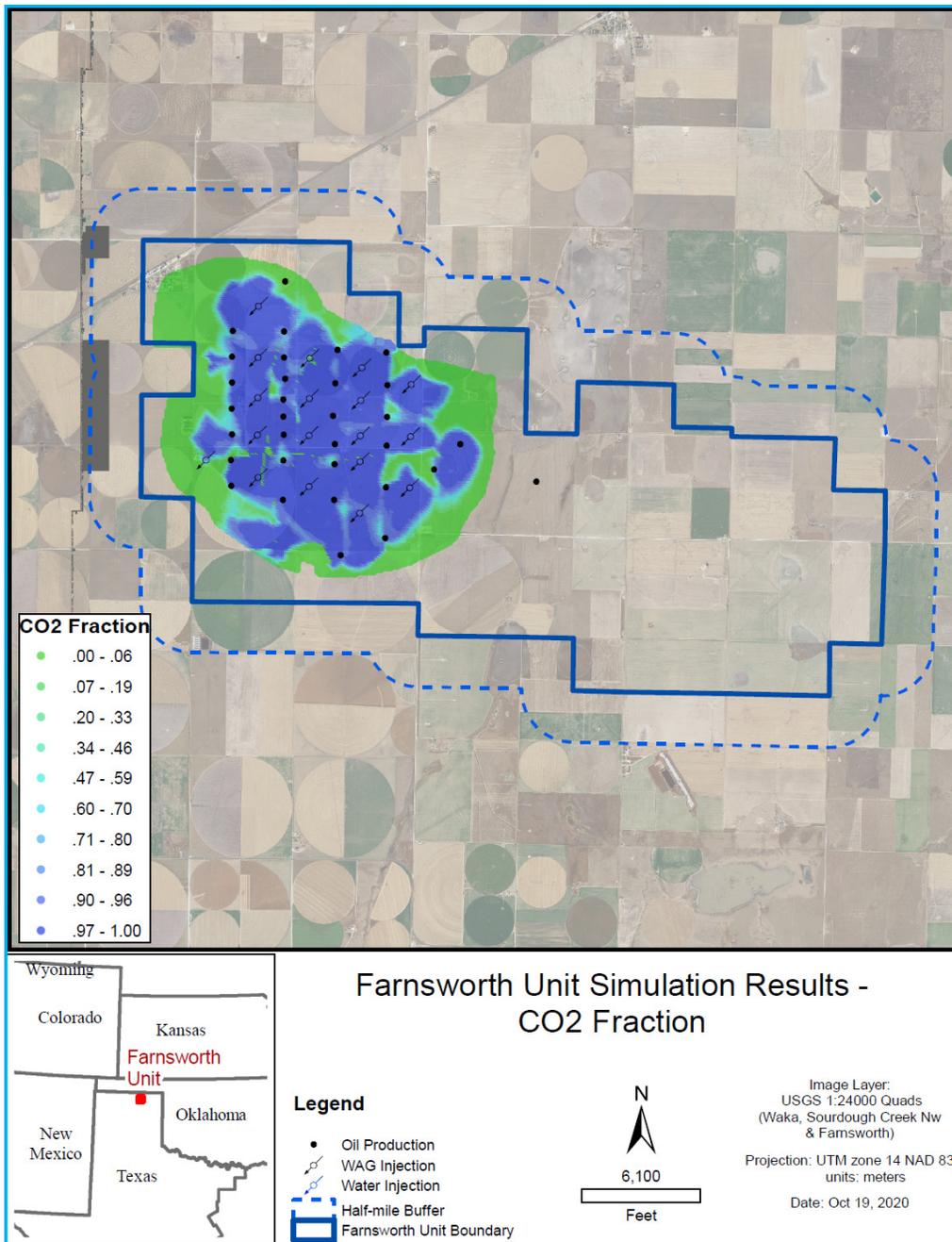


Figure 3.1-2 – CO₂ Plume Extent 5 years after Injection Ceased

3.1.2 Determination of buffer zone

Perdure intends to implement a buffer zone of one-half mile around the FWU, the minimum required by Subpart RR, because the site characterization of the FWU did not reveal any leakage pathways that would allow free-phase CO₂ to migrate laterally thereby warranting a buffer zone greater than one-half mile.

3.2 AMA

Currently, Perdure's operations are focused in the western portion of the FWU. However, it is anticipated as the project develops additional activity will occur in the eastern portion of the FWU; therefore, requiring active monitoring in that area. However, project development is driven by the market price of oil so Perdure is unable to provide a specific time in the future when the eastern portion of the FWU will be actively monitored. Therefore, for the purposes of this MRV plan, Perdure has chosen to include the entire FWU in the AMA.

4 Identification and Evaluation of Leakage Pathways

Since its discovery in 1955, its unitization in 1963, and the commencement of CO₂ EOR in 2010; the FWU has undergone extensive investigation and documentation as indicated in Section 2. From this body of work, Perdure has identified the following potential pathways of CO₂ leakage to the surface. This section will also address detection, verification, and quantification of leakage from each pathway.

4.1 Leakage from Surface Equipment

Ongoing field surveillance of pipelines, wellheads and other surface equipment and requirements in the Texas Administrative Code (TAC) rules for the Texas Railroad Commission (TRRC) Oil and Gas Division to report and quantify leaks, serve to minimize leakage of GHG from surface equipment. As described in Section 6.4 below, leakage from surface equipment will be evaluated according to the procedures in Subpart W of the GHGRP.

4.2 Leakage from Wells

Perdure has identified abandoned wells, injection wells, production wells, monitoring wells, and potential for drilling of new wells within the MMA and assessed their potential for leakage of CO₂ to the surface.

4.2.1 Abandoned Wells

Figure 4.2-1 shows all wells plugged and abandoned in the FWU. Because the FWU was unitized in 1963, all plugging and abandonment activities of wells within the FWU have been conducted under the regulations of the TRRC for plugging wells. Perdure concludes that leakage of CO₂ to the surface through abandoned wells is unlikely.

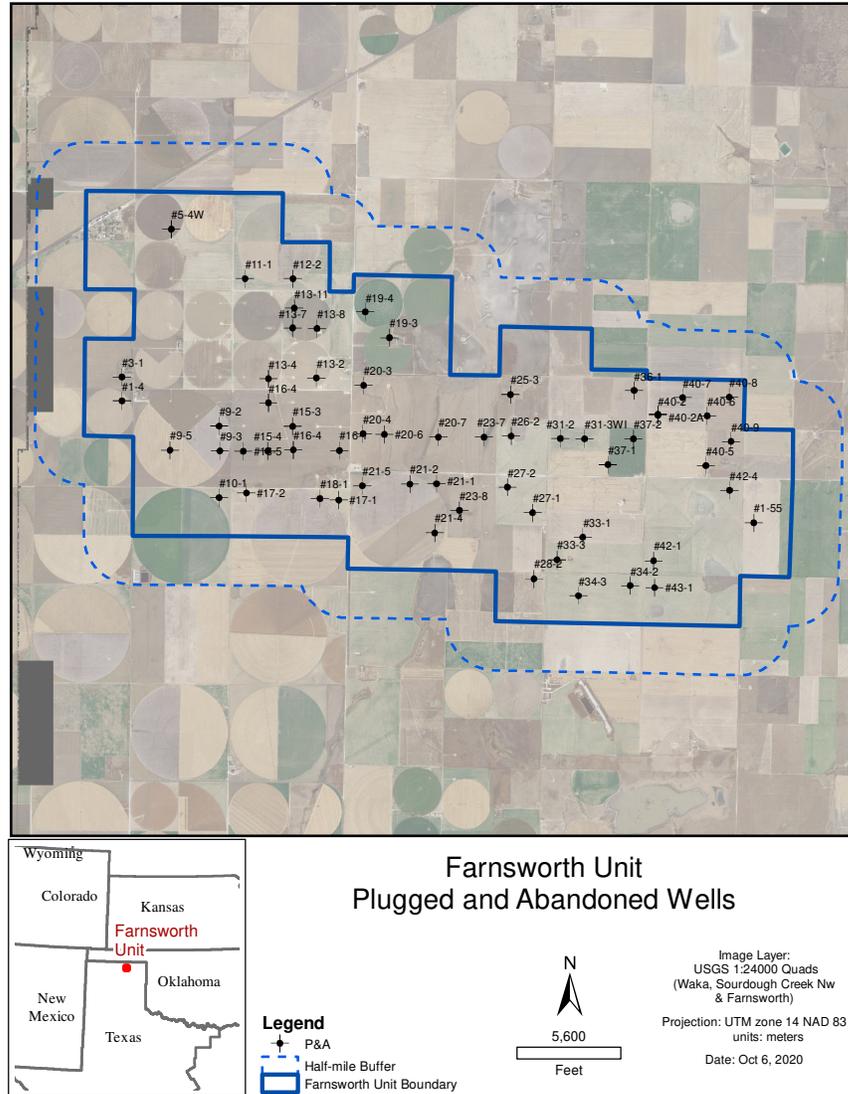


Figure 4.2-1: Plugged and Abandoned Wells in the FWU

4.2.2 Injection Wells

Mechanical integrity testing (MIT) is an essential requirement of the Underground Injection Control (UIC) program in demonstrating that injection wells themselves do not act as conduits for leakage into underground sources of drinking water (USDWs) and to the surface environment. Rule 46 and any special conditions pertaining to mechanical integrity testing the TRRC includes in the Class II permits issued to Perdure, ensure that active injection wells operate to be protective of subsurface and surface resources and the environment. Figure 4.2-2 and 4.2-3 shows the active and inactive, respectively, injection wells in the FWU. Perdure concludes that leakage of CO₂ to the surface through injection wells is unlikely.

