Farnsworth Unit, Texas (FWU)

MONITORING, REPORTING, AND VERIFICATION PLAN

Perdure Petroleum, LLC

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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 (CO_2) with a subsidiary or ancillary purpose of geologic sequestration of CO_2 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 CO_2-EOR project in December 2010. Perdure intends to continue CO_2-EOR operations until the end of the economic life of the CO_2-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 CO_2 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 CO_2 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 CO_2 in the MMA and evaluates the likelihood, magnitude, and timing, of surface leakage of CO_2 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 CO_2 as required by 40 CFR 98.448(a)(3), Subpart RR of the GHGRP. Finally, this section also demonstrates that the risk of CO_2 leakage through the identified pathways is minimal.

Section 5 describes the strategy for establishing the expected baselines for monitoring CO_2 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 CO_2 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 CO_2 injection

It is currently projected that Perdure will inject CO_2 for an additional 12 years.

2.1.2 Estimated volume of CO_2 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 CO_2 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 CO_2 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.

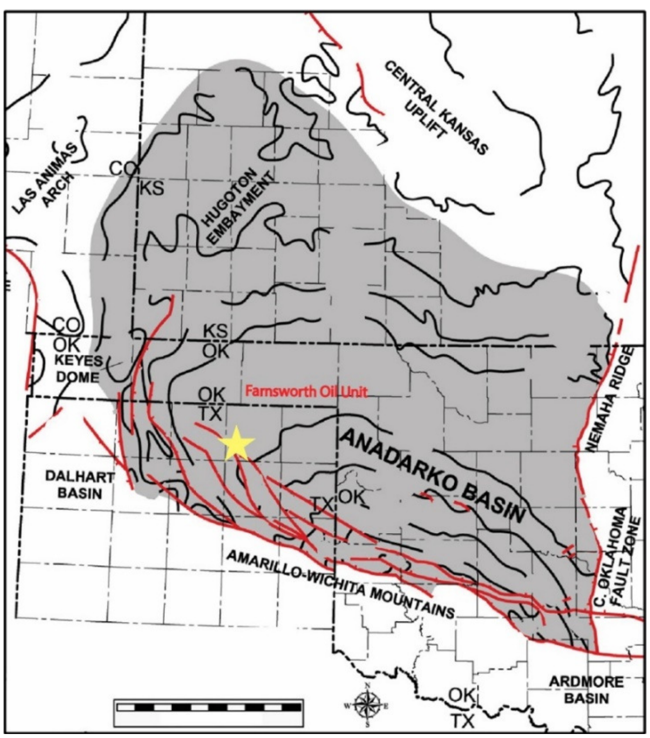

Figure 2.2-1- Location of the Farnworth Unit (FWU) on the Northwest Shelf of the Anadarko Basin in West Texas. Red lines are approximate locations of faults that have been documented in the region.

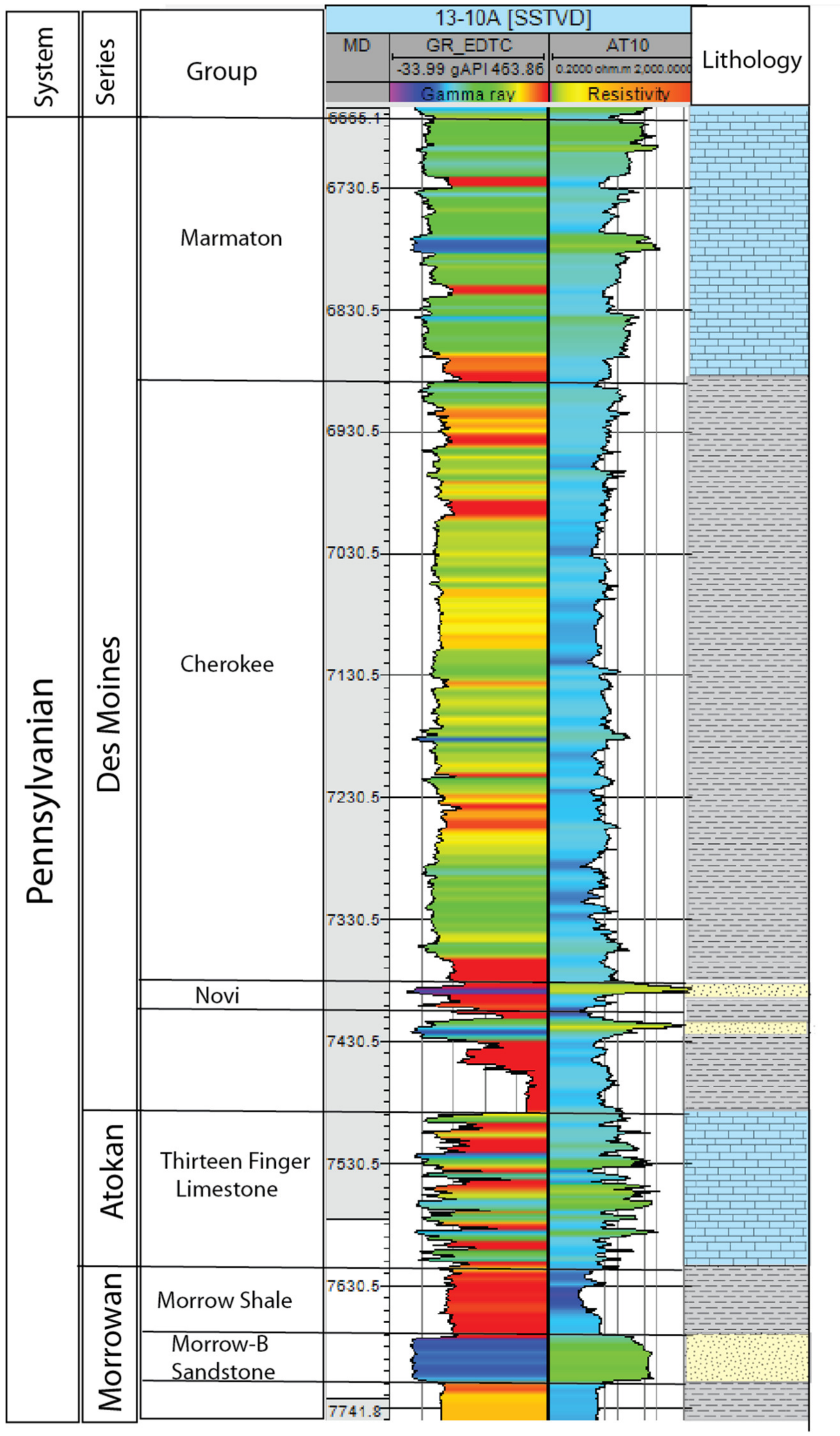

Figure 2.2-2- Stratigraphic section of the FWU.

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 depositon. 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 CO_2 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. CO_2 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 CO_2 to the field. The amount delivered is dependent on the production of CO_2 produced from the fermentation process. This amount will vary but should average 12 MMCFD. Once CO_2 enters the FWU there are three main processes involved in EOR operations. These processes are shown in Figure 2.3-1 and include:

1. CO_2 distribution and Injection. Purchased CO_2 is combined with recycled CO_2 from the FWU central tank battery and sent through the main CO_2 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.

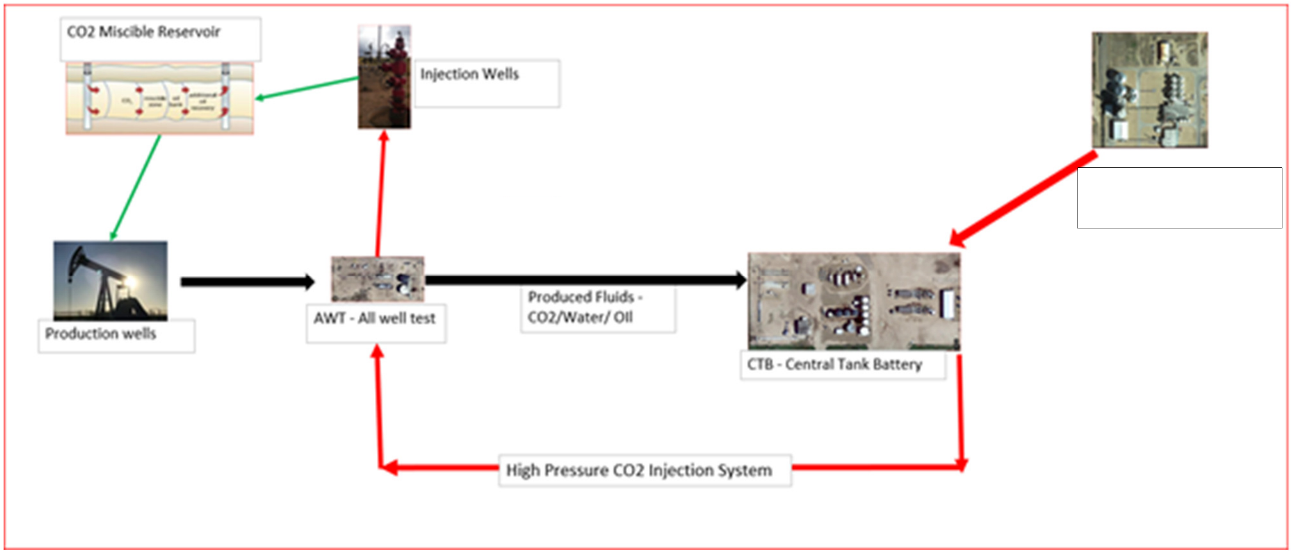

Figure 2.3-1 - Simplified flow diagram of the facilities and equipment within the boundaries of the Farnsworth Unit.

2.3.1 CO_2 Distribution and Injection

Perdure purchases CO_2 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 CO_2 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 CO_2, 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 CO_2, from the wells is compressed and metered by a similar totalizer meter as the purchase CO_2 meter and is recorded daily.

Perdure currently has three active injection manifolds and approximately 17 active injection wells that the CO_2 is distributed through. When the MRV plan becomes active, the daily injection volume of the combined purchased CO_2 and recycled CO_2 will be approximately 24 MMCFD. Of this volume 12 MMCFD is purchased CO_2 and 12 MMCFD is recycled CO_2. This ratio of purchased CO_2 to recycled CO_2 is expected to change over time, with the percentage of recycled CO_2 increasing and purchased CO_2 decreasing. The current reservoir management plan projects that CO_2 purchases will remain constant at 12 MMCFD for 12 years and decline after 2033. (Per Reservoir Characterization and Modelling, the CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2.

2.3.2 Produced Fluids Handling

As injected CO_2 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 CO_2 (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 CO_2 content in the oil being sold.

After separation, the gas phase, which is approximately 89-93% CO_2, 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 CO_2 in the water, analyses have shown the water typically contains <690 ppm (0.069%) CO_2.

