APPENDIX B

AREA OF REVIEW AND CORRECTIVE ACTION PLAN
40 CFR 146.84; 146.82(a)(13)

Jasper County Storage Facility

1. FACILITY INFORMATION

Facility Name: Jasper County Storage Facility

Facility Contact: [redacted]
501 Westlake Park Blvd., Houston, Texas 77079
[redacted]

Well Location: Jasper County, TX

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

2. INTRODUCTION

In satisfaction of the requirements of 40 Code of Federal Regulations (CFR) 146.84, this document (Plan) describes the hydrologic and geologic information used by BP Carbon Solutions LLC (BP) to determine the Area of Review (AoR). This Plan describes the computational model used to delineate the AoR and any future plans to reevaluate the AoR. The Plan includes a description of the simulator, the physical processes, the conceptual model, and any numerical implementations. This Plan also addresses the extent to which BP may need to undertake corrective action as a result of legacy oil and gas wells, and potentially other features, in the AoR that may penetrate the primary confining zone, as well as the extent to which corrective action is required to protect underground sources of drinking water (USDW) and the environment from threats of a release. Accordingly, this Plan describes BP's Corrective Action Plan for mitigating the potential threat of carbon dioxide (CO_2) migration.

3. COMPUTATIONAL MODELING APPROACH

In accordance with 40 CFR 146.84(b)(1) and (c)(1), BP developed a computational modeling approach that incorporates site-specific geological data into a dynamic model. The computational model utilizes the [redacted] to predict the behavior of CO_2 in the subsurface at the Jasper County Storage Facility (Site). The objective of the computational model was to:

1. Determine the total storage capacity of the Site;
2. Predict the lateral and vertical extent of the CO_2 plume, formation fluids, and associated pressure front during the injection and post injection phases;
3. Evaluate and mitigate potential risks to USDWs and human health;
4. Model CO_2 injection throughout the life of the project; and
5. Develop a plan to identify and mitigate potential issues through corrective actions and the Testing and Monitoring Plan (**Appendix E**).

3.1 Modeling Background

[redacted]

Key model assumptions were used to provide certain constraints to the model domain, including:

[redacted]

Dense-phase CO_2 and brine phases were modeled under non-isothermal conditions. The simulator automatically calculated gaseous and dense-phase pressure, volume, and temperature (PVT) properties using the Peng-Robinson EoS. Mutual solubility and salt drop out were not included in the full field model and were assessed independently for the near well zone.

The aqueous phases modeled were dependent on pressure, temperature, and depth. [redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted] Water and bicarbonate dissociation reactions were included to calculate pH conditions resulting from dissolution of CO_2. [redacted]

[redacted] Compressibility, density, and viscosity were adjusted for dynamic non-isothermal conditions.

[redacted] The main function of the EoS was to appropriately model the non-ideal behavior of CO_2 in the supercritical state. [redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted] This facilitated solubility calculations of CO_2 in aqueous solutions under non-ideal and non-isothermal conditions. The example Peng-Robinson formulation is as follows:

$$p = [RT/(V_m - b)] - [aA/(V_m^2 + 2bV_m - b^2)]$$

Where:
p - pressure (absolute)
V_m - molar volume (1 mole of gas or liquid)
R - ideal gas constant (8.3144621 J/(mol.K)
T - absolute temperature (K)
$A = [1 + k(1-T_r^{0.5})]^2$
$b = 0.07780RT_c/p_c$
$a = 0.45724\ R^2\ T_c^2/p_c$
and

T_c - critical temperature
p_c - critical pressure
$T_r = T/T_c$
$k = 0.37464 + 1.54226w - 0.26992w^2$, when $w > 0.49$

Reservoir injection conditions were simulated under non-isothermal conditions. Conditions incorporated dynamic PVT fluid conditions, rock thermal conductivity, and heat capacity. The reservoir zone temperature was a linear extrapolation between known points. In general, the reservoir temperature, salinity, and pressure data were obtained from appraisal well tests, while heat capacity and solubility were determined from various literature and academic sources. See **Section 2** of the **Application Narrative.** [redacted]

[redacted]

The storage reservoir was normally pressured, and a reference pressure (2,700 pounds per square inch (psi) at 6,000 feet (0.45 psi/ft)) calculated from brine salinity and temperature was specified at a reference depth. [redacted]

[redacted] The non-isothermal conditions and chemical reactions between the in-situ brine and injected CO_2 must be modeled to fully calculate and delineate the AoR for this Site.

Simulation time included one-year of model initialization to develop numerical stability. [redacted] The model also ran for an additional 50 years of post-injection site care (PISC) monitoring [redacted]).

3.2 Site Geology and Hydrology

In accordance with 40 CFR 146.84, BP assessed the site geology and hydrology of the AoR utilizing both published and/or purchasable resources and proprietarily collected data. Site-specific data included a full suite of geophysical logs, petrological, and geochemical analyses of whole core and rotary sidewall core (RSWC) samples, well test data from Step Rate Tests (SRT), Pressure Fall-Off Test (PFO), Multi-rate Test (MRT), and geochemical analysis of brine swabs collected from the A469 #1 stratigraphic test well ("A469").