4.2.3 Production Wells

Figure 4.2-2 4.2-3 shows the active and inactive, respectively, oil production wells in the FWU. However, as the project develops in the FWU additional production wells may be added and will be constructed according to the relevant rules of the TRRC. Additionally,

inactive wells may become active according to the rules of the TRRC. Perdure concludes that leakage of CO₂ to the surface through production wells is unlikely.

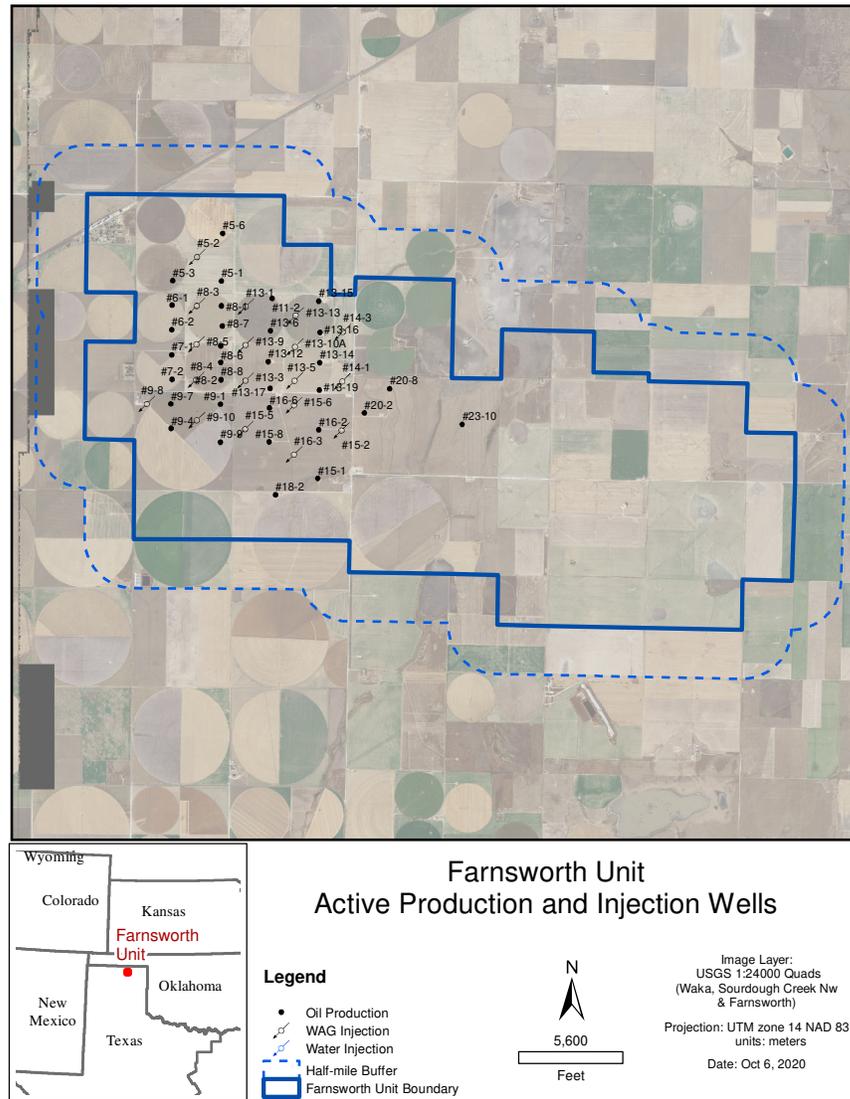


Figure 4.2-2: Active Production and Injection Wells in the FWU

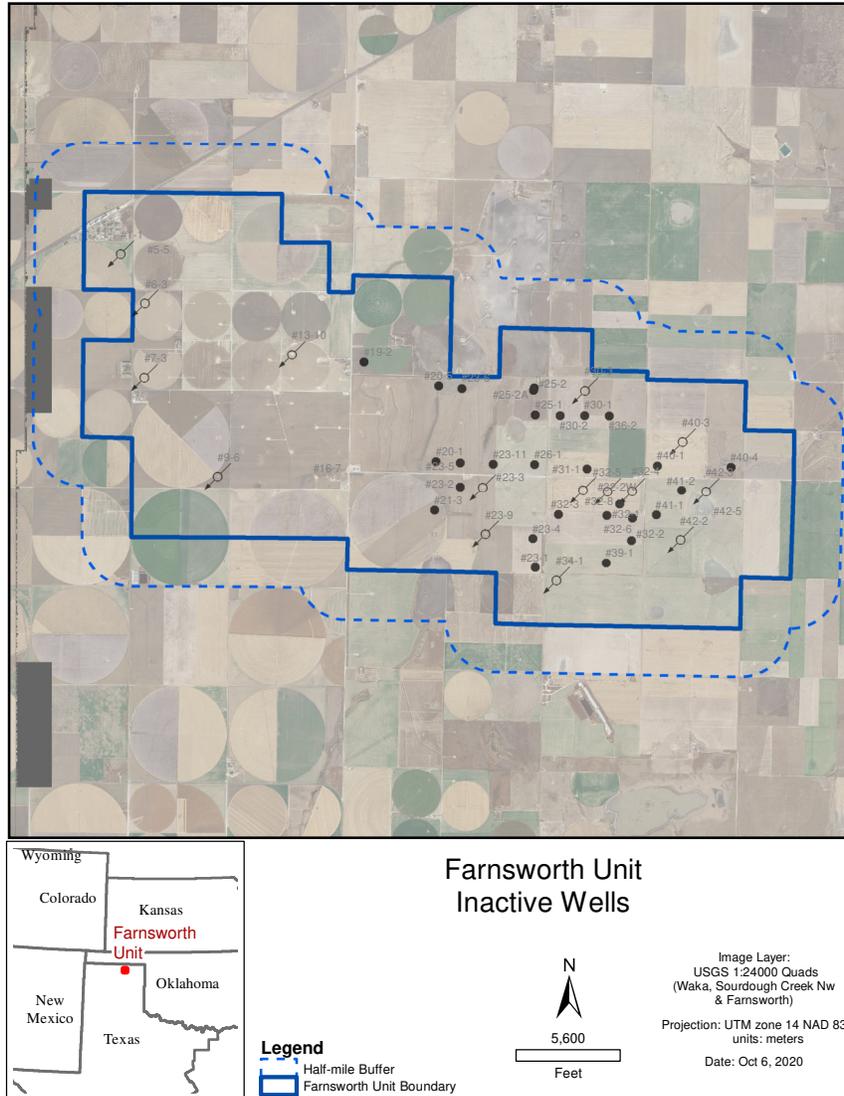


Figure 4.2-3: Inactive Production and Injection Wells in the FWU

4.2.4 Monitoring Wells

Well 13-10

The SWP has conducted monitoring of the Morrow B injection horizon and overlying seals in the area immediately adjacent to a WAG injection well (#13-10A), through the use of a dedicated monitoring well (#13-10). This unproductive well, drilled in 1971 to a TD of 7770' was repurposed for monitoring reservoir pressure and temperature, borehole temperature and microseismicity. To accomplish the task, the following equipment were permanently installed in the well:

- Downhole pressure and temperature gauges: Real time pressure and temperature monitoring of the reservoir
- Distributed Temperature Sensing (DTS): Real time monitoring of temperature along the wellbore for leakage detection.

- Sixteen level geophone array: Pseudo real time monitoring of passive and active (during injection and draw down cycles) microseismic activities within the FWU.
- Twenty surface seismometer stations: Monitor microseismic activities at the surface. Data is integrated with data from borehole geophone array to enhance event detection and location.

After the SWP has finished their Real time monitoring efforts and the equipment is released to Perdure, the long term usage of the equipment may be significantly reduced or cease to be used unless there is an ample indication of the need for gathering the huge volumes of data that are presently being collected.

4.2.5 New Wells

As the project develops, new production wells and injection wells may be added to the FWU. These will be constructed according to the relevant rules for the TRRC which ensure protection of subsurface and surface resources and the environment.

4.3 Leakage from Fractures, Faults and Bedding Plane Partings

Primary seals at FWU have been demonstrated to be mechanically very competent (see Section 2.2.2), thus the main concern of CO₂ migration at FWU is via seal bypass systems along fracture networks. The following several lines of analysis have been used to assess this risk in the area.

4.3.1 Presence of Hydrocarbons

The first and foremost argument against present day up-fault transmissibility is the 120 MMB of oil that was found trapped in the reservoir at the time of discovery (Munson, 1988). If significant escape pathways existed, oil would have drained from the reservoir prior to the current day.

4.3.2 Structural Analysis

The second argument against up-fault leakage are the results of an extensive field and regional analysis of core, 2D and 3D seismic data. 3D Reflection seismic data of the FWU was acquired in 2013 and reprocessed in 2017 to obtain a better image resolution. In-depth analysis of the reprocessed data gives us confidence that there are no significant faults or fractures in the field area. The Morrow B is only 60' thick in the area; below the resolution of the seismic signal to pick an exact top and base. Horizons identified as the Kansas City top, Thirteen Finger base, and as a reflector in the proximity of the Morrow B reservoir unit were picked in the 3D seismic data. Two horizons below the Morrow B, tentatively identified as the top of the Hunton limestone and top of the Sylvan shale, were also used in the structural analysis. A detailed isopach map of the Morrow B created from interpretation of 346 well logs were also used to crosscheck the seismic interpretation.

