Carbon TerraVault V
Class VI Permit Application
Narrative Report

9-12-2023

Submitted to:
U.S. Environmental Protection Agency Region 9
San Francisco, CA

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Document Version History

Version	Submission Date	File Name	Description of Change
1	7/12/2023	Att A – CTV V Narr_v1	Original Submission
2	9/12/2023	Att A – CTV V Narr_v2	Update Figure 2.2-11 and added references tables for Figure 2.2-11 in response to EPA comment letter dated 8/30/2023.

ATTACHMENT A: CLASS VI PERMIT APPLICATION NARRATIVE
40 CFR 146.82(a)
CTV V

1.0 Project Background and Contact Information

Carbon TerraVault Holdings LLC (CTV), a wholly owned subsidiary of California Resources Corporation (CRC), proposes to construct and operate six CO_2 geologic sequestration wells at the project area located in San Joaquin County, California. This application was prepared in accordance with the U.S. Environmental Protection Agency's (EPA's) Class VI regulations, in Title 40 of the Code of Federal Regulations (40 CFR 146.81). CTV is not requesting an injection depth waiver or aquifer exemption expansion.

CTV will obtain the required authorizations from applicable local and state agencies, including the associated environmental review process under the California Environmental Quality Act. **Appendix 1** outlines potential local, state, and federal permits and authorizations. The project wells and facilities will not be located on Indian Lands. Federal act considerations and additional consultation, which includes the Endangered Species Act, the National Historic Preservation Act and consultations with Tribes in the Area of Review (AoR), are presented in "**Appendix 2**: Applicable Federal Acts and Consultation."

CTV forecasts the potential CO_2 stored in the [redacted]

CTV is planning to construct a carbon capture and sequestration "hub" project (*i.e.*, a project that collects CO_2 from multiple sources over time and injects the CO_2 stream(s) via Class VI Underground Injection Control (UIC)-permitted injection well(s)). Therefore, CTV is currently considering multiple sources of anthropogenic CO_2 for the project. Potential sources include capture from existing and potential future industrial sources in the Sacramento Valley area, as well as Direct Air Capture (DAC).

The Carbon TerraVault V (CTV V) storage site is located in the Sacramento Valley, [redacted] California (**Figure 2.1-1**) within the southern Sacramento Basin. The project is comprised of six injectors (three into the [redacted] and three into the [redacted], surface facilities, and monitoring wells. This supporting documentation applies to the six injection wells.

CTV will actively communicate project details and submitted regulatory documents to County and State agencies:

1. California Geologic Energy Management Division (CalGEM)
Senior Oil and Gas Engineer – Erwin Sison
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2. CA Assembly District 13
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3. San Joaquin County
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4. San Joaquin County Community Development
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5. San Joaquin Council of Governments
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6. Region 9 Environmental Protection Agency
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2.0 Site Characterization

2.1 Regional Geology, Hydrogeology, and Local Structural Geology [40 CFR 146.82(a)(3)(vi)]

2.1.1 Field History

The CTV V storage site is [redacted]

[redacted]

[redacted]

2.1.2 Geology Overview

The CTV V storage site lies within the Sacramento Basin in northern California (**Figure 2.1-2**). The Sacramento Basin is the northern, asymmetric sub-basin of the larger, Great Valley Forearc. This portion of the basin, which contains a steep western flank and a broad, shallow eastern flank, spans approximately 240 miles in length and is 60 miles wide (Magoon, 1995).

2.1.2.1 Basin Structure

The Great Valley was developed during mid- to late-Mesozoic time. The advent of this development occurred under convergent-margin conditions via eastward, Farallon Plate subduction of oceanic crust beneath the western edge of North America (Beyer, 1988). The convergent, continental margin that characterized central California during the Late Jurassic through Oligocene time was later replaced by a transform-margin tectonic system. This occurred as a result of the northward migration of the Mendocino Triple Junction (from Baja California to its present location off the coast of Oregon), located along California's coast (**Figure 2.1-3**). Following this migration, the progressive cessation of both subduction and arc volcanism occurred as the progradation of a transform fault system moved in as the primary tectonic environment (Graham, 1984). The major current-day fault, the San Andreas, intersects most of the Franciscan subduction complex, which consists of the exterior region of the extinct convergent-margin system (Graham, 1984).

2.1.2.2 Basin Stratigraphy

The structural trough that developed subsequent to these tectonic events was named the Great Valley, which became a depocenter for eroded sediment and thereby currently contains a thick infilled sequence of sedimentary rocks. These sedimentary formations range in age from Jurassic to Holocene. The first deposits occurred as an ancient seaway, and through time were built up by the erosion of the surrounding structures. The basin is constrained on the west by the Coast Range Thrust, on the north by the Klamath Mountains, on the east by the Cascade Range and Sierra Nevada, and on the south by the Stockton Arch Fault (**Figure 2.1-2**). To the west, the Coastal Range boundary was created by uplifted rocks of the Franciscan Assemblage (**Figure 2.1-4**). The Sierra Nevada Mountains that make up the eastern boundary are a result of a chain of ancient volcanoes fed by pre-transform fault subduction.