The purpose of this characterization is to confirm the adequacy of the storage unit for the Site and identify potential areas of concern that may need to be addressed in the Corrective Action Plan (see **Section 6**, below) and/or Testing and Monitoring Plan (**Appendix E**).

Site-specific data regarding the geology and hydrology of the AoR is described in the **Application Narrative** of this permit application. The **Application Narrative** also includes associated figures, geologic maps, hydrologic maps, local stratigraphic columns, and cross-sections. This site-specific data from the appraisal wells and seismic was incorporated into BP's model for the AoR.

In summary, BP identified the following confining and injection zones at the Site:

Confining Zone: The confining zone is modeled within the Anahuac Formation of the Upper Oligocene Epoch and the Paleogene / Tertiary Period. This formation is Early Miocene to Late Oligocene in age, consisting mainly of shaley sequences that rest on the Frio Formation, which is overlain by the Fleming Group. The Anahuac Formation represents a transgressive marine shale sequence bound at the top and bottom by regressive sand sequences and centered within the Rio Grande Embayment.

The confining zone is further discussed in the **Application Narrative**.

***Injection Zone*:** The injection zone is modeled within the Frio Formation of the Oligocene Epoch and the Paleogene / Tertiary Period. The Oligocene-aged Frio Formation is interpreted as fluvio-deltaic sediments with distributary channels, interdistributary bay fills and barrier bar facies. The Frio Formation consists of a series of alternating sand and shale sequences overlain by the Anahuac Formation.

The Frio Formation is considered a major pro-gradational wedge located in the Texas Gulf Coast Basin. The Frio Formation and the updip Anahuac Formation are centered in the Houston and Rio Grande Embayments.

The injection zone is further discussed in the **Application Narrative**.

In accordance with 40 CFR 146.84(c)(1) and (e)(1), as BP gathers additional site characterization data, this information and data will be incorporated into the existing computational model used for the AoR delineation. If site-specific criteria trigger significant changes to the model, a reevaluation may be initiated for the AoR and corrective actions (**Section 7**).

3.3 Model Domain

[redacted]

Model domain information is summarized on **Table 1**. The plan view and cross-sectional figures showing the horizontal and vertical extent of the model grid are shown on **Figures 2** and **3**, respectively.

[redacted]

[redacted]

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The vertical datum is Mean Sea Level (MSL). Rectilinear tartan corner point grid with variable grid cell geometry is the basis for finite difference calculations. The number of nodes is as follows: x: 272, y: 226, z: 46.

3.4 Porosity and Permeability

Where density log data was available, the log porosity was calculated using the density porosity model. The formula utilized for density is as follows:

Density: (ρma – RHOB)/(ρma-ρfl),

where ρfl=1g/cm3, ρma =2.65g/cm3.

Where density log data was not available, sonic log data was used to derive porosity as described below:

Sonic: Raiga-Clemenceau, coefR =1.6

The density log and sonic log data used in these calculations is described in more detail in **Section 4.3,** below. BP anticipates using additional porosity and permeability data collected from core and logs during pre-operational testing to update the porosity and permeability relationship and property distribution in the static model. These updates will be provided to the UIC Program Director.

BP incorporated seismic attribute data to populate the lithological parameters in the inter-well space. This technique is considered a general best practice utilized in reservoir modeling and assumes that seismic attribute data can be related to reservoir properties, which can be used to provide soft conditioning information about the lithology (e.g., sand/shale).

3.5 Constitutive Relationships and Other Rock Properties

[redacted]

Published data based on sand pack experiments were used as the foundation to derive curves for each respective rock type.

[redacted] Pore pressure is representative of system pressure to this depth and controls system compressibility in a single-phase brine system. [redacted] such as those encountered in the A469 #1 well. [redacted] Lithostatic pressure becomes a significant constraint on compressibility at greater depths.

Van Genuchten model in terms of water saturation:

$$S_w = S_{wirr} + \frac{S_{wr} - S_{wirr}}{[1 + (\alpha . P_c)^n]^{1-\frac{1}{n}}}$$

Figure 1 provides a plot of resulting drainage and imbibition capillary pressure curves for rock type 1 and 2 (RT-1 and RT-2) scaled from published lab data for a loose sand pack.

[redacted]

3.6 Boundary Conditions

[redacted]

[redacted]

infinite-acting saline aquifer. The volume multiplier was applied in concentric layers (i.e., a [redacted] These boundary

modifiers effectively act as a proxy for a variable-head boundary condition, where changes in pressure during and after injection represent a change in flow across the boundaries.