Reprocessed data (Hobbs et al.) shows a series of seismic horizons that dip gently and thicken slightly to the southeast (Figure 4.3-1), consistent with the location of FWU on the western edge of the Anadarko basin dictating that sedimentary packages should thicken and dip towards the center of the basin. The most prominent feature of the seismic data is an increase in the intensity of the reflectors in the central and western part of the field (Figure

4.3-2). Based on the bifurcation of reflectors and on their lateral morphological changes they are interpreted as facies changes between carbonate or sandstone shelf deposits that transition laterally to shales. It is possible that such facies changes or channels could form preferential flow paths; however, these are relatively discontinuous, anastomosing and irregular features that would not constitute a pathway to the surface. Other notable features have been interpreted as We conclude that the structures visible in the seismic data can be interpreted as sedimentary/diagenetic features that include lateral facies changes, channel infills and karst collapse features.

In addition to the field-scale 3D seismic survey, over 70 mi of 2D seismic line in the region were used to constrain larger scale structural risk in the region. No faults were observed in any of the 2D lines.

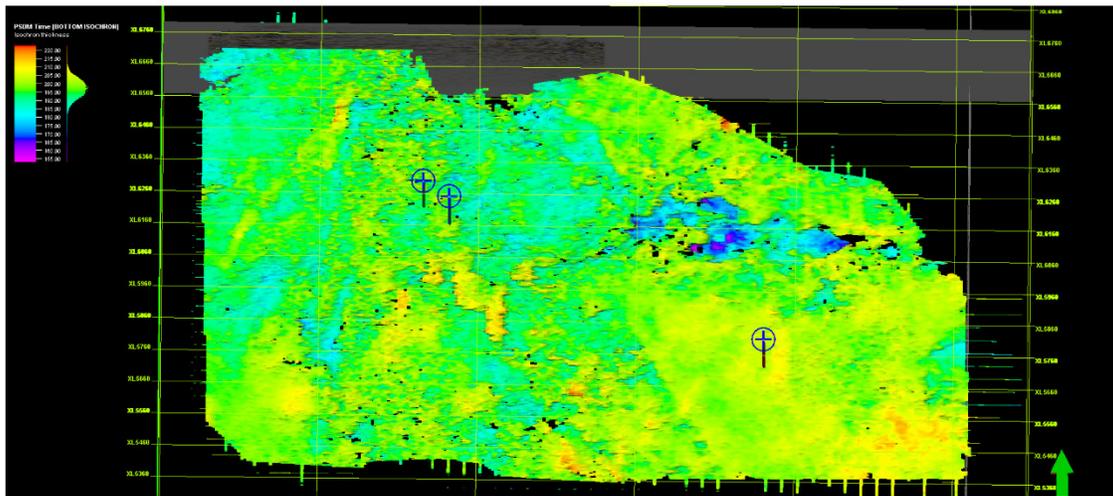
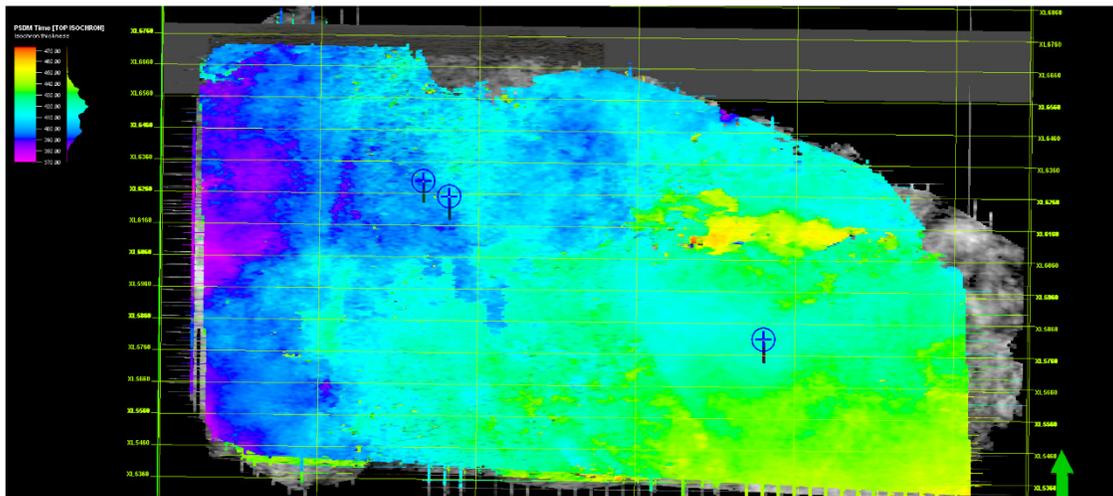
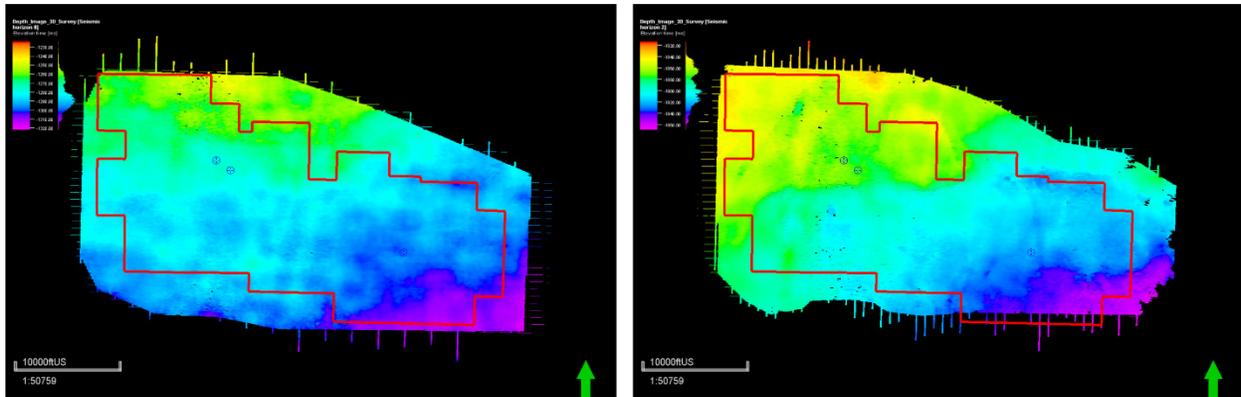


Figure 4.3-1 – a) depth (time) image of the Kansas City horizon (scale bar range – 1220-1320 milliseconds). b) depth (time) image of the Hunton base horizon (scale bar range – 1820-1960 milliseconds). c) Woodford base – Kansas City base isochron map (scale bar range – 470-370 milliseconds). d) Hunton base – Woodford base isochron map (scale bar range – 220-155 milliseconds).

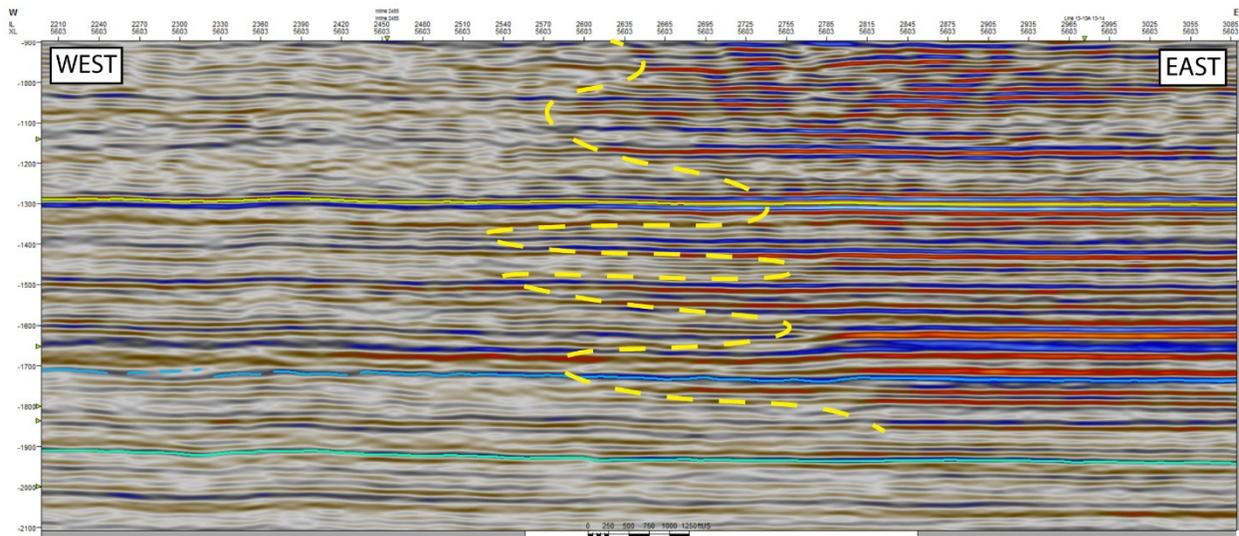
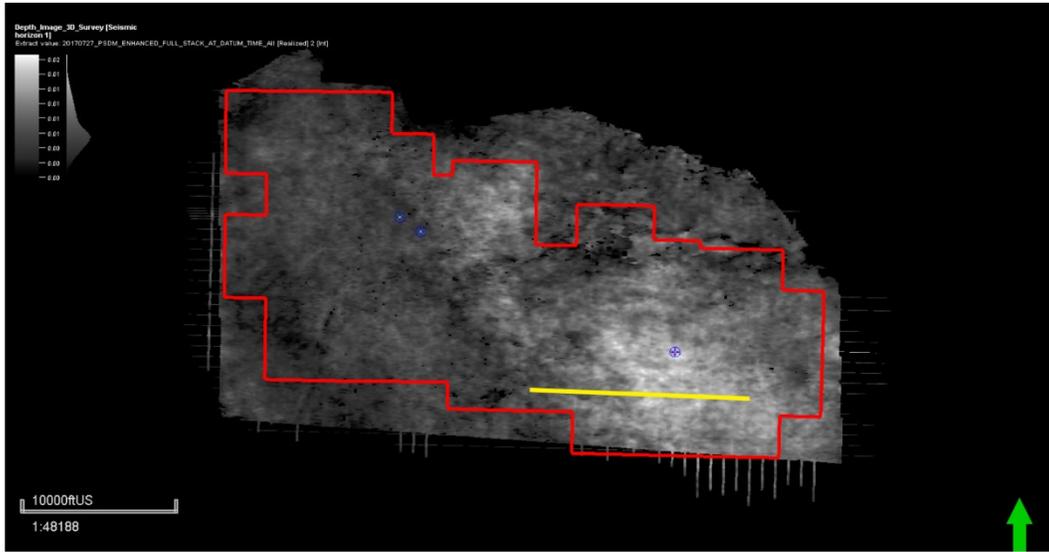