FWU production has trace amounts of hydrogen sulfide (H_2S), 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 H_2S detectors is protecting people from the risk of being harmed. The detection limit of the H_2S detectors is quantified for readings in the range of 0-100 ppm and will sound an alarm above 10 ppm. The secondary purpose H_2S 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 H_2S leakage is detected and located. Once identified, further a further response will be initiated and CO_2 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 CO_2 into a variable density liquid, which is then transported out via high pressure lines to the AWTs where a manifold splits this dense CO_2 to the wells that are on CO_2 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.

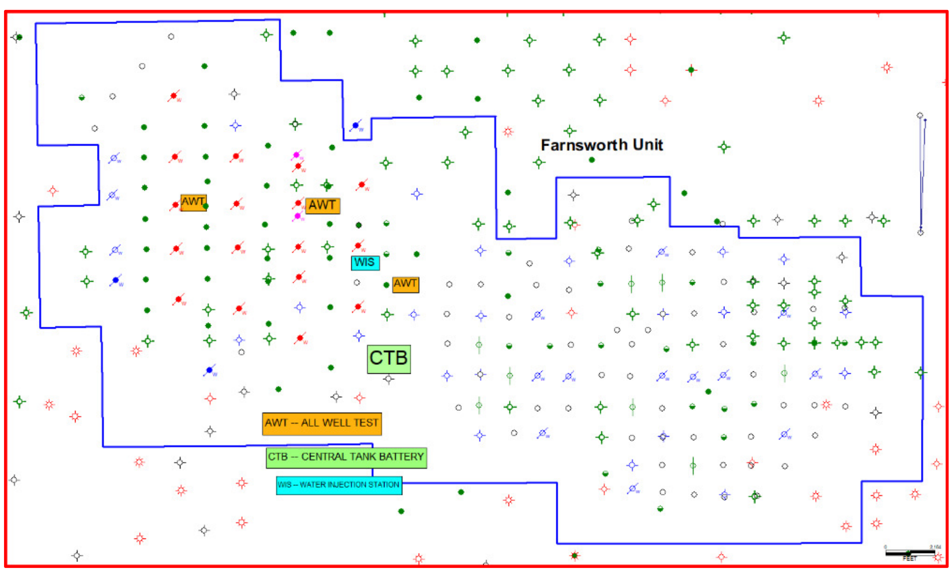

Figure 2.3-2 – Location of All Well Test (AWT) sites, Central Tank Battery (CTB) and Water Injection Station (WIS) in the FWU

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 CO_2 (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 CO_2 –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.

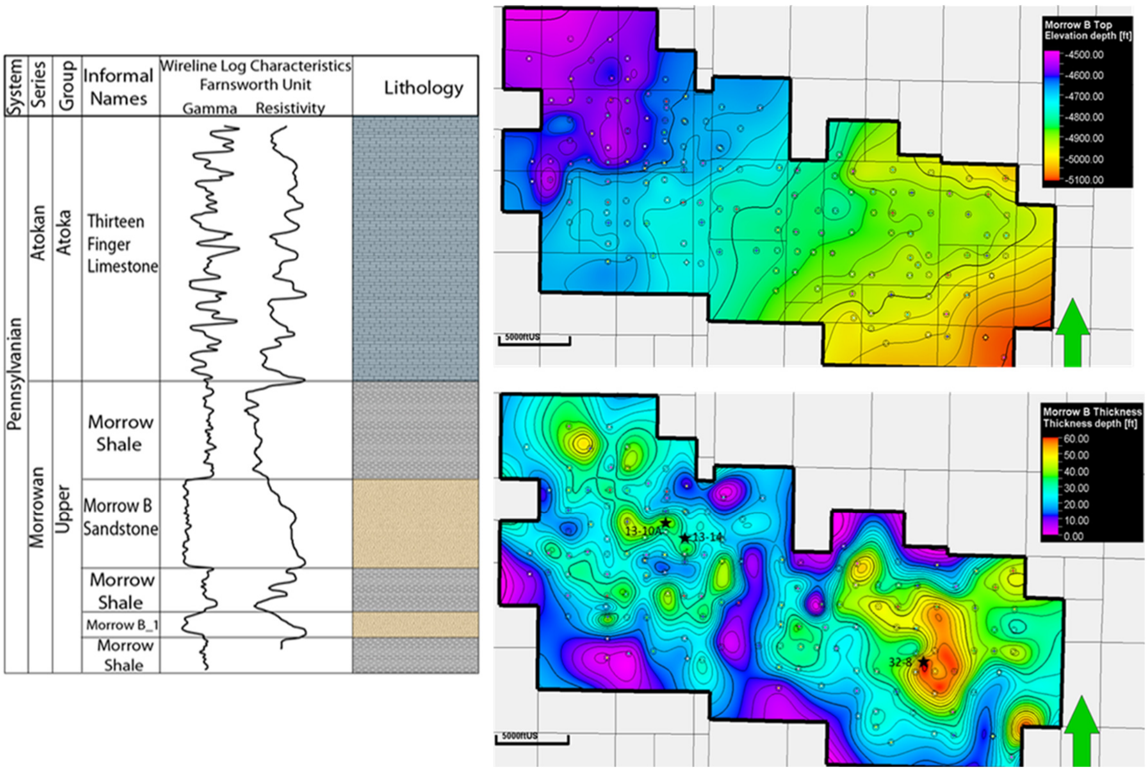

Figure 2.4-1- (Left) Type log of FWU caprock and reservoir. (Upper Right) Surface contour of Morrow B top. (Lower right) Thickness map of Morrow B sands (Gallagher 2014).

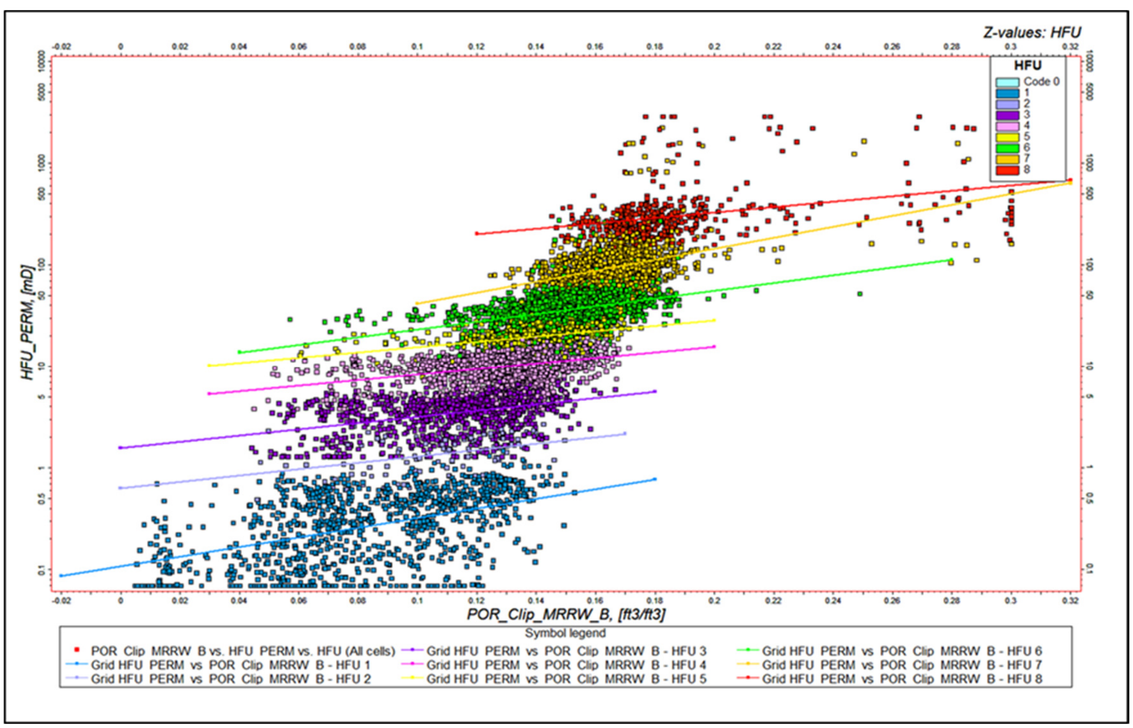

Figure 2.4-2 - Porosity versus permeability for the 51 cored wells, separated by pore throat size into hydraulic flow units.

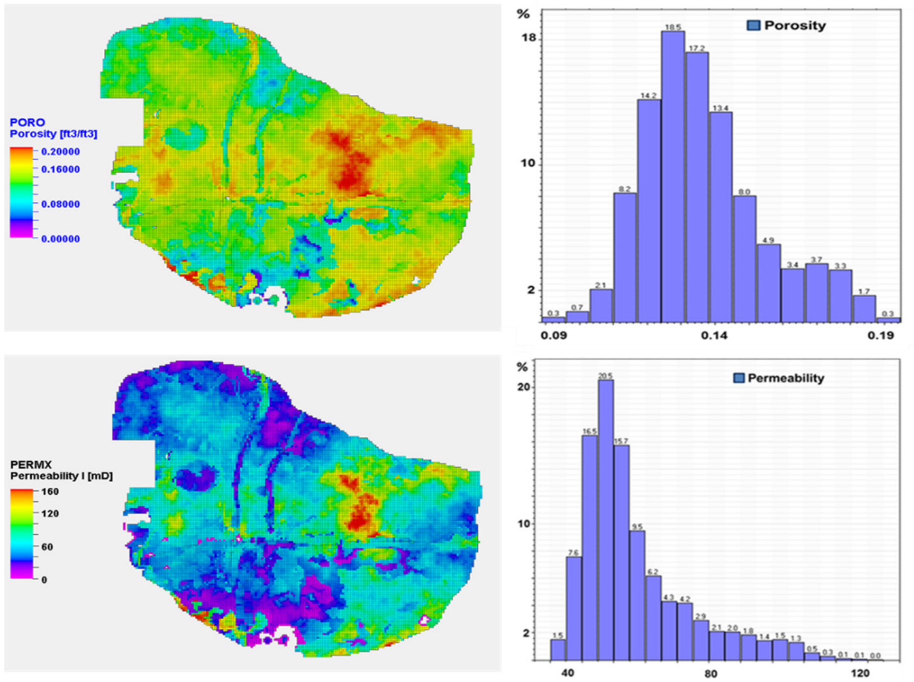

Figure 2.4-1- (Upper left) Porosity distribution using a Gaussian Simulation method for the west section of FWU used in the work. (Upper right) shows histogram illustrating a normal distribution of porosity with a mean of 14%. (Lower left) Permeability distribution constructed from porosity-permeability 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 PVTSimTM 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 CO_2 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).