[redacted]

BP mapped the reservoir containing the injection zone as laterally very extensive, so the primary goal of the horizonal boundary conditions was to mimic the pressure response numerically rather than building an overlarge grid. Several iterations of these horizonal boundary conditions were tested, [redacted]

[redacted]

[redacted]

3.7 Initial Conditions

BP assumed that the aqueous and gas phases present in the model were dynamically dependent on PVT conditions. This section details the correlations used for each dynamic property and how the properties varied spatially in the model.

Initial model conditions are detailed on **Table 2**.

[redacted]

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

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[redacted]	[redacted]			[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

3.8 Operational Information

[redacted] There are no planned production or withdrawal wells at the Site. Details on the injection operation are presented on **Table 3**.

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[redacted]				
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3.9 Fracture Pressure and Fracture Gradient

[redacted] This was calibrated to local and offset formation integrity test (FIT) data in the sandy overburden and is consistent with BP's best practice for modeling sand fracture gradients. [redacted]

Model conditions for fracture pressure, calculated fracture gradient, and maximum injection pressure values are given on **Table 4.**

[redacted]

[redacted]

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
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[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

4. COMPUTATIONAL MODELING RESULTS

4.1 Modeled Salinity

[redacted]. The simulator applied the pressure, temperature, and brine compositional controls on solubility, including the incremental TDS resulting from CO_2 dissolution. [redacted] Since [redacted] does not currently output the change in salinity associated with CO_2 dissolution, monitoring salinity change over time is irrelevant to understanding the AoR. The simulator does, however, output the changes in other aqueous properties that are impacted by the dissolution of CO_2, such as water density and viscosity.

Figures 4 through 7 illustrate how the aqueous properties vary spatially in the reservoir, both vertically and laterally, before, during, and after injection. [redacted]

For the properties shown, there is a sharp change from the initial status during the injection period when the CO_2 saturation around the well is at its highest. [redacted] This illustrates that the chemistry and physics of the model are performing as expected and that the system will stabilize post-injection. During AoR reevaluations, this progression will be investigated in further detail to validate the change in aqueous conditions.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

4.2 Modeled Gas Compressibility, Density, and Viscosity

[redacted] All properties were automatically adjusted for dynamic non-isothermal conditions. Using a single injection well for illustration, **Figures 8 and 9** demonstrate how the gas density varies spatially in the reservoir, both vertically and laterally, before, during and after injection.

[redacted]. During injection, there is a sharp change from the initial conditions during injection when the CO_2 saturation around the well is at its highest. [redacted] This illustrates that the processes of the model are performing as expected and that the system will stabilize post-injection. During AoR reevaluations, this progression will be investigated in further detail to validate the change in gaseous conditions.

[redacted]

[redacted]

4.3 Modeled Porosity and Permeability

Log porosity and permeability were calculated utilizing seven historical oil and gas wells within the AoR. The log data available in these wells is summarized on **Table 5** below:

Table 5. Log Porosity and Permeability

No.	Well Name	API	RES	DEN	GR	SONIC	NEUT	SP
1	[redacted]	[redacted]	YES	YES	YES	YES	YES	YES
2	[redacted]	[redacted]	YES	YES	YES	NO	YES	NO
3	[redacted]	[redacted]	YES	YES	YES	NO	YES	YES
4	[redacted]	[redacted]	YES	YES	YES	NO	YES	YES
5	[redacted]	[redacted]	YES	NO	YES	YES	NO	YES
6	[redacted]	[redacted]	YES	YES	YES	NO	NO	YES
7	[redacted]	[redacted]	YES	NO	YES	YES	NO	YES

Notes: RES - Resistivity Log; DEN - Density Log; GR - Gamma Ray Log; SONIC - Sonic Log; NEUT - Neutron Density Log; SP - Spontaneous Potential Log

Porosity was modeled using the fine-scale porosity logs from the wells on **Table 5.** Of the porosity logs identified, three had density logs and four had sonic logs. [redacted] Porosity distribution in the model across net reservoir is shown on **Figure 10.** [redacted] A histogram comparison of different steps is given on **Figure 10**. The modeled porosity distribution (the blue bars in the histogram) was kept within the range of the observed well log distribution. The shape of the distributions is also very similar.

[redacted]

[redacted]

In order to estimate permeability in the offset wells prior to collecting core data from the appraisal well, porosity-permeability trends were established from core data that BP accessed as a Joint Industry Project (JIP) member of the University of Texas at Austin Bureau of Economic Geology's (BEG) Deep Shelf Digital Database. The database was filtered down to only cored wells within nearby Hardin and Jefferson counties so that the results would be as site-specific as possible prior to appraisal data collection. The core porosity and core permeability relationship established from this data is shown on **Figure 11**. There is no information available on where the cores were sampled within the Frio reservoir and if any net confining stress or Klingenberg corrections have been made. The resulting porosity and permeability relationship is summarized below:

Permeability = $10^{(0.2x \text{ Total Porosity})-4.28}$

[redacted]

[redacted]

[redacted] The Frio Formation permeability distribution is shown on **Figure 12.** The shape of the modeled permeability distribution is similar to that of the fine-scale and upscaled well log permeability. In the histogram shown on **Figure 12**, the blue bars represent the permeability distribution associated with the simulation grid over the entire Frio interval of the model. The red bars are associated with the fine-scale well logs, and the green bars are associated with the blocked permeability curves at the wells. **Figure 13** shows the same distributions for the net-to-gross.