Figure 4.3-2 – a) amplitude intensity map of the base of the Woodford, yellow line shows location of the vertical seismic section. b) Lateral facies changes.

4.3.3 Fracture Analysis

Small aperture fractures were noted but not common in most of the reservoir cores we examined but most of these fractures appear to be drilling induced. Fractures in the Thirteen Finger limestone caprock were described using an industry-standard format for fracture class type, orientation, fracture dip, type of mineral fill, fracture porosity, fracture spacing, and intensity. Again, drilling induced fractures are most common. Natural mineral-filled fractures are quite rare, were formed during diagenesis at shallow depths, and are of Late Carboniferous age. Unless significantly damaged by large changes in reservoir pressure they are highly unlikely to provide migration pathways.

4.4 Leakage Through Confining / Seal System

A variety of analytical methods were used for caprock (confining system) analysis. Petrologic examination included standard thin section petrography and backscattered electron microscopy. Petrophysical analytical methods include retort analysis, pulse-decay permeability measurement, pressure decay permeability analysis for tight rocks, and intrusion-extrusion mercury porosimetry (MICP). Geomechanical analysis involved a standard series of mechanical tests: Brazil tension, unconfined compression, triaxial compression, and multi-stress compression.

Results of the MICP analysis show that the mudstone lithologies in the Morrow Shale and Thirteen Finger Limestone can support CO₂ column heights of ~1,000 to 10,000 feet. At an order of magnitude over the thickness of the Morrow reservoir, this should prove an effective seal for CO₂ storage in the Morrow B injection horizon.

Failure analyses show that the Morrow B sands are weaker than overlying lithologies, so that any fracture initiation around the injection well would not be expected to propagate into the overlying sealing units. Mechanical properties of the overlying shale and limestones provide an interesting and effective combination of strength and elasticity. Limestone layers are strong but brittle, while the shale layers are weaker but sufficiently ductile to prevent extensive fracture propagation.

It is unlikely for hydrocarbon migration pathways that charged the Morrow reservoir to be potential CO₂ migration pathways via primary pore networks today. Any potential CO₂ migration would be most likely due to leakage from wellbores or bypass through fault and fracture networks, discussed in Sections 4.2 and 4.3.

5 Determination of Expected Baselines

Since conversion to a CO₂ EOR project in 2010, ongoing operational monitoring and several research projects at the FWU have provided data for establishing baselines of CO₂ leakage/emissions from the target injection zone for the CO₂, the Morrow B sandstone, and from surface equipment.

5.1 Visual Inspection

Perdure operational field personnel visually inspect surface equipment daily and report and act upon any event indicating leakage.

5.2 Well Surveillance

Perdure adheres to the requirements of Rule 46 for the TRRC governing fluid injection into productive reservoirs. Rule 46 includes requirement for monitoring, reporting, and testing of Class II injection wells. Furthermore, TRRC includes special conditions regarding monitoring, reporting and testing in the individual permits for each injection well if they are deemed necessary.

Perdure also adheres to the requirements of Rule 20 for the TRRC governing the notification of fire breaks, leaks or blow-outs. Rule 20 requires that all operators report leaks to TRRC including measured or estimated quantities of product leaked.

5.3 Groundwater Monitoring Wells

Since 2013, the Southwest Regional Partnership on Carbon Sequestration (SWP) has been regularly sampling and analyzing fluids from Ogallala aquifer groundwater wells in around the FWU (Figure 5.3-1). The SWP performs major ion and trace metal analyses to evaluate leakage of CO₂, brine and/or hydrocarbons from the Morrow B and shallower zones, and/or wellbores. To date, no indication of fluid leakage has been identified from any of the 14 groundwater monitoring wells in the area. Perdue may choose to continue periodic monitoring of any of these wells to evaluate leakage.

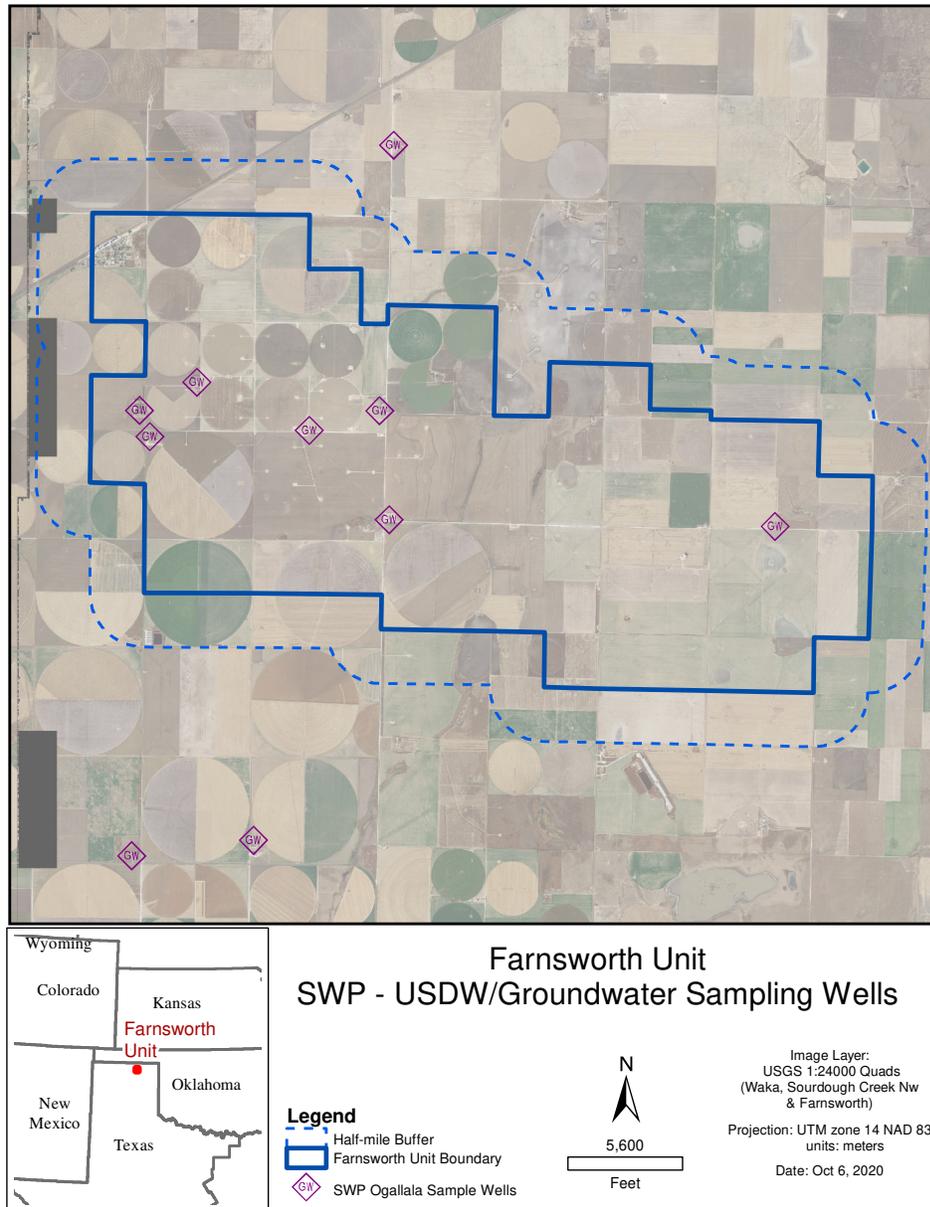


Figure 5.3-1: Ogallala groundwater monitoring wells

5.4 Soil CO₂ Monitoring

Since 2013, SWP has been conducting regular soil flux surveys within the western half of the FWU, to evaluate CO₂ leakage from the Morrow B. The SWP installed 94 PVC soil flux chamber collars around the 13-10A injection well (Figure 5.4-1); CO₂ soil flux was measured on a monthly basis, using a LiCor LI-8100 infrared gas analyzer, for a little over a year and then surveys were scaled back to once every 3 months. While CO₂ soil flux variations have been observed from the SWP surveys, these are all attributed to seasonal changes, and crop growth and rotation. The SWP soil flux collar network has identified no CO₂ leakage at the FWU, from any sources, since monitoring activities began.