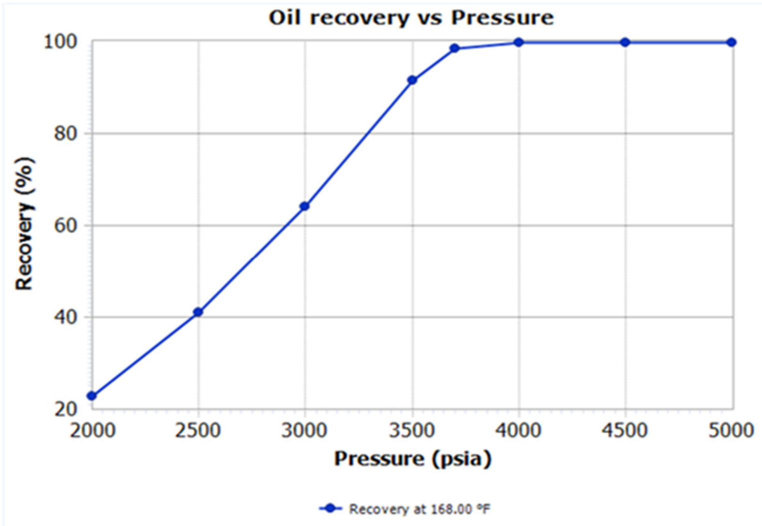

Figure 2.4-4. Oil recovery plot for 1D slim tube test

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 CO_2 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 CO_2 breakthrough. Simulated gas production and CO_2 injection rates were unable to match measured volumes after the CO_2 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 CO_2 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, CO_2 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 CO_2-WAG commenced (December 2010). About 93% of the purchased CO_2 remains as of August 2020.

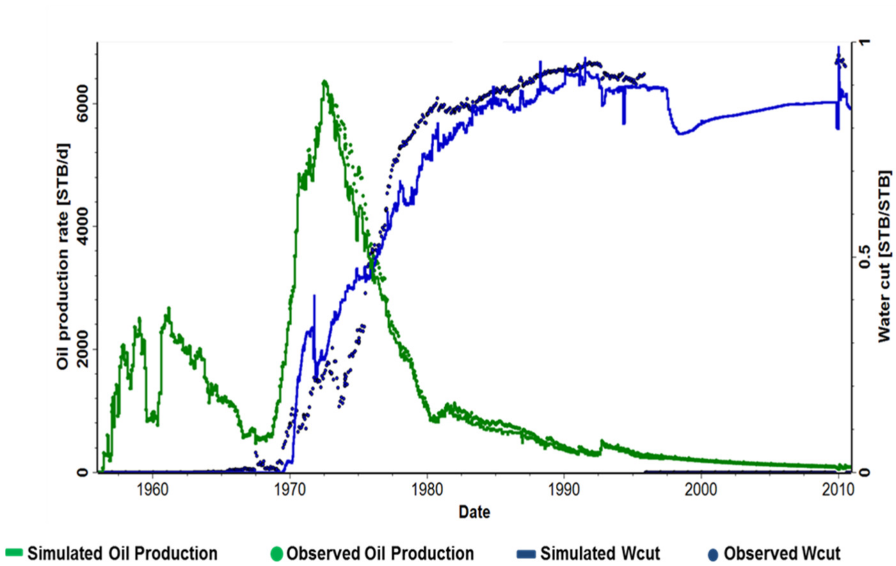

Figure 2.4-5- Calibration of simulated oil production rate and water cut vs. observed for primary and secondary history matching process.

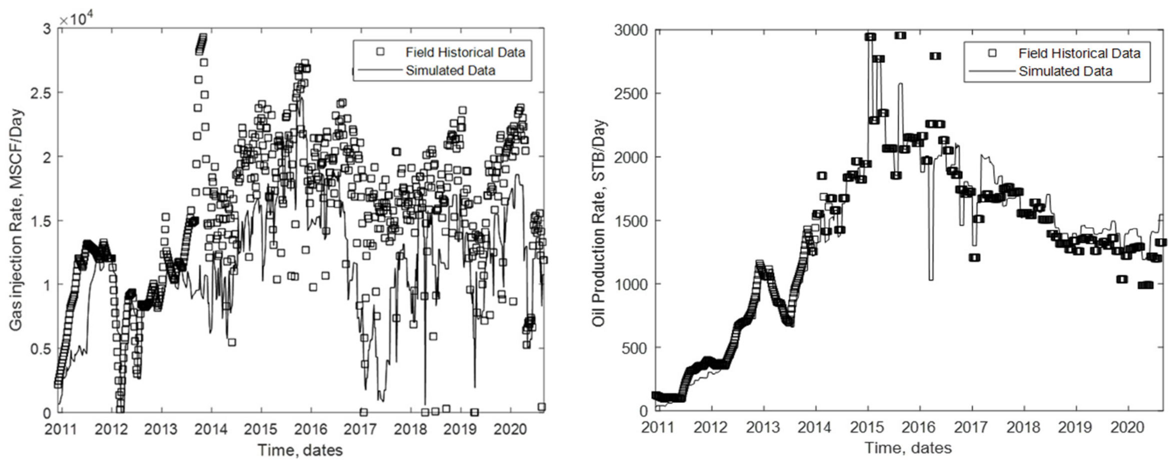

Figure 2.4-6- Calibration of simulated vs observed responses for tertiary recovery including CO_2 injection (left) and oil production rate (right).

2.4.4 CO_2 –EOR Performance Scenarios

Once an acceptable history match was reached, CO_2 flood performance could be predicted to optimize oil production and CO_2 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 CO_2 prediction model. There is an anticipated constant CO_2 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 CO_2 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 CO_2 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 CO_2 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.

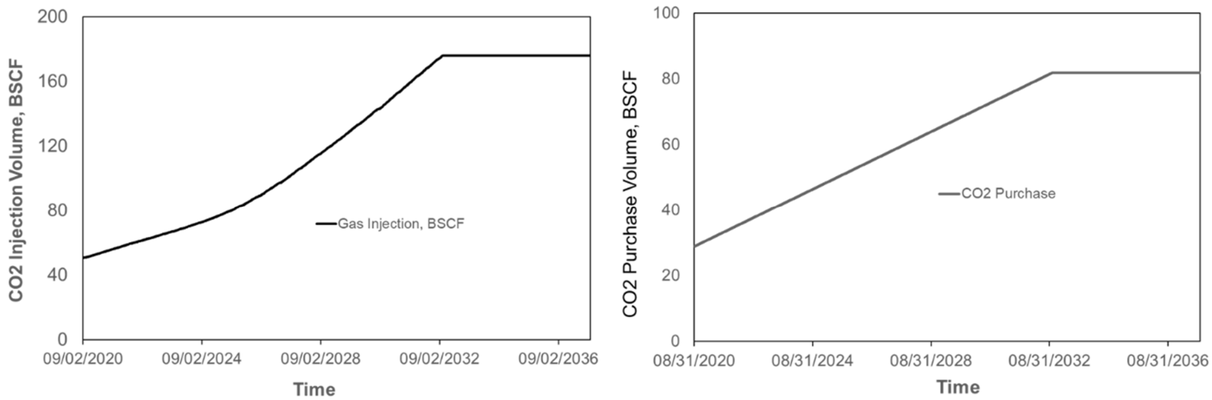

Figure 2.4-7 - Simulated Cumulative CO_2 injection Volume and CO_2 purchase volume for the Forecasting Scenario

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 CO_2 plume until the CO_2 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 CO_2 composition results that are displayed in Section 3.1.1 indicate that all of the CO_2 will remain in modelled area is projected to contain the free phase CO_2 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 CO_2 composition depicting the lateral extent of CO_2 in the injection zone. The injection area shows the significant high concentration of CO_2 which reiterates the containment within the injection zone and area. The simulation depicts the tertiary CO_2 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 CO_2 fraction which illustrates most of the CO_2 injected has not reach the model boundary even after a total of 22 years of potential CO_2 injection into the Morrow B formation.