[redacted]

[redacted]

[redacted]

[redacted]

Two rock types were modeled. The first rock type was defined as Net and the second rock type was defined as Non-Net. [redacted]

The approach for populating the lithological parameters in the inter-well space incorporated the attributes of 3D seismic data (see **Section 2.4 of Application Narrative** for additional details). This technique is considered a general good practice utilized in reservoir modeling and assumes that seismic attribute data can be related to reservoir properties, which can be used to provide soft conditioning information about the lithology (e.g., sand/shale). [redacted] **Figure 14** below illustrates the workflow of seismic resampling.

[redacted]

The petro-seismic calibration was used to integrate seismic for spatial information of properties distribution. [redacted]

[redacted]

BP used its interpretation of the porosity and permeability, as described in this section, to create a representative Frio Formation geologic model to assess storage capacity, injection potential, and initial approximations of plume geometry and spatial extent. As described in **Section 3.6** (Boundary Conditions), there was a need to balance the size and granularity of the model within the limits of the computational power of the simulator. [redacted] These features will be included in future, supplemental AoR modeling.

[redacted]

[redacted]

4.4 Time-Series and Flux Data

[redacted]

- [redacted]
- [redacted]

The trapping mechanisms present in the model change through time and space in the grid. Some snapshots have been included to illustrate the progression through time. BP has also provided a graph showing the relative contribution of each phase (i.e., free gas, dissolved gas, and residually trapped gas).

Flux data provide a visual representation of fluid movement in the model but has no impact on the overall AoR. [redacted]

[redacted]

Depending on the flux surface modeled, the magnitude and direction of water flux vary significantly. [redacted]

Figure 16 illustrates the differences between the vertical flux surfaces. The spike of water influx in the early time period is due to the commencement of injection. [redacted]

An example plot of water influx across the north and south surfaces is shown on **Figure 17**.

Time series images are included as **Attachment 1**.

[redacted]

[redacted]

[redacted]

[redacted]

4.5 Predictions of System Behavior

[redacted] The geographic boundaries of the AoR, and its evolution through time, can be seen on **Figure 18** below.

To account for subsurface uncertainties and in accordance with 40 CFR 146.84(a), the AoR was delineated to represent the largest area in which USDWs may be endangered by the injection activity. Over time, the AoR is delineated either by the modeled CO_2 plume or by the modeled CO_2 pressure front, whichever is bigger.

See **Section 3.6** ("Boundary Conditions") and **Section 3.7** ("Initial Conditions") for examples illustrating how gas mass density, aqueous density, and aqueous viscosity change spatially in the model through time. See **Figures 18 and 19** for illustrations of how the free-phase CO_2 plume and pressure front change spatially in the model through time. Please also see **Section 4.4** ("Time Series and Flux Data") for additional images illustrating the CO_2 mass progression through time as free gas, dissolved gas, and trapped gas.

[redacted]

[redacted]

[redacted]

4.6 Model Calibration and Validation

The current model underpinning the AoR has not yet been calibrated or history-matched, nor have any sensitivity analyses been run to help inform uncertainty ranges. Site-specific appraisal well data (including injectivity testing) was acquired after the existing model was built and will be included during AoR reevaluation as part of the model calibration process.

BP recognizes the importance of model calibrations and developing the sensitivity analysis to identify key parameters that have impacts on the model. A sensitivity analysis will be conducted to identify parameters for additional attention during data collection, parameter estimation, and model calibration. BP will consider the use of various calibration statistics that include the mean error, mean-absolute error, and the root-mean squared error.

4.7 Current Model Build – Key Assumptions

The AoR model was developed based on the following key assumptions :

[redacted]

[redacted]

These assumptions were developed to provide a conservative approach to identifying legacy wells and potential corrective actions within the AoR. The future model updates will refine the overall AoR, which may potentially reduce the overall AoR size and extent compared to the current model.

[redacted]

[redacted]

5. AoR DELINEATION

5.1 Critical Pressure Calculations

To delineate the pressure front, the minimum or critical pressure (ΔP_{crit}) must be calculated. ΔP_{crit} is the pressure necessary to reverse the flow direction between the lowermost USDW and the injection zone and thus cause fluid flow from the injection zone into the USDW formation matrix. See **Section 5.2** below for how the depth of the lowermost USDW was determined. BP calculated ΔP_{crit} (Nicot 2009[2]), where the pressure front is given by:

[redacted]

Where,

ΔP Critical pressure (MPa)

g Gravitational acceleration (m/s^2)

Z_v base USDW (m)

Z_i top injection zone depth (m)

λ Density gradient λ at constant TDS (kg/L-m)

ξ Initial density gradient ξ in borehole (kg/L-m)

$P_{i,\lambda}$ Final density difference at base of USDW (kg/L)

This method estimates a pressure differential that would displace fluid initially present in a hypothetical borehole into the lowermost USDW and is based on two assumptions:
(1) hydrostatic conditions; and (2) initially linearly varying densities in the borehole and constant density once the injection zone fluid is lifted to the top of the borehole.