Because the area around the FWU is predominantly agricultural, the majority of the soil collar installations are limited to road-side rights-of-way, with sparse deployment on well-pads. For the purposes of monitoring potential CO₂ emissions from the Morrow B and infrastructure (leaking wellbores/pipelines), Perdure may continue to monitor the existing SWP-affiliated soil flux collars immediately surrounding the 13-10A well and may also choose to expand the soil collar network to other well pads and ROWs in the western and eastern halves of the unit.

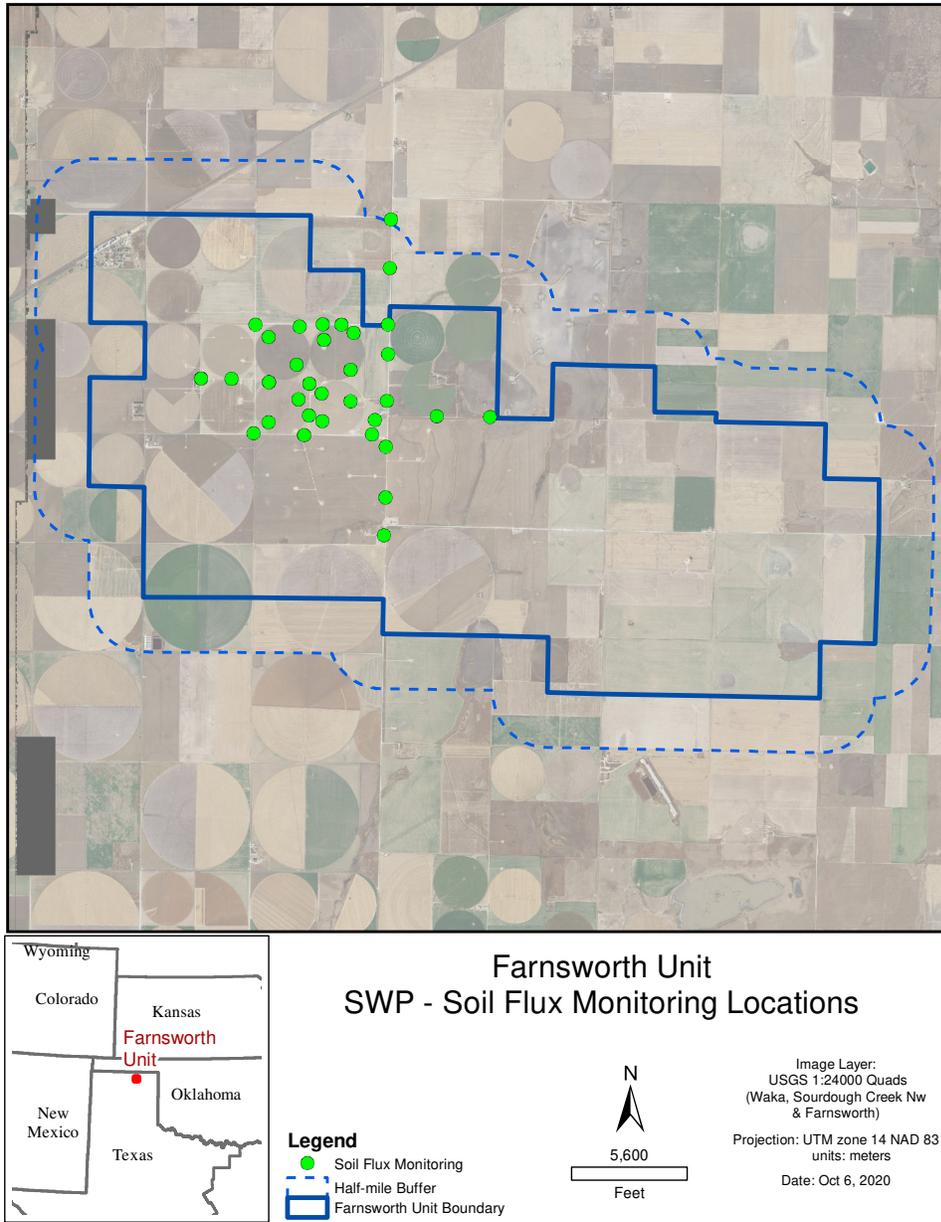


Figure 5.4 -1: Soil Flux

5.5 Site Characterization and Modeling

As described in Sections 2.2.2 and 2.4, the Morrow B sandstone is isolated both above and below by shale units of the Morrow. The primary seal consists of 180 – 200 ft of Morrow shale and Thirteen Finger Limestone which in turn is overlain by over a thousand feet of younger shale and limestone. These units provide a suitable seal to prevent the migration of CO₂ out of the injection reservoir.

Since 2013, several studies conducted by the SWP have evaluated the risk associated with leakage pathways through the seal units, including leakage of CO₂ to an overlying USDW or to the atmosphere through wellbores (Xiao et al, 2016, Xiao et al, 2017). The work of Ting et

al (2017), in particular, looked at the potential geochemical impacts of CO₂-fluid interaction on typical cements used in regional wellbore completions, as well as the surrounding caprock. The diffusive flow of CO₂ and the mixing of brine fluids results in a reaction within the Portlandite cement, forming calcite. The calcite formation within the cement reduces the porosity of the cement, effectively sealing pathways. The calcium-silica-hydrate in the Portlandite, conversely, is not significantly degraded by the CO₂-fluids, suggesting that the wellbore maintains its integrity and structure. These self-sealing attributes of the wellbore cements of the FWU wells suggest that CO₂ injected into the Morrow B are not at risk of leakage to overlying units, USDWs or the atmosphere.

6 Site Specific Considerations for Determining the Mass of CO₂ Sequestered

Of the twelve RR equations in 98.443 of Subpart RR, the following are relevant to Perdure's operations.

6.1 Determining Mass of CO₂ Received

Perdure currently receives CO₂ to its FWU facility through their own pipeline from the Arkalon Ethanol plant in Liberal, Kansas. Perdure also recycles CO₂ from their production wells in the FWU.

$$CO_{2T,r} = \sum_{p=1}^4 (r_p - S_r) * D * C_{CO_2,p,r} \quad (\text{Equation RR-2})$$

where:

$CO_{2T,r}$ = Net annual mass of CO₂ received through flow meter r (metric tons).

r_p = Quarterly volumetric flow through a receiving flow meter r in quarter p at standard conditions (standard cubic meters).

S_r = Quarterly volumetric flow through a receiving flow meter r that is redelivered to another facility without being injected into your well in quarter p (standard cubic meters).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

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

p = Quarter of the year.

r = Receiving flow meter.

6.2 Determining Mass of CO₂ Injected

Perdure injects CO₂ into the injection wells listed in Appendix 1.

$$CO_{2,u} = \sum_{p=1}^4 r_{p,u} * D * C_{CO_2,p,u} \quad (\text{Equation RR-5})$$

where:

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

$Q_{p,u}$ = Quarterly volumetric flow rate measurement for flow meter u in quarter p at standard conditions (standard cubic meters per quarter).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

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

p = Quarter of the year.

u = Flow meter.

6.3 Determining Mass of CO₂ Produced from Oil Production Wells

Perdure also recycles CO₂ from its production wells which are part of its operations in the FWU. Therefore, the following equation is relevant to its operations.

$$CO_{2,w} = \sum_{p=1}^4 Q_{p,w} * D * C_{CO_2,p,w} \quad (\text{Equation RR-8})$$

Where:

$CO_{2,w}$ = Annual CO₂ mass produced (metric tons) through separator w.

$Q_{p,w}$ = Volumetric gas flow rate measurement for separator w in quarter p at standard conditions (standard cubic meters).

D = Density of CO₂ at standard conditions (metric tons per standard cubic meter): 0.0018682.

$C_{CO_2,p,w}$ = CO₂ concentration measurement in flow for separator w in quarter p (vol. percent CO₂, expressed as a decimal fraction).

p = Quarter of the year.

w = Separator.

To aggregate production data, Perdure will sum the mass of all of the CO₂ separated at each gas-liquid separator in accordance with the procedure specified in Equation RR-9 below:

$$CO_{2P} = (1 + X) * \sum_{w=1}^W CO_{2,w} \quad (\text{Equation RR-9})$$

Where:

CO_{2P} = Total annual CO₂ mass produced (metric tons) through all separators in the reporting year.

$CO_{2,w}$ = Annual CO₂ mass produced (metric tons) through separator w in the reporting year.

X = Entrained CO₂ in produced oil or other fluid divided by the CO₂ separated through all separators in the reporting year (weight percent CO₂, expressed as a decimal fraction).

w = Separator.

6.4 Determining Mass of CO₂ Emitted by Surface Leakage

As required by 98.448 (d) of Subpart RR, Perdure will assess leakage from the relevant surface equipment listed in Sections 98.233 and 98.234 of Subpart W. According to 98.233 (r) (2) of Subpart W, the emissions factor listed in Table W-1A of Subpart W shall be used to estimate all streams of gases, including recycle CO₂ stream, for facilities that conduct EOR operations.