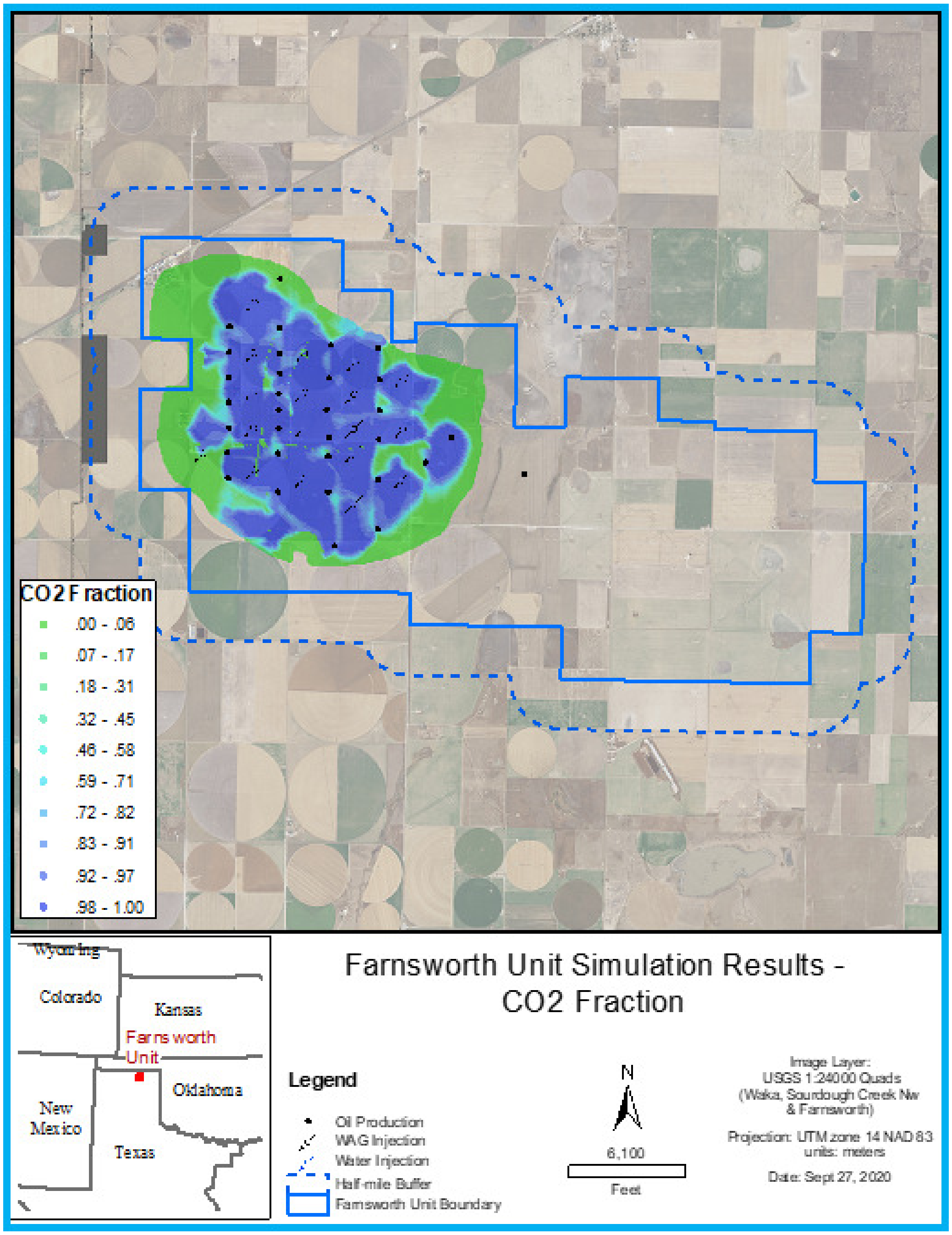

Figure 3.1-1: Model simulation of the tertiary CO_2 flood

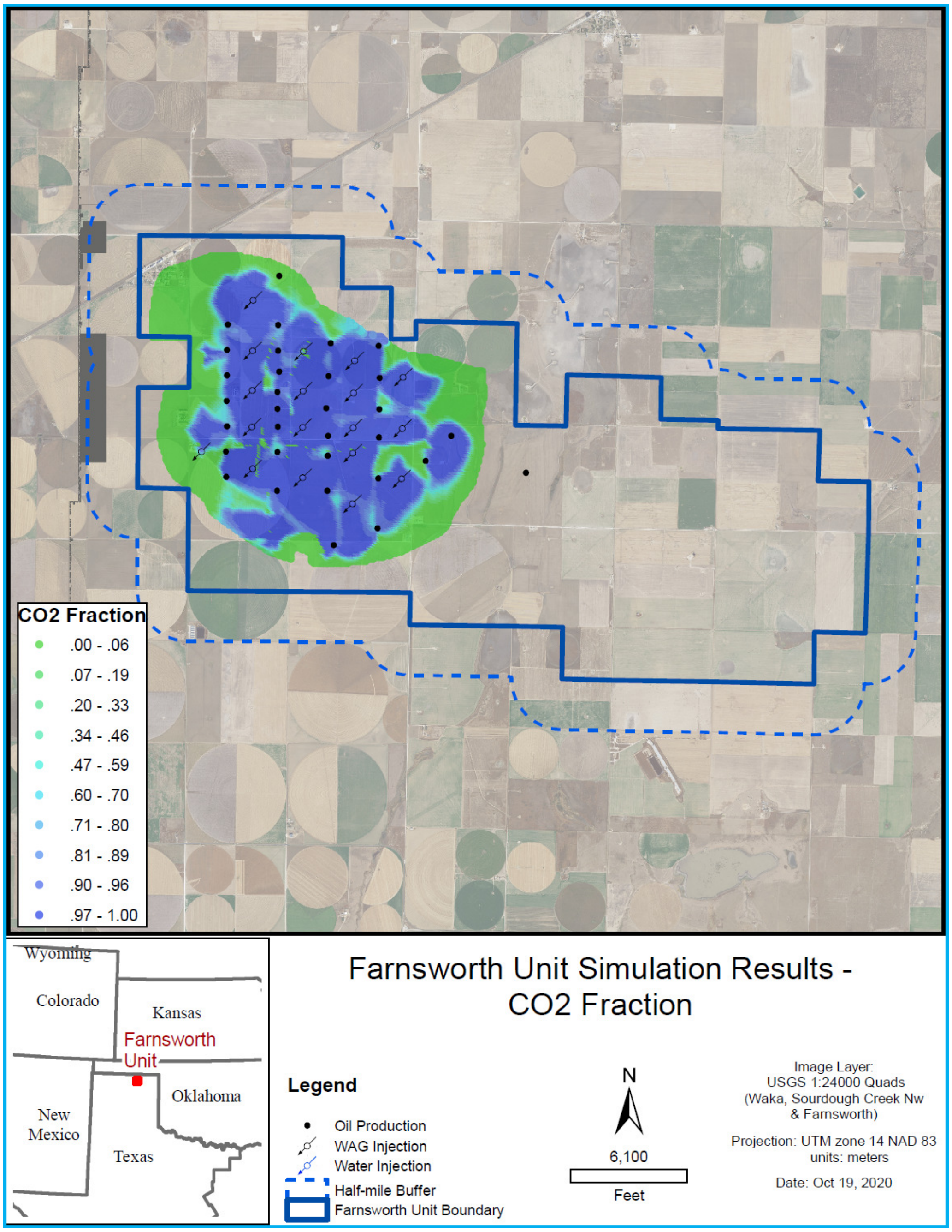

Figure 3.1-2 – CO_2 Plume Extent 5 years after Injection ceased.

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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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.

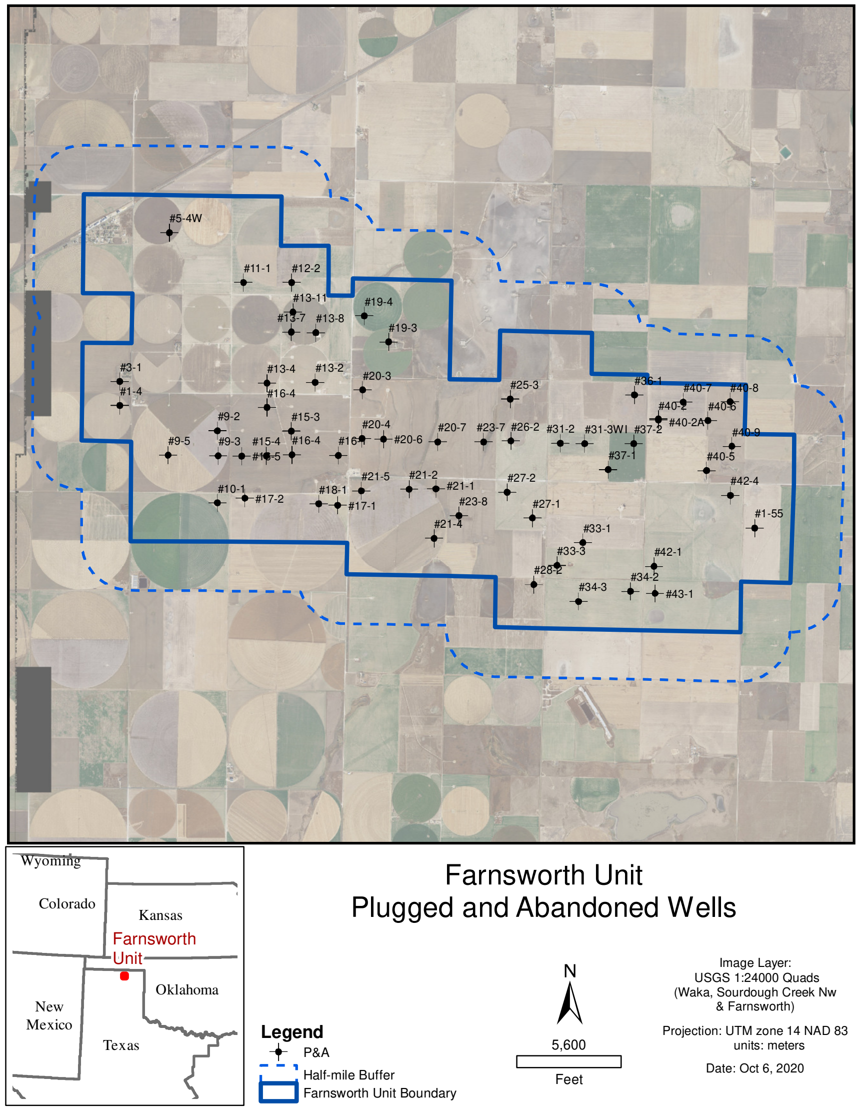

Figure 4.2-1: Plugged and Abandoned Wells in the FWU

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 CO_2 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 CO_2 to the surface through production wells is unlikely.