The data and assumptions used in the pressure front delineation calculations are:

- [redacted]
  - [redacted]

2 Jean-Philippe Nicot, Curtis M. Oldenburg, Steven L. Bryant, and Susan D. Hovorka, 2009. Pressure perturbations from geologic carbon sequestration: Area-of-review boundaries and borehole leakage driving forces

[redacted]

[redacted]

[redacted]

5.2 Lowermost USDW Determination

To determine the depth of the lowermost USDW, or 10,000 mg/L TDS interface, both published resources and proprietarily site-specific collected data were utilized. A subregional assessment of USDW interface depth was conducted across the area of interest by Petrotek. Their full report, *USDW Evaluation, Jasper County Storage Facility,* for BP dated June 2023 can be found in **Attachment 2**. [redacted]

[redacted] This lowermost USDW depth was utilized in the critical pressure calculation described above.

To further refine BP's understanding of USDW variation across the full AoR for monitoring and legacy well risk analysis, BP used additional data sources pertaining to Base of Useable Quality Water (BUQW). The BUQW is defined as water containing less than 3,000 parts per million of TDS. The BUQW is widely available in this region and is the total depth that surface casing must cover to protect water resources based on Railroad Commission of Texas (RRC) regulations for hydrocarbon drilling operations.

Before a hydrocarbon well can be drilled, the operator must obtain a Groundwater Protection Determination from the RRC's Groundwater Advisory Unit (GAU) that states the depth to the BUQW. The RRC database includes historical BUQW Determination Letters. [redacted] Please note that these determinations are predictions, based on the RRC's private database of what the BUQW is likely to be in an undrilled location, and do not constitute sampled depths of the BUQW.

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[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

The BEG provides a Surface Casing Estimator tool that was funded in part by the RRC and provides logged control points for BUQW determinations and BUQW. This information is provided for a limited number of counties and did not provide full coverage across the AoR. [redacted]

[redacted]

[redacted]

[redacted] The result is a continuous prediction of USDW across the AoR that incorporates both granularity from relatively dense BUQW information and truth-tie points for USDW depth prognosis.

5.3 AoR Delineation

Section 4.7 ("Current Model Build – Key Assumptions"), above, describes how the AoR was developed to delineate the maximum extent of the CO_2 plume and pressure front.

Section 4.5 ("Predictions of System Behavior"), above, details how BP's current AoR was delineated to represent the largest area in which USDWs may be endangered and how BP intends to supplement the AoR modeling.

Section 7 ("Reevaluation Schedule and Criteria"), below, describes how BP will utilize monitoring wells and geophysical surveys to verify the AoR delineation—or modify it as needed. After pre-operational testing, BP intends to reevaluate the AoR to ensure that model predictions align with collected well and baseline geophysical monitoring data prior to the start of injection.

Section 10 ("CO_2 Plume and Pressure Front Tracking") in the Testing and Monitoring Plan (**Appendix E**) shows the locations of monitoring equipment and discusses how BP will use monitoring to verify the extent and location of the CO_2 plume and AoR pressure front through time.

In accordance with 40 CFR 146.82(c)(1), the AoR will be finalized after incorporating all site data and pre-injection testing information.

6. CORRECTIVE ACTION

6.1 Tabulation of Wells within the AoR

In compliance with 40 CFR 146.84(c)(2), BP identified all artificial penetrations located within the delineated AoR, including active and abandoned wells and underground mines, that may penetrate the confining zone. As required in 40 CFR 146.82(a)(4), descriptions were developed for each well's type, construction, date drilled, location, depth, and if applicable, the record of plugging and/or completion. These records can be found in **Attachment 4** of this Plan.

6.1.1 Wells within the AoR

[redacted] The wells were evaluated using information from the public RRC and Texas Water Development Board (TWDB) and the private Enverus subscription-based Geographical Information System (GIS) databases gathered in March 2023. The identified wells within in the AoR, including type and status of each well, are listed on **Table 7** below.

For wells identified on **Table 7** that have significant data gaps on their current condition, location, and/or plugging specifics, site reconnaissance will be initiated to further review these wells. Other sources that may be used in the future to either fill data gaps in currently identified wells or to identify currently unknown or undocumented wells include aerial and satellite imagery reviews and geophysical surveys.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

6.1.2 Wells Penetrating the Confining Zone

[redacted] In general, wells were assessed based on the well completion depths within the USDWs and confining zones, dates of plugging and abandonment, identified casing with well development and abandonment, location of the plug in relation to the USDWs and confining zone, casing and cementing records for indications of integrity, well deviations, and historical records of mechanical integrity testing that would indicate potential issues.