Perdure will calculate the total annual mass of CO₂ emitted from all leakage pathways in accordance with the procedure specified in Equation RR-10 below:

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

where:

CO_{2E} = Total annual CO₂ mass emitted by surface leakage (metric tons) in the reporting year.

$CO_{2,x}$ = Annual CO₂ mass emitted (metric tons) at leakage pathway x in the reporting year.

x = Leakage pathway.

6.5 Determining Mass of CO₂ Sequestered

The following Equation RR-11 pertains to facilities that are actively producing oil or natural gas.

$$CO_2 = CO_{2I} - CO_{2P} - CO_{2E} - CO_{2FI} - CO_{2FP} \quad \text{(Equation RR-11)}$$

Where:

CO_2 = Total annual CO₂ mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

CO_{2I} = Total annual CO₂ mass injected (metric tons) in the well or group of wells in the reporting year.

CO_{2P} = Total annual CO₂ mass produced (metric tons) in the reporting year.

CO_{2E} = Total annual CO₂ mass emitted (metric tons) by surface leakage in the reporting year.

CO_{2FI} = Total annual CO₂ mass emitted (metric tons) from equipment leaks and vented emissions of CO₂ 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 of the GHGRP.

CO_{2FP} = Total annual CO₂ mass emitted (metric tons) from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity, for which a calculation procedure is provided in subpart W of the GHGRP.

The following Equation RR-12 pertains to facilities that are not actively producing oil or natural gas. This equation may become relevant to Perdure's operation as it evolves in the future. However, this does not apply to Perdure's current operations.

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

CO_2 = Total annual CO₂ mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

CO_{2I} = Total annual CO₂ mass injected (metric tons) in the well or group of wells in the reporting year.

CO_{2E} = Total annual CO₂ mass emitted (metric tons) by surface leakage in the reporting year.

CO_{2FI} = Total annual CO₂ mass emitted (metric tons) from equipment leaks and vented emissions of CO₂ 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 of the GHGRP.

7 Estimated Schedule for implementation of MRV plan

Perdure expects to begin implementing the approved MRV plan on January 1, 2021.

8 GHG Monitoring and Quality Assurance Program

Perdure will meet the monitoring and QA/QC requirements of 98.444 of Subpart RR including those of Subpart W for emissions from surface equipment as required by 98.444 (d).

8.1 GHG Monitoring

As required by 40 CFR 98.3(g)(5)(i), Perdure's 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 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.

8.1.1 General

Measurement of CO₂ Concentration – All measurements of CO₂ concentrations of any CO₂ quantity will be conducted according to an appropriate standard method published by a consensus-based standards organization or an industry standard practice such as the Gas Producers Association (GSA) standards.

Measurement of CO₂ Volume – All measurements of CO₂ volumes will be converted to the following standard industry temperature and pressure conditions for use in Equations RR-2, RR-5 and RR-8 of Subpart RR of the GHGRP: Standard cubic meters at a temperature of 60 degrees Fahrenheit and at an absolute pressure of 1 atmosphere. Perdure will adhere to the American Gas Association (AGA) Report #3 – Orifice Metering)

8.1.2 CO₂ received.

Daily totalized volumetric flow meters are used to record CO₂ received via pipeline from the Arkalon ethanol plant in Liberal, Kansas. using a volumetric totalizer using accepted flow calculations for CO₂ according to the AGA Report #3.

8.1.3 CO₂ injected.

Daily CO₂ injection is recorded by combining the totals for the recycle compressor meter and the received CO₂ meter from Arkalon based on what's delivered on a 24-hour basis. This data is taken from the meter daily and stored in Perdure's data warehouse for records and reservoir management.

8.1.4 CO₂ produced.

The point of produced gas measurement is from a meter downstream of the compressors prior to being combined with purchase CO₂. The produced gas is sampled at least quarterly for the CO₂ content.

8.1.5 CO₂ emissions from equipment leaks and vented emissions of CO₂.

As required by 98.444 (d), Perdure will follow the monitoring and QA/QC requirements specified in Subpart W of the GHGRP for equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead and between the flow meter used to measure production quantity and the production wellhead.

As required by 98.448 (d) of Subpart RR, Perdure will assess leakage from the relevant surface equipment listed in Sections 98.233 and 98.234 of Subpart W. According to 98.233 (r) (2) of Subpart W, the emissions factor listed in Table W-1A of Subpart W shall be used to estimate all streams of gases, including recycle CO₂ stream, for facilities that conduct EOR operations. The default emission factors for production equipment are applied to the carbon capture utilization and storage (CCUS) injection operations reporting under Subpart RR.

8.1.6 Measurement devices.

As required by 40 CFR 98.444(e), Perdure 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) of 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, the American National Standards Institute (ANSI), the American Gas Association (AGA), the Gas Producers Association (GPA), the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API), and the North American Energy Standards Board (NAESB).
- All flow meters are National Institute of Standards and Technology (NIST) traceable.

8.2 QA/QC Procedures

Perdure will adhere to all QA/QC requirements in Subparts A, RR, and W of the GHGRP, 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.

8.3 Estimating Missing Data

Perdure will estimate any missing data according to the following procedures in 40 CFR 98.445 of Subpart RR of the GHGRP, as required.

- A quarterly flow rate of CO₂ received that is missing would be estimated using invoices or using a representative flow rate value from the nearest previous time period.
- A quarterly CO₂ concentration of a CO₂ stream received that is missing would be estimated using invoices or using a representative concentration value from the nearest previous time period.
- A quarterly quantity of CO₂ injected that is missing would be estimated using a representative quantity of CO₂ injected from the nearest previous period of time at a similar injection pressure.
- For any values associated with CO₂ emissions from equipment leaks and vented emissions of CO₂ from surface equipment at the facility that are reported in this subpart, missing data estimation procedures specified in subpart W of 40 CFR Part 98 would be followed.
- The quarterly quantity of CO₂ produced from subsurface geologic formations that is missing would be estimated using a representative quantity of CO₂ produced from the nearest previous period of time.

8.4 Revisions of the MRV Plan

Perdure will revise the MRV Plan as needed to reflect changes in production processes, monitoring instrumentation, and quality assurance procedures; or to improve procedures for the maintenance and repair of monitoring systems to reduce the frequency of monitoring equipment downtime.

9 Records Retention

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

- (1) A list of all units, operations, processes, and activities for which GHG emissions were calculated.
- (2) The data used to calculate the GHG emissions for each unit, operation, process, and activity. These data include:
 - (i) The GHG emissions calculations and methods used.
 - (ii) Analytical results for the development of site-specific emissions factors, if applicable.
 - (iii) The results of all required analyses.
 - (iv) Any facility operating data or process information used for the GHG emission calculations.
- (3) The annual GHG reports.
- (4) Missing data computations. For each missing data event, Perdure will retain a record of the cause of the event and the corrective actions taken to restore malfunctioning monitoring equipment.
- (5) A copy of the most recent revision of this MRV Plan.
- (6) 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.
- (7) Maintenance records for all continuous monitoring systems, flow meters, and other instrumentation used to provide data for the GHGs reported.
- (8) Quarterly records of CO₂ received, including mass flow rate of contents of container (mass or volumetric) at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- (9) Quarterly records of produced CO₂, including mass flow or volumetric flow at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- (10) Quarterly records of injected CO₂ including mass flow or volumetric flow at standard conditions and operating conditions, operating temperature and pressure, and concentration of these streams.
- (11) Annual records of information used to calculate the CO₂ emitted by surface leakage from leakage pathways.
- (12) Annual records of information used to calculate the CO₂ emitted from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead.

(13) Annual records of information used to calculate the CO₂ emitted from equipment leaks and vented emissions of CO₂ from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity.

(14) Any other records as specified for retention in this EPA-approved MRV plan.

10 Appendices

Appendix 1 - Perdure Wells

Table A1. 1 – Production wells.