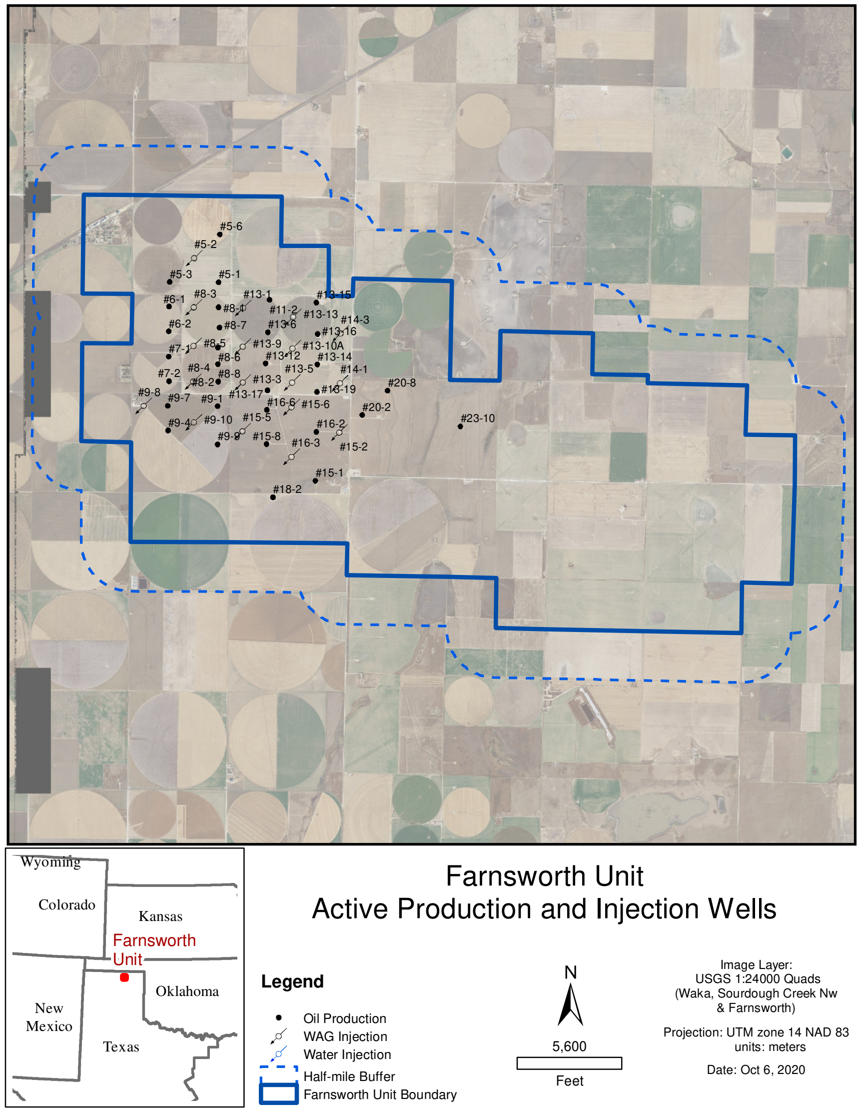

Figure 4.2-2: Active Production and Injection Wells in the FWU

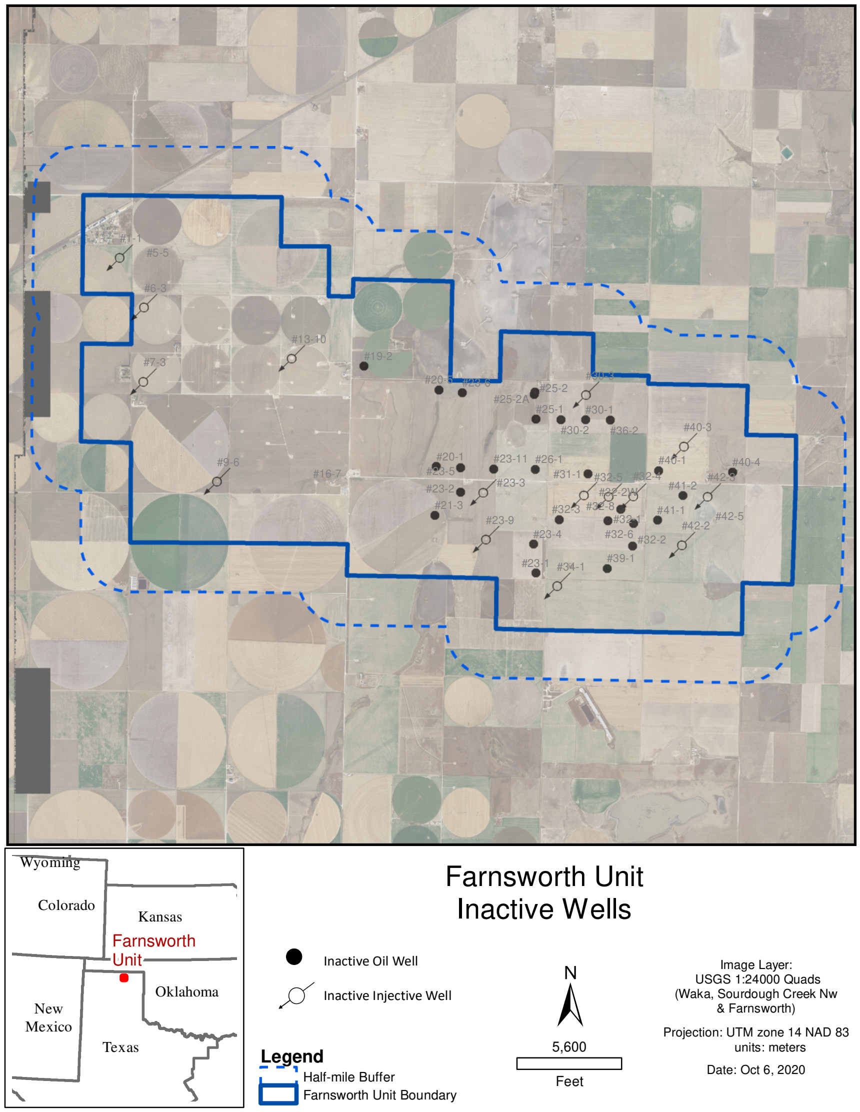

Figure 4.2-3: Inactive Production and Injection Wells in the FWU

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 CO_2 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.

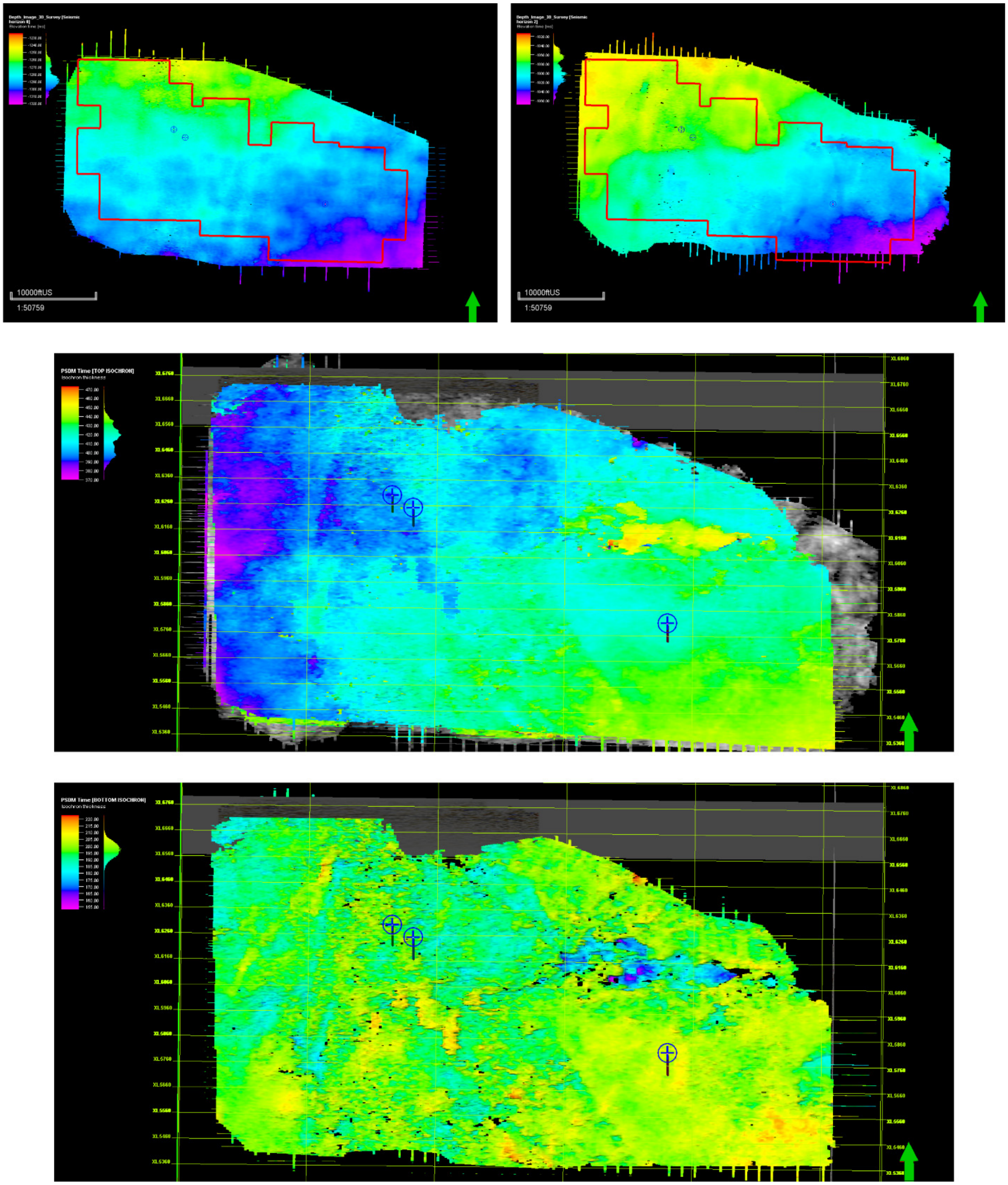

Figure 4.3-1 – a) depth (time) image of the Kansas City horizon (scale bar range – 1220-1320 milliseconds). b) depth (time) image of the Hunton base horizon (scale bar range – 1820-1960 milliseconds). c) Woodford base – Kansas City base isochron map (scale bar range – 470-370 milliseconds). d) Hunton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

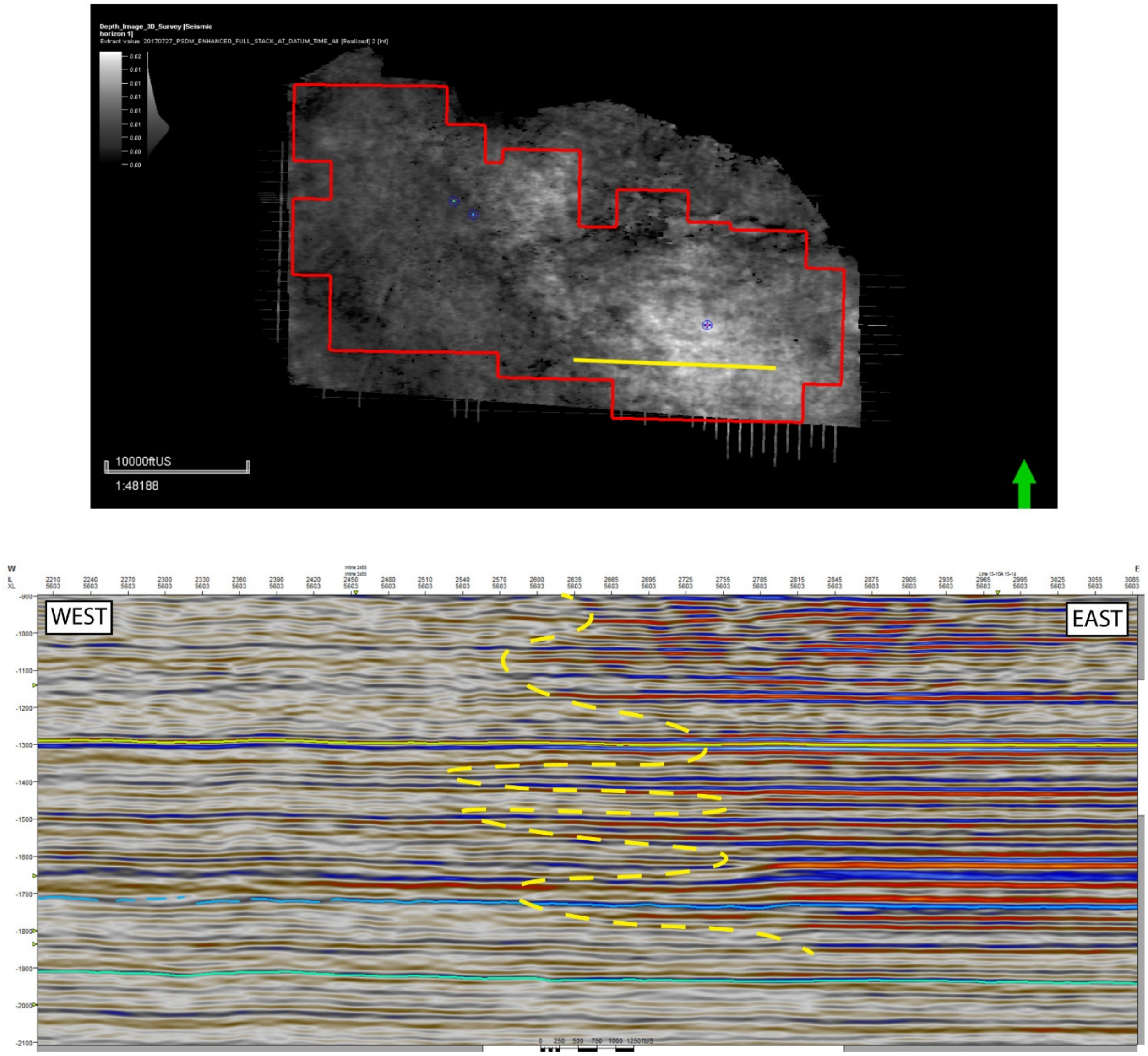

Figure 4.3-2 – a) amplitude intensity map of the base of the Woodford, yellow line shows location of the vertical seismic section. b) Lateral facies changes.