In accordance with 40 CFR 146.84(c)(3), wells that do not appear to have been plugged in a manner to prevent the movement of CO_2 or other fluids into a USDW will be further assessed for corrective action through field work. BP will work with the UIC Program Director to confirm if other requirements may be recommended for the identified wells (e.g., surface cement plugs and/or additional plugs based on site-specific circumstances).

BP established which abandoned wells in the AoR have not been plugged in a manner that would prevent the movement of CO_2 or other fluids that may endanger USDWs [40 CFR 146.84(c)(3)]. BP conducted a detailed review of the wells within the AoR that penetrate the confining zone to identify wells that will require future field testing. A detailed search for well records for wells within the AoR and specifically penetrating the confining zone was conducted. For wells with no digital information available, hard copies are being requested from the RRC. If well documentation identified difficulties experienced during the abandonment procedures but also showed cased holes with adequate plugs and cement situated to isolate the injection zone from other fluid-containing zones, such records were used to demonstrate that the well had been plugged in a manner that prevents the movement of CO_2 or other fluids that may endanger USDWs per CFR 40 146.84(c)(3). If well records were incomplete or indicated that the well was not, or was not adequately, plugged, follow-up field investigation will be performed to determine the quality of plugging.

Field investigations may include additional surveys and/or specific tests to identify potential concerns with the casing, cementing, and plugging of legacy wells, and potential workovers on the wells to confirm and mitigate potential cementing and plugging issues. The casing and cement plugs will be evaluated due to the potential for joints within weak formations to result in failed cement and casing buckling. BP will evaluate well plug integrity through use of caliper log, sonic and ultrasonic tools, cased-hole mobility and fluid tests, and/or sidewall cores, although other tests may be used based on field conditions.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

BP will conduct corrective action on a phased basis according to the AoR reevaluation period. [redacted] Wells will have corrective action performed sufficiently prior to the AoR intersecting with those penetrations yet not so far in advance as to preclude BP's ability to respond to potential AoR changes through time that might remove further-out wells from the final life-of-project AoR. Enhanced monitoring of artificial penetrations within the AoR wells (e.g., groundwater and indirect geophysical techniques) will be considered to ensure the safety of USDWs in proximity to these wells.

In accordance with 40 CFR 146.84(b), BP will report tests completed on abandoned wells to the UIC Program Director and will supplement the list of wells (**Table 8**) for which corrective action will be conducted.

Prior to receiving the permit to inject, BP will submit a report on the status of corrective actions on wells within the AoR in accordance with 40 CFR 146.82(c)(6). The report will identify the number, type, and location of the plugs installed as part of BP-implemented corrective action. BP will also submit records of remedial cementing completed, along with cement logs showing the methods used and the results of the remedial cementing.

As discussed in **Section 7**, significant changes in the AoR may impact the necessary corrective actions on wells within the AoR. If the AoR changes significantly, BP will provide an update to the corrective action plan to the UIC Program Director for approval.

6.2 Plan for Site Access

BP is in the process of acquiring site access to wells potentially needing corrective action in accordance with 40 CFR 146.84(b)(iv). **Figure 22** below shows the location of legacy wells identified by the risk profile relative to progress on site access as of May 31, 2023.
BP will access the remaining legacy oil and gas wells requiring plugging/re-plugging as part of the required corrective action (i) by agreement with the surface owner and/or the last operator of record of the well in question, (ii) by contracting with the RRC to conduct the plugging activity pursuant to a RRC plugging order issued pursuant to Subchapter C of Chapter 89 of the Texas Natural Resources Code, and/or (iii) by assuming operatorship of an orphaned well pursuant to Section 89.047 of the Texas Natural Resources Code.

[redacted]

6.3 Corrective Action Schedule

In accordance with 40 CFR 146.84(b)(2)(iv), BP intends to phase corrective action for wells that the pressure front is not expected to reach in the first five years of operation. BP will seek approval from the UIC Program Director for the phased evaluation and corrective action of the

applicable wells. The phased approach is described in **Section 6.1.2.** BP will aim to have the corrective actions completed before the injection pressure front is predicted to reach each well. However, there is potential for a small number of corrective actions to be completed after operations have ceased based on testing and monitoring data.

The following field tests will be performed on the identified wells to evaluate the integrity of the abandoned wells. [redacted]

If it is determined that there is degraded cement quality, a defect in casing that could enable formation fluids to migrate out of the injection zone, channels between the cement and casing or cement and formation, or missing cement such that these wells could serve as a conduit for fluid movement and endanger USDWs, then corrective actions will be performed.

6.3.1 Plugging of Wells

BP will complete corrective actions in a manner that provides multiple barriers to CO_2 migration and avoids underground cross-flow. The wells within the AoR that penetrate the primary confining zone require adequate cement isolation across the primary confining zone. Wells with records that indicate a cement plug does not exist across the primary confining zone, that is plugged improperly, or for which no records exist will be redrilled to a depth below the confining zone and replaced with new cement plugs. New cement plugs will be placed from the injection zone to the top of the confining zone. Additional plugs may be required for the bottom of casing and across USDWs. A surface plug may also be required.