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#1501	42357000600000	Oil Prod	Active	CO2		
#802	42357004140000	Oil Prod	Active	CO2	1	0
#1306	42357007960000	Oil Prod	Active	CO2	1	0
#901	42357009390000	Oil Prod	Active	CO2	1	0
#2008	42357020580000	Oil Prod	Active	CO2	1	0
#701	42357020620000	Oil Prod	Active	CO2	1	0
#602	42357020630000	Oil Prod	Active	CO2	1	0
#801	42357020650000	Oil Prod	Active	CO2	1	0
#904	42357022130000	Oil Prod	Active	CO2	1	0
#2310	42357300490000	Oil Prod	Active	CO2	1	0
#1802	42357319870000	Oil Prod	Active	CO2	1	0
#806	42357330090000	Oil Prod	Active	CO2	1	0
#1312	42357330130000	Oil Prod	Active	CO2	1	0
#909	42357330610000	Oil Prod	Active	CO2	1	0
#1606	42357329830000	Oil Prod	Active	CO2	1	0
#1508	42357330630000	Oil Prod	Active	CO2	1	0
#1102	42357330000000	Oil Prod	Active	CO2	1	0
#3001	42357002490000	Oil Prod	Inactive	CO2	0	0
#3002	42357002510000	Oil Prod	Inactive	CO2	0	0
#2001	42357004700000	Oil Prod	Inactive	CO2	0	0
#4004	42357005140000	Oil Prod	Inactive	CO2	0	0
#2302	42357007760000	Oil Prod	Inactive	CO2	0	0
#2304	42357007930000	Oil Prod	Inactive	CO2	0	0
#4101	42357009990000	Oil Prod	Inactive	CO2	0	0
#3802W	42357020390000	Oil Prod	Inactive	CO2	0	0
#2301	42357020560000	Oil Prod	Inactive	CO2	0	0
#2103	42357020670000	Oil Prod	Inactive	CO2	0	0
#4102	42357021920000	Oil Prod	Inactive	CO2	0	0
#3203	42357022060000	Oil Prod	Inactive	CO2	0	0
#3602	42357023350000	Oil Prod	Inactive	CO2	0	0
#3101	42357023370000	Oil Prod	Inactive	CO2	0	0
#3201	42357023450000	Oil Prod	Inactive	CO2	0	0
#2305	42357023680000	Oil Prod	Inactive	CO2	0	0
#2502A	42357300990000	Oil Prod	Inactive	CO2	0	0

#2311	42357313550000	Oil Prod	Inactive	CO2	0	0
#3206	42357319890000	Oil Prod	Inactive	CO2	0	0
#4001	42357811720000	Oil Prod	Inactive	CO2	0	0
#4201	42357000040000	Oil Prod	P&A	CO2	0	0
#401	42357001560000	Oil Prod	P&A	CO2	0	0
#1604	42357004760000	Oil Prod	P&A	CO2	0	0
#1604	42357004760000	Oil Prod	P&A	CO2	0	0
#2308	42357007790000	Oil Prod	P&A	CO2	0	0
#301	42357009340000	Oil Prod	P&A	CO2	0	0
#903	42357009400000	Oil Prod	P&A	CO2	0	0
#1601W	42357020400000	Oil Prod	P&A	CO2	0	0
#4009	42357020570000	Oil Prod	P&A	CO2	0	0
#1504	42357023340000	Oil Prod	P&A	CO2	0	0
#3102	42357023360000	Oil Prod	P&A	CO2	0	0
#4002	42357023480000	Oil Prod	P&A	CO2	0	0
#1308	42357023490000	Oil Prod	P&A	CO2	0	0
#1302	42357023500000	Oil Prod	P&A	CO2	0	0
#1304	42357023510000	Oil Prod	P&A	CO2	0	0
#1307	42357023520000	Oil Prod	P&A	CO2	0	0
#902	42357023530000	Oil Prod	P&A	CO2	0	0
#4005	42357023640000	Oil Prod	P&A	CO2	0	0
#4006	42357023650000	Oil Prod	P&A	CO2	0	0
#4301	42357023690000	Oil Prod	P&A	CO2	0	0
#2003	42357023810000	Oil Prod	P&A	CO2	0	0
#504	42357300510000	Oil Prod	P&A	CO2	0	0
#1202	42357319860000	Oil Prod	P&A	CO2	0	0
#3403	42357319880000	Oil Prod	P&A	CO2	0	0

Table A1. 2 - Proved Undeveloped (PUD) Wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#1607	42357334230000	PUD	Inactive	CO2	0	0
#505	42357050509999	PUD	Inactive	CO2	0	0
#1507 (INJ)	42357150709999	PUD	PUD	CO2	0	0
#1509 (INJ)	42357334240000	PUD	PUD	CO2	0	0

Table A1.3 – Water Alternating Gas (WAG) Injection Wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#1301 (INJ)	42357007950000	WAG Inj	Active	CO2	0	1
#1303 (INJ)	42357007940000	WAG Inj	Active	CO2	0	1
#1305 (INJ)	42357007990000	WAG Inj	Active	CO2	0	1
#1309 (INJ)	42357811020000	WAG Inj	Active	CO2	0	1
#1310A (INJ)	42357331790000	WAG Inj	Active	CO2	0	1
#1313 (INJ)	42357333320000	WAG Inj	Active	CO2	0	1
#1401 (INJ)	42357020410000	WAG Inj	Active	CO2	0	1
#1502 (INJ)	42357007030000	WAG Inj	Active	CO2	0	1
#1505 (INJ)	42357020300000	WAG Inj	Active	CO2	0	1
#1506 (INJ)	42357301210000	WAG Inj	Active	CO2	0	1
#1603 (INJ)	42357004720000	WAG Inj	Active	CO2	0	1
#502 (INJ)	42357023310000	WAG Inj	Active	CO2	0	1
#803 (INJ)	42357810840000	WAG Inj	Active	CO2	0	1
#804 (INJ)	42357003990000	WAG Inj	Active	CO2	0	1
#805 (INJ)	42357301160000	WAG Inj	Active	CO2	0	1
#9010 (INJ)	42357330770000	WAG Inj	Active	CO2	0	1
#908 (INJ)	42357301860000	WAG Inj	Active	CO2	0	1
#101 (INJ)	42357009380000	WAG Inj	Inactive	CO2	0	0
#1310 (INJ)	42357301030000	WAG Inj	Inactive	CO2	0	0
#2303 (INJ)	42357020290000	WAG Inj	Inactive	CO2	0	0
#2309 (INJ)	42357020380000	WAG Inj	Inactive	CO2	0	0
#3003 (INJ)	42357020470000	WAG Inj	Inactive	CO2	0	0
#3202 (INJ)	42357811590000	WAG Inj	Inactive	CO2	0	0
#3204 (INJ)	42357811610000	WAG Inj	Inactive	CO2	0	0
#3205 (INJ)	42357317680001	WAG Inj	Inactive	CO2	0	0
#3401 (INJ)	42357020500000	WAG Inj	Inactive	CO2	0	0
#4003 (INJ)	42357811740000	WAG Inj	Inactive	CO2	0	0
#4202 (INJ)	42357811820000	WAG Inj	Inactive	CO2	0	0
#4203 (INJ)	42357020330001	WAG Inj	Inactive	CO2	0	0
#603 (INJ)	42357303410000	WAG Inj	Inactive	CO2	0	0
#703 (INJ)	42357302540000	WAG Inj	Inactive	CO2	0	0
#906 (INJ)	42357020340000	WAG Inj	Inactive	CO2	0	0
#1101 (INJ)	42357020350000	WAG Inj	P&A	CO2	0	0
#1403 (INJ)	42357020660000	WAG Inj	P&A	CO2	0	0
#1503 (INJ)	42357006060000	WAG Inj	P&A	CO2	0	0
#1601 (INJ)	42357020400000	WAG Inj	P&A	CO2	0	0
#2307 (INJ)	42357020430000	WAG Inj	P&A	CO2	0	0
#2702 (INJ)	42357020510000	WAG Inj	P&A	CO2	0	0
#1402 (INJ)	42357002670001	WAG Inj	TA'd	CO2	0	0

Table A1.4 – Waste Salt Water (WSW) Injection Wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#1 (WSW)	42357810690000	WSW	Active	CO2	0	0
#2 (WSW)	42357810700000	WSW	Active	CO2	1	0

Table A1.5 – Water Injection Wells

Well Name	API	Well Type	Status	Gas Makeup	Active Production	Active Injection
#1605 (INJ)	42357020370000	Wtr Inj	P&A	CO2	0	0
#1903 (INJ)	42357806020000	Wtr Inj	P&A	CO2	0	0
#2005 (INJ)	42357252290000	Wtr Inj	P&A	CO2	0	0
#2006 (INJ)	42357020360000	Wtr Inj	P&A	CO2	0	0
#2007 (INJ)	42357020450000	Wtr Inj	P&A	CO2	0	0
#2101 (INJ)	42357020310000	Wtr Inj	P&A	CO2	0	0
#2102 (INJ)	42357020270000	Wtr Inj	P&A	CO2	0	0
#2104 (INJ)	42357020280000	Wtr Inj	P&A	CO2	0	0
#2503 (INJ)	42357020460000	Wtr Inj	P&A	CO2	0	0
#2602 (INJ)	42357020420000	Wtr Inj	P&A	CO2	0	0
#3103 (INJ)	42357020480000	Wtr Inj	P&A	CO2	0	0
#3301 (INJ)	42357000290000	Wtr Inj	P&A	CO2	0	0
#3303 (INJ)	42357021340000	Wtr Inj	P&A	CO2	0	0
#3402 (INJ)	42357008730000	Wtr Inj	P&A	CO2	0	0
#3601 (INJ)	42357020490000	Wtr Inj	P&A	CO2	0	0
#3702 (INJ)	42357811690000	Wtr Inj	P&A	CO2	0	0
#4007 (INJ)	42357811780000	Wtr Inj	P&A	CO2	0	0
#424 (INJ)	42357010010000	Wtr Inj	P&A	CO2	0	0

Appendix 2 - Referenced Regulations

U.S. Code > Title 26. INTERNAL REVENUE CODE > Subtitle A. Income Taxes > Chapter 1. NORMAL TAXES AND SURTAXES > Subchapter A. Determination of Tax Liability > Part IV. CREDITS AGAINST TAX > Subpart D. Business Related Credits > [Section 45Q - Credit for carbon oxide sequestration](#)

Texas Administrative Code (TAC) > Title 16 - Economic Regulation > Part 1 – Railroad Commission of Texas > [Chapter 3 – Oil and Gas Division](#)