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 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, 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 migration pathways via primary pore networks today. Any potential CO_2 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 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, 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.

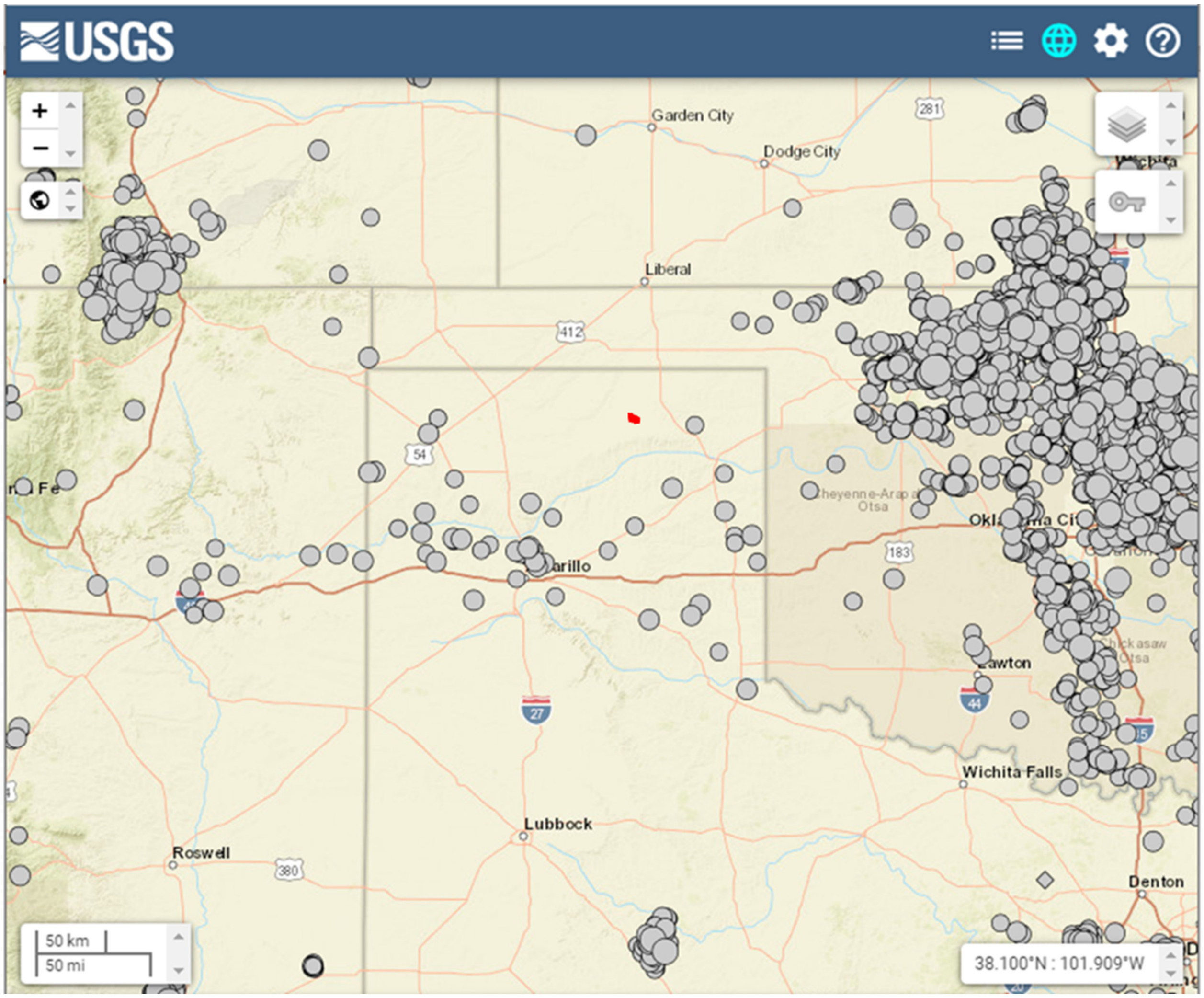

Figure 4.6: USGS earthquakes (+2.5 magnitude) for last 40 years with FWU highlighted red

There is no direct evidence that natural seismic activity poses a significant risk for loss of CO_2 to the surface in the FWU.

In the unlikely event that induced seismicity resulted in a pathway for material amounts of CO_2 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 CO_2 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 CO_2 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 CO_2 leakage.

Table 1 Response Plan for CO_2 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, values, 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 CO_2 Losses

Major CO_2 losses are typically event driven and require a process to assess, address, track, and if applicable quantify potential CO_2 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 CO_2 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 CO_2 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 CO_2 geysers) suggest that the amount released from routine leaks would be small as compared to the amount of CO_2 that would remain stored in the formation.

5 Strategy for Determining CO_2 Baselines for CO_2 Monitoring

Since conversion to a CO_2 EOR project in 2010, ongoing operational monitoring and several research projects at the FWU have provided data for establishing baselines of surface CO_2 leakage/emissions from the target injection zone for the CO_2, 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 CO_2 baselines. Baseline groundwater monitoring conducted since 2013 indicates no leakage of CO_2 from underlying formations or wells into the local Ogallala aquifer. Soil flux monitoring also conducted since 2013 shows CO_2 flux ranging between 3 and 15 micromoles per second and square meter (µmol/m2/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 CO_2 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 CO_2 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 CO_2-fluid interaction on typical cements used in regional wellbore completions, as well as the surrounding caprock. The diffusive flow of CO_2 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 CO_2-fluids, suggesting that the wellbore maintains its integrity and structure. These self-sealing attributes of the wellbore cements of the FWU wells suggest that CO_2 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 CO_2, 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 CO_2 or brine contamination, as SWP studies (see section 5.1) have suggested minimal risk of groundwater contamination from CO_2 leakage from depth.

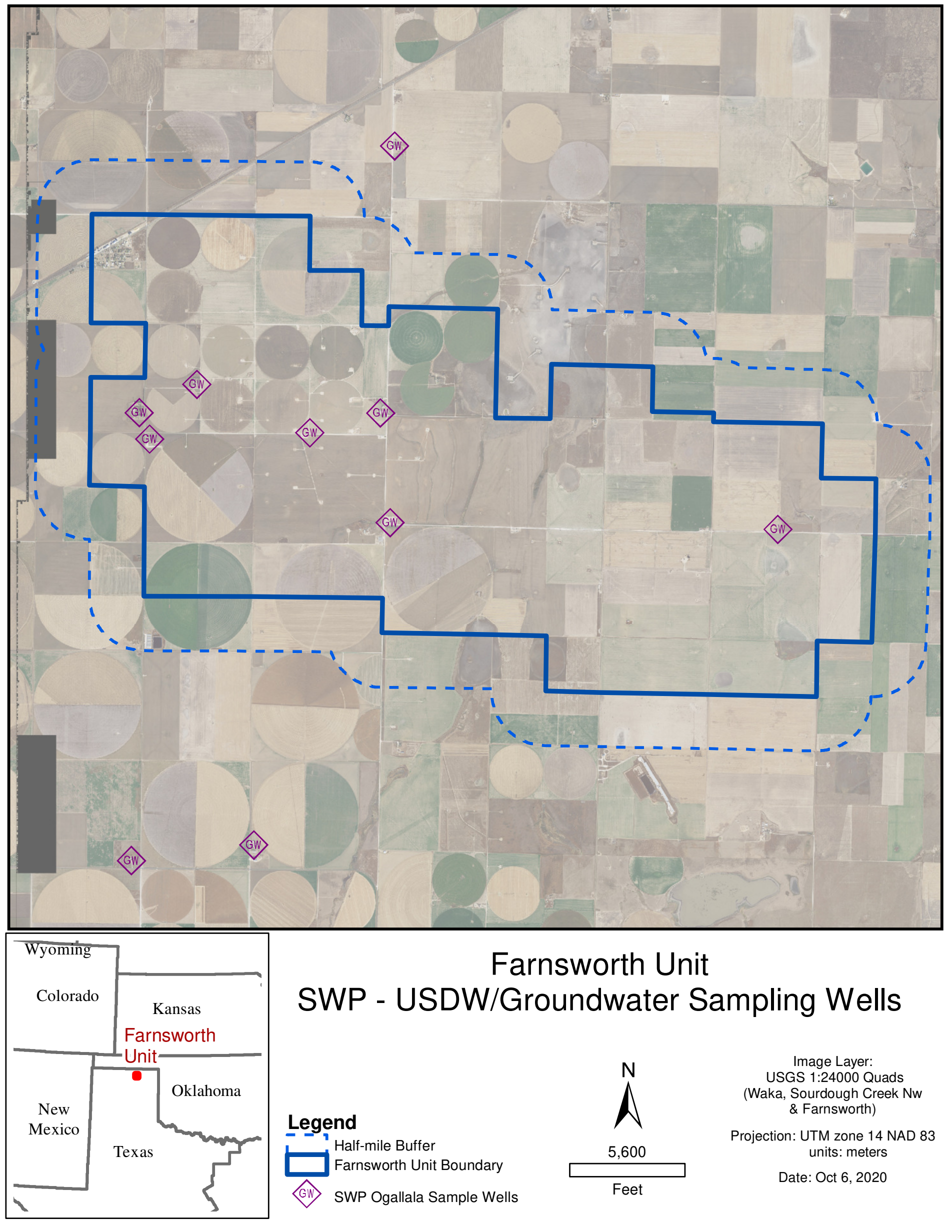

Figure 5.2-1: Ogallala groundwater monitoring wells

5.3 Soil CO_2 Monitoring

Since 2013, SWP has been conducting regular soil flux surveys within the western half of the FWU, to evaluate CO_2 leakage from the Morrow B. The SWP installed 94 PVC soil flux chamber collars around the 13-10A injection well (Figure 5.3-1); CO_2 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 CO_2 soil flux variations have been attributed to seasonal changes, and crop growth and rotation. The SWP soil flux collar network has identified no CO_2 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 CO_2 concentration in the FWU area to be 390±10 ppmv (Parts Per Million by Volume), with CO_2 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 CO_2 and if the CO_2 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 CO_2 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 CO_2 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 CO_2 concentrations from the Moody, Texas station can be used for background CO_2 values in the FWU area.