In accordance with 40 CFR 146.84(d), CO_2-resistant cement will be utilized for the cement plugs. Additional cement plugs will be placed below USDWs or other permeable formations that may exhibit cross-flow of mobilized fluids.

6.3.2 Remedial Cementing

In accordance with the EPA guidance, for cased-hole wells within the AoR that penetrate the primary confining zone and have inadequate annular cement isolation that could enable formation fluids to migrate out of the injection zone, a cement squeeze will be performed. The remedial cement operations will be conducted with a packer squeeze. The casing will be

perforated at a depth below the primary confining zone to ensure adequate cement can be placed on the casing annulus from the injection zone through the confining zone. A bridge plug will be set in the casing to isolate the area below the perforated depth to be cemented. A casing packer will be set above the treated area. CO_2-resistant cement will be utilized for the cement squeeze. The cement squeeze operation will be conducted under low pressure to avoid exceeding the fracture pressure of the formation.

Depending on specific site conditions, acrylic grouts and/or polymers may be used due to their compliance with 40 CFR 146.84(d) for CO_2-resistant cement.

7. REEVALUATION SCHEDULE AND CRITERIA

7.1 AoR Reevaluation Cycle

BP will reevaluate the above described AoR every five years during the injection and post-injection phases as required by 40 CFR 146.84(e). AoR reevaluation will consist of a comparison of modeling predictions and operational site data gathered through the Testing and Monitoring Plan (**Appendix E**).

After commencement of injection, the AoR will be defined by a robust static and dynamic simulation containing information from BP's appraisal well A469 #1 and the newly constructed injection and monitoring wells. Because BP will have multiple well data sources available upon the start of injection, reevaluating the AoR on the minimum fixed frequency of five years is appropriate.

BP will take the following steps to reevaluate the AoR:

1) Collect and analyze available monitoring and operational data from injection wells, monitoring wells, geophysical surveys, and other sources. Assess whether the various collected data types consistently describe the CO_2 plume and pressure migration. Monitoring activities to be conducted are described in the Testing and Monitoring Plan (**Appendix E**) and quality control procedures are described in the Quality Assurance and Surveillance Plan (**Appendix E**). This review includes:
    a. Confirming that ground water chemistry monitoring data acquired from the shallow monitoring wells show no evidence of excursion of CO_2 or brines that represent endangerment to any USDWs.
    b. Verification that operational data, e.g., injection rates and pressures, are consistent with inputs used in the most recent modeling effort.
    c. Correlation of time-lapse Reservoir Saturation Tool (RST) saturation logs, seismic and other geophysical surveys to locate and track movement of the CO_2 plume through time. A good correlation between data sets will provide strong evidence in validating model predictions.
    d. Review of downhole reservoir pressure and temperature data collected from various locations and intervals to track the CO_2 pressure front through time.
    e. Assessment of whether any geological data acquired since the last modeling effort, e.g., additional site characterization or new petrophysical analysis, materially differs from modeling inputs or assumptions.
2) Compare the results of computational modeling used for AoR delineation to collected monitoring and operational data. This process will demonstrate the degree of accuracy of the computational model's predicted properties (e.g., plume location, rate of movement, and pressure decay). This data will be submitted to the UIC Program Director and include information on how it is being incorporated into existing models. Comparison information will be provided in the form of graphics and informative maps that show the

general agreement between monitoring results and the model predictions and that the monitoring data is considered, including fluid chemistry monitoring, pressure monitoring, and geophysical surveys. The relative error difference between monitoring data and model predictions will be quantified via calibration statistics.

3) If the information reviewed is consistent with, or is unchanged from, the most recent modeling assumptions or confirms modeled predictions about the maximum extent of plume and pressure front movement, BP will prepare a report demonstrating that no reevaluation of the AoR is needed. The report will include the data and results demonstrating that no changes are necessary.
4) If material changes have occurred (e.g., in the behavior of the plume, pressure front, operations, or site conditions) such that the actual plume or pressure front may extend beyond the modeled predictions, BP will take the following steps:
    a. Perform the AoR delineation process as described in the **Section 5** utilizing any new site characterization, operational, or monitoring data.
    b. Review wells in any newly identified areas of the AoR and apply corrective action to deficient wells as described in the Corrective Action section of this AoR and Corrective Action Plan.
    c. Prepare a report documenting the AoR reevaluation process, data inputs, final results, and a schedule detailing the status of corrective actions to be performed. The report will be submitted to the UIC Program Director within one year of the reevaluation and will include maps that highlight similarities and differences with previous AoR delineations. If necessary, BP will provide a demonstration of adequate surface access rights to perform additional, required corrective action.
    d. Update the AoR and Corrective Action Plan to reflect the revised AoR, along with other related project plans, as needed.