Rules

- §3.1 Organization Report; Retention of Records; Notice Requirements
- §3.2 Commission Access to Properties
- §3.3 Identification of Properties, Wells, and Tanks
- §3.4 Oil and Geothermal Lease Numbers and Gas Well ID Numbers Required on All Forms
- §3.5 Application To Drill, Deepen, Reenter, or Plug Back
- §3.6 Application for Multiple Completion
- §3.7 Strata To Be Sealed Off
- §3.8 Water Protection
- §3.9 Disposal Wells
- §3.10 Restriction of Production of Oil and Gas from Different Strata
- §3.11 Inclination and Directional Surveys Required
- §3.12 Directional Survey Company Report
- §3.13 Casing, Cementing, Drilling, Well Control, and Completion Requirements
- §3.14 Plugging
- §3.15 Surface Equipment Removal Requirements and Inactive Wells
- §3.16 Log and Completion or Plugging Report
- §3.17 Pressure on Bradenhead
- §3.18 Mud Circulation Required
- §3.19 Density of Mud-Fluid
- §3.20 Notification of Fire Breaks, Leaks, or Blow-outs
- §3.21 Fire Prevention and Swabbing
- §3.22 Protection of Birds
- §3.23 Vacuum Pumps
- §3.24 Check Valves Required
- §3.25 Use of Common Storage
- §3.26 Separating Devices, Tanks, and Surface Commingling of Oil
- §3.27 Gas to be Measured and Surface Commingling of Gas
- §3.28 Potential and Deliverability of Gas Wells to be Ascertained and Reported
- §3.29 Hydraulic Fracturing Chemical Disclosure Requirements
- §3.30 Memorandum of Understanding between the Railroad Commission of Texas (RRC) and the Texas Commission on Environmental Quality (TCEQ)
- §3.31 Gas Reservoirs and Gas Well Allowable
- §3.32 Gas Well Gas and Casinghead Gas Shall Be Utilized for Legal Purposes

§3.33	Geothermal Resource Production Test Forms Required
§3.34	Gas To Be Produced and Purchased Ratably
§3.35	Procedures for Identification and Control of Wellbores in Which Certain Logging Tools Have Been Abandoned
§3.36	Oil, Gas, or Geothermal Resource Operation in Hydrogen Sulfide Areas
§3.37	Statewide Spacing Rule
§3.38	Well Densities
§3.39	Proration and Drilling Units: Contiguity of Acreage and Exception Thereto
§3.40	Assignment of Acreage to Pooled Development and Proration Units
§3.41	Application for New Oil or Gas Field Designation and/or Allowable
§3.42	Oil Discovery Allowable
§3.43	Application for Temporary Field Rules
§3.45	Oil Allowables
§3.46	Fluid Injection into Productive Reservoirs
§3.47	Allowable Transfers for Saltwater Injection Wells
§3.48	Capacity Oil Allowables for Secondary or Tertiary Recovery Projects
§3.49	Gas-Oil Ratio
§3.50	Enhanced Oil Recovery Projects--Approval and Certification for Tax Incentive
§3.51	Oil Potential Test Forms Required
§3.52	Oil Well Allowable Production
§3.53	Annual Well Tests and Well Status Reports Required
§3.54	Gas Reports Required
§3.55	Reports on Gas Wells Commingling Liquid Hydrocarbons before Metering
§3.56	Scrubber Oil and Skim Hydrocarbons
§3.57	Reclaiming Tank Bottoms, Other Hydrocarbon Wastes, and Other Waste Materials
§3.58	Certificate of Compliance and Transportation Authority; Operator Reports
§3.59	Oil and Gas Transporter's Reports
§3.60	Refinery Reports
§3.61	Refinery and Gasoline Plants
§3.62	Cycling Plant Control and Reports
§3.63	Carbon Black Plant Permits Required
§3.70	Pipeline Permits Required
§3.71	Pipeline Tariffs
§3.72	Obtaining Pipeline Connections
§3.73	Pipeline Connection; Cancellation of Certificate of Compliance; Severance
§3.76	Commission Approval of Plats for Mineral Development
§3.78	Fees and Financial Security Requirements
§3.79	Definitions
§3.80	Commission Oil and Gas Forms, Applications, and Filing Requirements
§3.81	Brine Mining Injection Wells
§3.83	Tax Exemption for Two-Year Inactive Wells and Three-Year Inactive Wells

- §3.84 Gas Shortage Emergency Response
- §3.85 Manifest To Accompany Each Transport of Liquid Hydrocarbons by Vehicle
- §3.86 Horizontal Drainhole Wells
- §3.91 Cleanup of Soil Contaminated by a Crude Oil Spill
- §3.93 Water Quality Certification Definitions
- §3.95 Underground Storage of Liquid or Liquefied Hydrocarbons in Salt Formations
- §3.96 Underground Storage of Gas in Productive or Depleted Reservoirs
- §3.97 Underground Storage of Gas in Salt Formations
- §3.98 Standards for Management of Hazardous Oil and Gas Waste
- §3.99 Cathodic Protection Wells
- §3.100 Seismic Holes and Core Holes
- §3.101 Certification for Severance Tax Exemption or Reduction for Gas Produced From High-Cost Gas Wells
- §3.102 Tax Reduction for Incremental Production
- §3.103 Certification for Severance Tax Exemption for Casinghead Gas Previously Vented or Flared
- §3.106 Sour Gas Pipeline Facility Construction Permit
- §3.107 Penalty Guidelines for Oil and Gas Violations

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Appendix 4 - Abbreviations and Acronyms

2D – 2 dimensional
3D – 3 dimensional
AGA – American Gas Association
AMA – Active Monitoring Area
ANSI – American National Standards Institute
API – American Petroleum Institute
ASTM - American Society for Testing and Materials
Bscf – billion standard cubic feet
B/D – barrels per day
bopd – barrels of oil per day
C4 – butane
C5 – pentane
C7 – heptane
C7+ - standard heptane plus
CCE – constant composition expansion
CCUS – carbon capture utilization and storage
cf – cubic feet
CH₄ – methane
cm – centimeter(s)
CO₂ – carbon dioxide
EOR – Enhanced Oil Recovery
EOS – Equation of State
EPA – US Environmental Protection Agency
ESD – Emergency Shutdown Device
ft – foot (feet)
FWU – Farnsworth Unit
GHG – Greenhouse Gas
GHGRP – Greenhouse Gas Reporting Program
GPA – Gas Producers Association
H₂S – hydrogen sulfide
HFU – hydrocarbon flow unit
m – meter(s)
mD – millidarcy(ies)
MICP – mercury injection capillary pressure
MIT – mechanical integrity test
MMA – maximum monitoring area
MMB – million barrels
MMP – minimum miscible pressure
MMscf – million standard cubic feet
MMstb – million stock tank barrels
MRV – Monitoring, Reporting, and Verification
MMMT – Million metric tonnes

MT -- Metric tonne
NIST - National Institute of Standards and Technology
NAESB – North American Energy Standards Board
OOIP – Original Oil-In-Place
OWC – oil water contact
PPM – Parts Per Million
psia – pounds per square inch absolute
PVT – pressure, volume, temperature
QA/QC – quality assurance/quality control
RMS – root mean square
SEM – scanning electron microscope
SWP - Southwest Regional Partnership on Carbon Sequestration
TAC – Texas Administrative Code
TRRC – Texas Railroad Commission
TSD – Technical Support Document
TVDSS – True Vertical Depth Subsea
UIC – Underground Injection Control
USDW – Underground Source of Drinking Water
WAG – Water Alternating Gas (Gas is recycled CO₂ and purchase CO₂)
XRD – x-ray diffraction

Appendix 5 - Conversion Factors

Perdure reports CO₂ at standard conditions of temperature and pressure as defined in the State of Texas in the Texas Administrative Code for the Oil and Gas Division, Rule 3.79 as follows:

Cubic foot of gas or standard cubic foot of gas--The volume of gas contained in one cubic foot of space at a standard pressure base and at a standard temperature base. The standard pressure base shall be 14.65 pounds per square inch absolute, and the standard temperature base shall be 60 degrees Fahrenheit.

To calculate CO₂ mass from CO₂ volume, EPA recommends using the database of thermodynamic properties developed by the National Institute of Standards and Technology (NIST). This online database is available at:

<https://webbook.nist.gov/chemistry/fluid/>

It provides density of CO₂ using the Span and Wagner equation of state (EOS) at a wide range of temperature and pressures.

At State of Texas standard conditions, the Span and Wagner EOS gives a density of CO₂ of 0.002641684 lb-moles per cubic foot. Converting the CO₂ density in units of metric tonnes per cubic foot:

$$Density_{CO_2} \left(\frac{MT}{ft^3} \right) = Density_{CO_2} \left(\frac{lb - moles}{ft^3} \right) \times MW_{CO_2} \times \frac{1 MT}{2204.62 lbs}$$

Where:

$$Density_{CO_2} = \text{Density of CO}_2 \text{ in metric tonnes (MT) per cubic foot}$$

$$Density_{CO_2} = 0.002641684$$

$$MW_{CO_2} = 44.0095$$

$$Density_{CO_2} = 5.2734 \times 10^{-5} \frac{MT}{ft^3} \text{ or } 5.2734 \times 10^{-2} \frac{MT}{Mcf}$$

The conversion factor 5.2734×10^{-2} MT/Mcf is used to convert CO₂ volumes in standard cubic feet to CO₂ mass in metric tonnes.