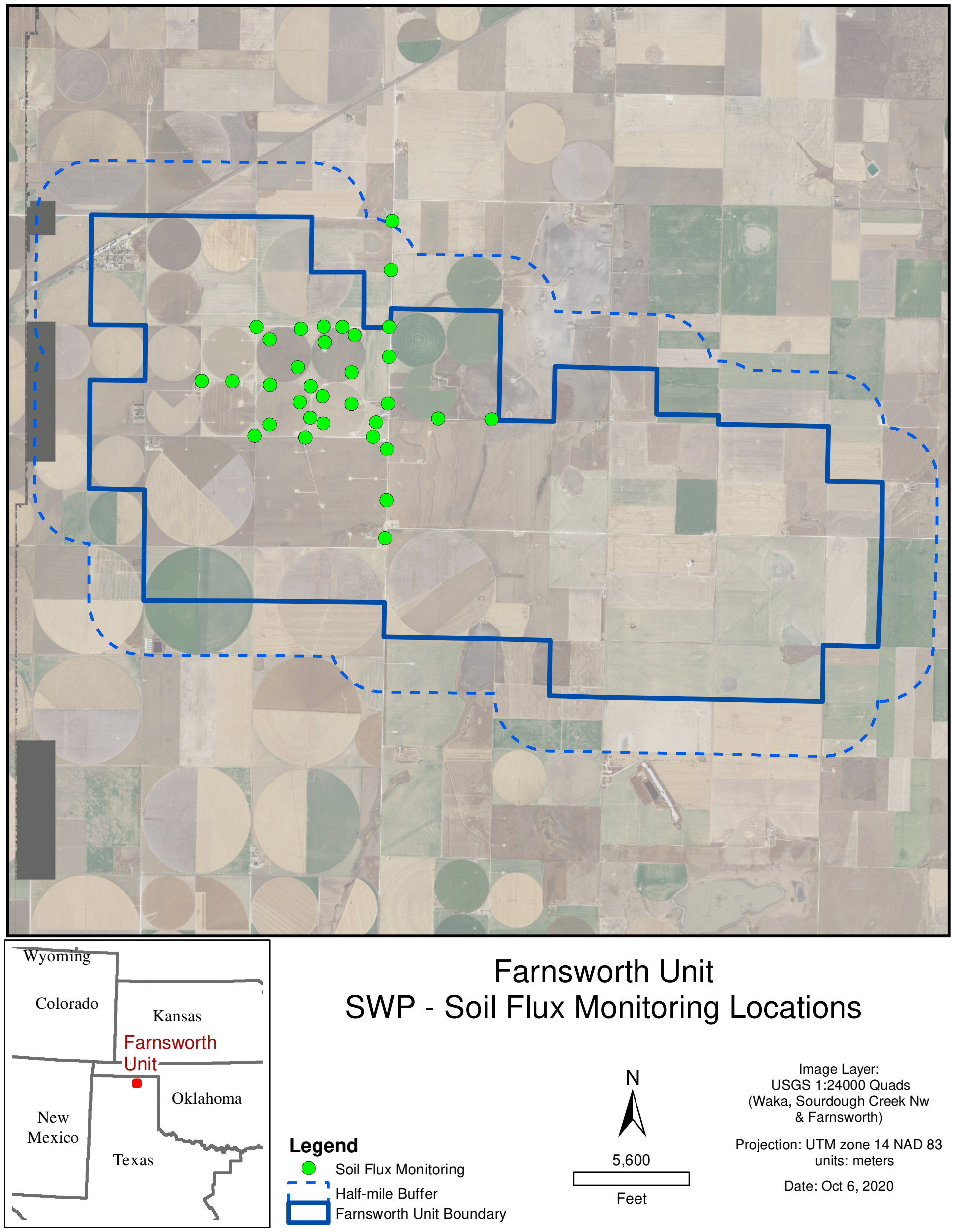

Figure 5.3 -1: Soil Flux

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 CO_2 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 CO_2 Received

Perdure currently receives CO_2 to its FWU facility through their own pipeline from the Arkalon Ethanol plant in Liberal, Kansas. Perdure also recycles CO_2 from their production wells in the FWU.

$$CO_{2T,r} = \sum^{4}{}_{=1} \quad {}_{r,} \; - S_{r,} \,) * D * C_{CO_{2,p,r}} \qquad \text{(Equation RR-2)}$$

where:

$CO_{2T,r}$ = Net annual mass of CO_2 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 CO_2 at standard conditions (metric tons per standard cubic meter): 0.0018682.

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

p = Quarter of the year.

r = Receiving flow meter.

6.2 Determining Mass of CO_2 Injected

Perdure injects CO_2 into the injection wells listed in Appendix 1.

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

where:

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

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

D = Density of CO_2 at standard conditions (metric tons per standard cubic meter): 0.0018682.

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

p = Quarter of the year.

u = Flow meter.

6.3 Determining Mass of CO_2 Produced from Oil Production Wells

Perdure also recycles CO_2 from its production wells which are part of its operations in the FWU. Therefore, the following equation is relevant to its operations.

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

Where:

$CO_{2,w}$ = Annual CO_2 mass produced (metric tons) through separator w.

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

D = Density of CO_2 at standard conditions (metric tons per standard cubic meter): 0.0018682.

$C_{CO_{2,p,}}$ = CO_2 concentration measurement in flow for separator w in quarter p (vol. percent CO_2, 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 CO_2 separated at each gas-liquid separator in accordance with the procedure specified in Equation RR-9 below:

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

Where:

CO_{2P} = Total annual CO_2 mass produced (metric tons) through all separators in the reporting year.

$CO_{2,w}$ = Annual CO_2 mass produced (metric tons) through separator w in the reporting year.

X = Entrained CO_2 in produced oil or other fluid divided by the CO_2 separated through all separators in the reporting year (weight percent CO_2, expressed as a decimal fraction).

w = Separator.

6.4 Determining Mass of CO_2 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 CO_2 stream, for facilities that conduct EOR operations.

Perdure will calculate the total annual mass of CO_2 emitted from all leakage pathways in accordance with the procedure specified in Equation RR-10 below:

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

where:

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

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

x = Leakage pathway.

6.5 Determining Mass of CO_2 Sequestered

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

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

Where:

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

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

CO_{2P} = Total annual CO_2 mass produced (metric tons) in the reporting year.

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

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

CO_{2FP} = Total annual CO_2 mass emitted (metric tons) from equipment leaks and vented emissions of CO_2 from equipment located on the surface between the 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 CO_2 mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

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

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

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

7 Estimated Schedule for implementation of MRV plan

Perdure expects to begin implementing the approved MRV plan when the new CO_2 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 CO_2 Concentration – All measurements of CO_2 concentrations of any CO_2 quantity will be conducted according to an appropriate standard method published by a consensus-based standards organization or an industry standard practice such as the Gas Producers Association (GSA) standards.

Measurement of CO_2 Volume – All measurements of CO_2 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 CO_2 received.

Daily totalized volumetric flow meters are used to record CO_2 received via pipeline from the Arkalon ethanol plant in Liberal, Kansas. using a volumetric totalizer using accepted flow calculations for CO_2 according to the AGA Report #3.

8.1.3 CO_2 injected.

Daily CO_2 injection is recorded by combining the totals for the recycle compressor meter and the received CO_2 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 CO_2 produced.

The point of produced gas measurement is from a meter downstream of the compressors prior to being combined with purchase CO_2. The produced gas is sampled at least quarterly for the CO_2 content.

8.1.5 CO_2 emissions from equipment leaks and vented emissions of CO_2.

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 CO_2 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 CO_2 received that is missing would be estimated using invoices or using a representative flow rate value from the nearest previous time period.
- A quarterly CO_2 concentration of a CO_2 stream received that is missing would be estimated using invoices or using a representative concentration value from the nearest previous time period.
- A quarterly quantity of CO_2 injected that is missing would be estimated using a representative quantity of CO_2injected from the nearest previous period of time at a similar injection pressure.
- For any values associated with CO_2 emissions from equipment leaks and vented emissions of CO_2 from surface equipment at the facility that are reported in this subpart, missing data estimation procedures specified in subpart W of 40 CFR Part 98 would be followed.
- The quarterly quantity of CO_2 produced from subsurface geologic formations that is missing would be estimated using a representative quantity of CO_2 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 CO_2 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 CO_2, 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 CO_2 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 CO_2 emitted by surface leakage from leakage pathways.

(12) Annual records of information used to calculate the CO_2 emitted from equipment leaks and vented emissions of CO_2 from equipment located on the surface between the flow meter used to measure injection quantity and the injection wellhead.

(13) Annual records of information used to calculate the CO_2 emitted from equipment leaks and vented emissions of $CO_2$from equipment located on the surface between the 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	CO_2	0	1
#8-4 (INJ)	42357003990000	WAG Inj	Active	CO_2	0	1
#8-5 (INJ)	42357301160000	WAG Inj	Active	CO_2	0	1
#9-10 (INJ)	42357330770000	WAG Inj	Active	CO_2	0	1
#9-8 (INJ)	42357301860000	WAG Inj	Active	CO_2	0	1
#11-1 (INJ)	42357020350000	WAG Inj	Inactive	CO_2	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	CO_2	0	0
#2 (WSW)	42357810700000	WSW	Active	CO_2	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

Al-Shaieb, Z., Puckette, & Abdalla A. (1995). Influence of sea-level fluctuation on reservoir quality of the upper Morrowan sandstones, northwestern shelf of the Anadarko Basin, in Hyne, N.J., ed., Sequence stratigraphy of the midcontinent: Tulsa Geological Society Special Publication, no. 4, 249-268.

Ampomah W., R. Balch, M. Cather, D. Rose-Coss, Z. Dai, J. Heath, T. Dewers, and P. Mozley (2016a), Evaluation of CO_2 Storage Mechanisms in CO_2 Enhanced Oil Recovery Sites: Application to Morrow Sandstone Reservoir. Energy &Fuels Article ASAP.

Ampomah, W., Balch, R. S., Grigg, R. B., McPherson, B., Will, R. A., Lee, S.-Y., Dai, Z. and Pan, F. (2016b), Co-optimization of CO_2-EOR and storage processes in mature oil reservoirs. Greenhouse Gas Sci Technol. doi:10.1002/ghg.1618

Blakeney, B.A., Krystinik, L.F., Downey, A.A. (1990) Reservoir heterogeneity in Morrow Valley Fills, Stateline Trend: implications for reservoir management and field expansion in Sonnenberg, S.A., ed., Morrow Sandstones of SE Colorado, and Adjacent Areas: Denver, Colorado, RMAG, p. 131-141Bowen et al., 1990

Bowen, D.W., Krystinik, L.F., and Grantz, R.E., (1990) Geology and reservoir characteristics of the Sorrento-Mt. Pearl field complex, Cheyenne County, Colorado: in Sonnenberg, S.A., ed., Morrow Sandstones of SE Colorado, and Adjacent Areas: Denver, Colorado, RMAG, p. 67-77.

Bowen, D. W., & Weimer, P. (2003). Regional sequence stratigraphic setting and reservoir geology of Morrow incised-valley sandstones (lower Pennsylvanian), eastern Colorado and western Kansas. American Association of Petroleum Geologists Bulletin, 87(5), 781–815.

Bowen, D. W., & Weimer, P. (2004). Reservoir geology of Nicholas and Liverpool cemetery fields (lower Pennsylvanian), Stanton county, Kansas, and their significance to the regional interpretation of the Morrow Formation incised-valley- fill systems in eastern Colorado and western Kansas. American Association of Petroleum Geologists Bulletin, 88(1), 47–70.