In accordance with 40 CFR 146.90(j), BP will incorporate AoR reevaluations with material changes into the Testing and Monitoring Plan **(Appendix E).**

7.2 Triggers for AoR Reevaluations Prior to the Next Scheduled Reevaluation

BP will review monitoring and operational data at specific frequencies outlined in the Testing and Monitoring Plan (**Appendix E**) throughout the injection and post-injection phases of the Project. If operational data suggests that there is potential for a significant divergence from the modeled vertical and/or horizontal size and/or the shape of the actual CO_2 plume or pressure front, BP will initiate an immediate AoR reevaluation. Unscheduled re-evaluation of the AoR will be based on quantitative changes of the following monitoring parameters:

- Pressure: Changes in pressure that are unexpected and outside 3 standard deviations from an appropriate average.
- Temperature: Changes in temperature that are unexpected and outside 3 standard deviations from an appropriate average.

- RST Saturation: Increases in CO_2 saturation that indicate the movement of CO_2 into or above the confining zone will trigger reevaluation of the AoR unless the changes are found to be related to the well integrity. Any well integrity issues will be investigated and addressed as per the procedures outlined in the Emergency and Remedial Response Plan (**Appendix H**).
- Deep ground water constituent concentrations: Unexpected changes in fluid constituent concentrations that indicate movement of CO_2 or brines into or above the confining zone will trigger a new evaluation of the AoR unless the changes are found to be related to the well integrity. Any well integrity issues will be investigated and addressed as per the procedures outlined in the Emergency and Remedial Response Plan (**Appendix H**).
- Geochemical Sampling: Results of groundwater geochemical sampling indicate separate-phase (e.g., supercritical, liquid, or gaseous) CO_2 migration outside of the boundaries of the AoR delineation or at rates significantly greater than predicted by the model.
- Exceeding Fracture Pressure Conditions: Pressure in any of the injection or monitoring wells approaching 90% of the geologic formation fracture pressure at the point of measurement. The Testing and Monitoring Plan (**Appendix E**) and the well operations discussed in the Application Narrative provide discussion of pressure monitoring and specific procedures that will be completed during the injection start-up period.
- Petrophysics: New site characterization data changes the computational model to such an extent that the predicted plume or pressure front extends vertically or horizontally beyond the predicted AoR.
- Exceeding Established Initial Condition Hydrochemical/Physical Parameter Patterns: A statistically significant difference between observed and initial condition hydrochemical/physical parameter patterns (e.g., fluid conductivity, pressure, temperature) immediately above the confining zone. The Testing and Monitoring Plan (**Appendix E**) provides extended information regarding how pressure, temperature, and fluid conductivity will be monitored.
- Compromise in Injection Well Mechanical Integrity: A significant change in pressure within the protective annular pressurization system surrounding each injection well that indicates a loss of mechanical integrity at an injection well. Any well integrity issues will be investigated and addressed as per the procedures outlined in the Emergency and Remedial Response Plan (**Appendix H)**.
- Seismic Monitoring Identification of Subsurface Structural Features: Seismic monitoring data that indicates the presence of a fault or fracture in or near the confining zone or a fault or fracture within the injection zone that indicates propagation into the confining zone. The Testing and Monitoring Plan (**Appendix E**) provides extended information about the micro seismic monitoring network.
- Indirect Monitoring: Identified CO_2 migration outside of the boundaries of the AoR delineation and/or at rates significantly greater than the current model estimates.

Significant changes in site operations may alter model predictions and the AoR delineation. Example changes include the number of Class VI injection wells injecting into the same injection

zone and/or injection rate changes; volumes, or pressures outside the limits of the original permit; and/or changes to the composition of the injectate or fluid production rates from injection or overlying zones.

An unscheduled AoR reevaluation may also be needed if:

- A seismic event greater than M3.5 has occurred within the AoR;
- There has been an exceedance of any Class VI operating permit condition (e.g., exceeding the permitted volumes of CO_2 injected); or
- Another Class VI permit is issued in close proximity to the AoR.

BP will discuss any such events with the UIC Program Director to determine if an AoR reevaluation is required. If an unscheduled reevaluation is triggered, BP will submit AoR changes to the UIC Program Director with an associated timeframe for instituting the changes to the AoR and for conducting any additional corrective actions. The timeframe will be based on the specific changes and related mitigation efforts required to reevaluate the AoR and conduct necessary corrective actions.

For future AoR reevaluations, the static and dynamic properties of the model will be updated as new site-specific data is acquired, which will trigger evaluations of the applicable correlations or approximations used in the simulation. The model outputs will be compared to the original AoR using a combination of workflows in [redacted] to identify changes in the CO_2 trapping mechanisms and plume extent.

Attachment 1

[redacted]

Attachment 2

[redacted]

USDW Evaluation

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June 2023

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Attachment 3

[redacted]

Railroad Commission of Texas - GAU Determinations

Attachment 4

[redacted]