Devries, A.A., 2005, Sequence Stratigraphy and Micro-Image Analysis of the Upper Morrow Sandstone in the Mustang East Field, Morton County, Kansas: M.S. Thesis, Oklahoma State University.

Evans, J.L. (1979). Major structural and stratigraphic features of the Anadarko Basin: in N. J. Hyne, ed., Pennsylvanian sandstones of the mid-continent: Tulsa Geological Society Special Publication 1, 97–113.

Gallagher, S. R. (2014). Depositional and diagenetic controls on reservoir heterogeneity: Upper Morrow Sandstone, Farnsworth Unit, Ochiltree County, Texas. MS thesis, New Mexico Institute of Mining and Technology. p. 214.

Gragg, Evan J. (2016) Petroleum System Modeling of the northwest Anadarko Basin: Implications for Carbon Storage: M.S. Thesis, New Mexico Institute of Mining and Technology, ProQuest Dissertations Publishing, 2016. 10116887.

Gragg E., Will R., Rose-Coss D., Trujillo N., Hutton A., Ampomah W., van Wijk J., and Balch R.S. (2018) Geomodelling, Geomechanics, and Evaluating the Subsurface for Carbon Storage. AAPG Southwest Section meeting, 4/9/2018. El Paso, TX

Gunda D., Ampomah, W., Grigg, R. B. and Balch, R. S. (2015) Reservoir Fluid Characterization for Miscible Enhanced Oil Recovery. Carbon Management Technology Conference November 16-19 2015, Sugarland, Houston-Texas USA.

Heath, J. E., Dewers, T. A., Mozley, P. S. (2015). Characteristics of the Farnsworth Unit, Ochiltree County , Texas : Southwest Partnership CO_2 Storage - EOR Project.

Higley, D. K., Cook, T. A., & Pawlewicz, M. J. (2014). Petroleum Systems and assessment of undiscovered oil and gas in the Anadarko Basin Province, Colorado, Kansas, Oklahoma, and Texas — Woodford Shale Assessment Units. In Higley, D.K., Compiler, Petroleum Systems and Assessment of Undiscovered Oil and Gas in the Anadarko Basin Province, Colorado, Kansas, Oklahoma, and Texas - USGS Province 58: USGS Digital Data Series DDS-69-EE, 24.

Hobbs, Noah; van Wijk, Jolante; Axen, Gary; 3D Interpretation of the Farnsworth Unit, unpublished report, New Mexico Institute of Mining and Technology, pp 9.

Hobbs N., van Wijk J., Axen G. (2019) - Tectonic-landscape evolution model of the Anadarko basin. American Geophysical Union Fall Meeting, San Francisco CA December 8-15, 2019

Jorgensen, D.G. (1989). Paleohydrology of the Anadarko Basin, central United States. In: Johnson, K.S., ed., Anadarko Basin Symposium, 1988: Oklahoma Geological Survey Circular 90, 176–193.

Krystinik, L.F., & Blakeney, B.A. (1990). Sedimentology of the upper Morrow Formation in eastern Colorado and western Kansas, in Sonnenberg, S. A., et al., eds., Morrow sandstones of southeast Colorado and adjacent areas: Rocky Mountain Association of Geologists, Denver, Colorado, 37-50.

Lohrenz, J., Bray, B.G., Clark, C.R. (1964). “Calculating Viscosities of Reservoir Fluids from their compositions”, SPE Paper 915, Journal of Petroleum Technology, p. 1171-1176.

McKay, R. H., & Noah, J. T. (1996). Integrated perspective of the depositional environment and reservoir geometry, characterization, and performance of the Upper Morrow Buckhaults Sandstone in the Farnsworth Unit, Ochiltree County, Texas: Oklahoma Geological Survey Circular, no. 98, p. 101-114.

Munson, T., 1988, “Depositional, diagenetic, and production history of the Upper Morrowan Buckhaults sandstone, Farnsworth Field, Ochiltree County, Texas,” unpub. MS thesis, West Texas State University, Canyon, TX. 354. pp.

Munson, T. W. (1989). Depositional, diagenetic, and production history of the Upper Morrowan Buckhaults Sandstone, Farnsworth Field, Ochiltree County Texas, The Shale Shaker, July-August 1989, p 1-19.

Nelson, P.H. and Gianoutsos, N.J, 2014, Potentiometric Surfaces for Seven Stratigraphic Units and an Explanation for Underpressure , Chapter 9 of 13 in the Greater Anadarko Basin, Oklahoma, Texas, Kansas, and Colorado in Petroleum systems and assessment of undiscovered oil and gas in the Anadarko Basin Province, Colorado, Kansas, Oklahoma, and Texas: USGS Province 58, compiled by Debra Higley.

The Paleontology Portal, The Carboniferous in Texas, US. (Site was funded by the National Science Foundation under award no. 0234594.) http://paleoportal.org/index.php?globalnav=time_space&sectionnav=state&state_id=42&period_id=12

Pedersen, K.S., Thomassen, P., and Fredenslund, A.: "Characterization of Gas Condensate Mixtures,"C7+ Fraction Characterization, L.G.Chorn and G.A. Mansoori (eds.), Advances in Thermodynamics, Taylor & Francis, New York City (1989)

Pedersen, K. S., Calsep, A. S., Milter, J., Sørensen, H., & Calsep, A. S. (n.d.). SPE 77385 Cubic Equations of State Applied to HT / HP and Highly Aromatic Fluids (2002).

Peneloux, A., Rauzy, E., and Freze, R.: "A Consistent Correction for Redlich-Kwong-Soave Volumes," Fluid Phase Equilibria (1982)

Peng, D.Y. and Robinson, D.B. (1976). A New Two-Constant Equation of State. Ind.Eng.Chem. Fundamentals, 15, 59-64

Perry, W. J., Jr. (1989). Tectonic evolution of the Anadarko basin region, Oklahoma: U.S. Geological Survey Bulletin 1866-A, 19 pp.

Puckette, J., Abdalla, A., Rice, A., & Al-Shaieb, Z. (1996). The upper Morrow reservoirs: Complex fluvio-deltaic depositional systems, in Johnson, K.S., ed., Deltaic reservoirs in the southern midcontinent, 1993 symposium: Oklahoma Geological Survey Circular, no. 98, 47-84.

Puckette, J., Al-Shaieb, Z., & Van Evera, E. (2008). Sequence stratigraphy, lithofacies, and reservoir quality, upper Morrow sandstones, northwestern shelf, Anadarko Basin, in Andrews, R. D., ed., Morrow and Springer in the southern midcontinent, 2005 symposium: Oklahoma Geological Survey Circular, no. 111, 81-97.

Rasmussen, L., Fan, T., Rinehart, A., Luhmann, A., Ampomah, W., Dewers, T., Heath, J, Cather, M., and Grigg, R. (2019). Carbon Storage and Enhanced Oil Recovery in Pennsylvanian Morrow Formation Clastic Reservoirs: Controls on Oil/Brine and Oil/ CO_2 Relative Permeability from Diagenetic Heterogeneity and Evolving Wettability. Energies, Special Issue "CO_2 EOR and CO_2 Storage in Oil Reservoirs" Energies 2019, 12(19), 3663.

Rose-Coss, D. (2017). A Refined Depositional Sequence Stratigraphic and Structural Model for the Reservoir and Caprock Intervals at the Farnsworth Unit, Ochiltree County TX. M.S. Thesis, New Mexico Institute of Mining and Technology, ProQuest Dissertations Publishing, 2017. 10258790.

Rose-Coss, D., Ampomah, W., Cather M., Balch, R. S., Mozley P (2016): "An Improved Approach for Sandstone Reservoir Characterization" paper SPE-180375-MS presented at SPE Western Regional Meeting held in Anchorage, Alaska, May 23-26.

Schlumberger, https://www.software.slb.com/products/eclipse

Sonnenberg, S.A., 1985, Tectonic and Sedimentation Model for Morrow Sandstone Deposition, Sorrento Field Area, Denver Basin, Colorado: The Mountain Geologist, v. 22. p 180-191.

Swanson, D., 1979, Deltaic Deposits in the Pennsylvanian upper Morrow Formation in the Anadarko Basin, in Pennsylvanian sandstones of the mid-continent: Tulsa Geological Society special publication, no. 1, p. 115-168.

Trujillo, N, A., (2018). Influence of Lithology and Diagenesis on Mechanical and Sealing Properties of the Thirteen Finger Limestone and Upper Morrow Shale, Farnsworth Unit, Ochiltree County, Texas. M.S. Thesis. New Mexico Institute of Mining and Technology, ProQuest Dissertations Publishing, 2018. 10689420.

Wheeler, D. M., Scott, A. J., Coringrato, V. J., and Devine, P. E., 1990, Stratigraphy and depositional history of the Morrow Formation, southeast Colorado, and southwest Kansas; in, Morrow Sandstones of Southeast Colorado and Adjacent Areas, S. A. Sonnenberg, L. T. Shannon, K. Rader, W. F. von Drehle, and G. W. Martin, eds.: The Rocky Mountain Association of Geologists, Special Paper, p. 3-35.

Xiao, T., McPherson, B., Pan, F., Esser, R., Jia, W., Bordelon, A., & Bacon, D. (2016). Potential chemical impacts of CO_2 leakage on underground source of drinking water assessed by quantitative risk analysis. *International Journal of Greenhouse Gas Control*, *50*, 305–316.

Xiao, T., McPherson, B., Bordelon, A., Viswanathan, H., Dai, Z., Tian, H., Esser, R., Jia, W., & Carey, W. (2017). Quantification of CO_2-cement-rock interactions at the well-caprock-reservoir interface and implications for geological CO_2 storage. *International Journal of Greenhouse Gas Control*, *63*, 126–140.

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
CO_2 – 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
H_2S – 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 CO_2 and purchase CO_2)
XRD – x-ray diffraction

Appendix 5 - Conversion Factors

Perdure reports CO_2 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 CO_2 mass from CO_2 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 CO_2 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 CO_2 of 0.002641684 lb-moles per cubic foot. Converting the CO2 density in units of metric tonnes per cubic foot:

$$Density_{CO2}\left(\frac{MT}{ft^3}\right) = Density_{CO2}\left(\frac{lb - moles}{ft^3}\right) \times MW_{CO2} \times \frac{1\ MT}{2204.62\ lbs}$$

Where:

$$Density_{CO2} = Density\ of\ CO2\ in\ metric\ tonnes\ (MT)\ per\ cubic\ foot$$

$$Density_{CO2} = 0.002641684$$

$$MW_{CO2} = 44.0095$$

$$Density_{CO2} = 5.2734\ x\ 10^{-5}\frac{MT}{ft^3}\ \ or\ \ 5.2734\ x\ 10^{-2}\ \frac{MT}{Mcf}$$

The conversion factor 5.2734 x 10^{-2} MT/Mcf is used to convert CO_2 volumes in standard cubic feet to CO_2 mass in metric tonnes.