Basin development is broken out into evolutionary stages at the end of each time period of the arc-trench system, from Jurassic to Neogene, in **Figure 2.1-5**. As previously stated, sediment infill began as an ancient seaway and was later sourced from the erosion of the surrounding structures. Sedimentary infill consists of Cretaceous-Paleogene fluvial, deltaic, shelf, and slope sediments. Due to the southward tilt of the basin, sedimentation [redacted] creating sequestration-quality sandstones.

[redacted]

2.1.2.3 Submarine Canyons

Falling sea level and tectonics caused the [redacted] submarine canyons [redacted] to form throughout the [redacted] (**Figure 2.1-2**). The erosional events associated with these canyons played a large part in the current distribution and continuity of [redacted] Trending in a [redacted] direction and cutting deeply into sediments of the [redacted] this erosional event spans [redacted] This event caused erosional troughs that were later filled in with fine-grained submarine fan deposits and transgressive deep-water shale due to renewed rising sea levels. [redacted]

2.1.3 Geological Sequence

[redacted]

[redacted]

2.2 Maps and Cross-Sections of the AoR [40 CFR 146.82(a)(2), 146.82(a)(3)(i)]

2.2.1 Data

[redacted]

Well data are used in conjunction with two -dimensional (2D) and three -dimensional (3D) seismic to define the structure and stratigraphy of the injection zones and confining layers (**Figure 2.2-3**). **Figure 2.2-4** shows outlines of the seismic data used to build a structural framework for the area. The 3D surveys were mapped in their entirety, and an additional 2D seismic line was incorporated to the east to constrain the structural model in conjunction with well control. The 3D surveys were pre-stack merged as part of a larger regional effort in 2013 to incorporate advances in seismic processing and allow for a seamless interpretation. Also shown are the seismic well ties made to the 2D and 3D data. Available seismic data were mapped for the following surfaces-:

- A shallow marker to aid in controlling the structure of the velocity field
- [redacted]
- [redacted]
- [redacted]

- [redacted]
- [redacted]

The [redacted] was chosen to be the base of the model due to its reliability as a seismic marker and its depth beneath the injection zones. A basement reflector could not be picked across the entirety of the mapped area due to the depth to basement increasing to the west. Interpretation of these layers began with a series of well ties at well locations shown in **Figure 2.2-4**. These well ties create an accurate relationship between wells, which are in depth, and the seismic, which is in time. The layers listed above were then mapped in time and gridded across the 3D surveys and 2D seismic line. Alongside this mapping was the interpretation of any faulting in the area, which is discussed further in Section 2.3 (Faults and Fractures) of this document.

The gridded time maps and a sub-set of the highest quality well ties and associated velocity data were then used to create a 3D velocity model. This model is guided between well control by the time horizons and is iterated to create an accurate and smooth function. The velocity model is used to convert both the gridded time horizons and any interpreted faults into the depth domain. The result is a series of depth grids of the layers listed above, which are then used in the next step of this process.

The depth horizons are the basis of a framework which uses conformance relationships to create a series of depth grids that are controlled by formation well tops picked on well logs. The grids are used as structural control between these well tops to incorporate the detailed mapping of the seismic data. These grids incorporate the thickness of zones from well control and the formation strike, dip, and any fault offset from the seismic interpretation. The framework is set up to aid in building the following depth grids for input in to the geologic and plume growth models:

- Upper Injection Zone Model:
  - [redacted]
  - [redacted]
  - [redacted]
  - [redacted]

- Lower Injection Zone Model:
  - [redacted]
  - [redacted]
  - [redacted]

2.2.2 Stratigraphy

[redacted]

[redacted]

2.2.2.1 [redacted] *(Below Lower Injection Zone)*

[redacted]
The [redacted] is a regionally extensive [redacted]

[redacted]
The [redacted] is an [redacted]

2.2.2.2 [redacted] *(Lower Injection Zone)*

The [redacted] is comprised of [redacted]

Three injectors will inject into [redacted] sands as shown above in **Figure 2.2-6**. A total of six injectors are planned for the combined [redacted] (**Figure 2.2-7**).

2.2.2.3 [redacted] *(Internal Barrier)*

The [redacted] is a regional [redacted] Due to its [redacted]

2.2.2.4 [redacted] *(Upper Injection Zone)*

The [redacted]

Three injectors will inject into the [redacted] sands as shown above in **Figure 2.2-8**. A total of six injectors are planned for the combined [redacted] formations (**Figure 2.2-7**).

2.2.2.5 [redacted] *(Upper Confining Zone)*

The [redacted] that acts as the upper confining zone for the storage project. [redacted] serves as the sealing facies above the Upper and Lower Injection Zones; it will prevent the upward migration of CO_2 from the storage reservoirs, thus protecting USDWs.

2.2.2.6 [redacted] *(Dissipation Zone)*

The [redacted] This formation serves as a monitoring zone above the Upper and Lower Injection Zones. [redacted]

2.2.2.7 [redacted] (Additional Barrier)

Above the [redacted] is the [redacted] which is [redacted]

2.2.2.8 [redacted]

The upper [redacted]

2.2.3 Maps of the Area of Review

As required by 40 CFR 146.82(a)(2), **Figure 2.2-9** shows surface bodies of water, surface features, transportation infrastructure, political boundaries, and cities and the project AoR. AoR delineation is presented in **Attachment B** (AoR and Corrective Action Plan). Major surface water bodies located in the area include [redacted]

[redacted]

[redacted] This cleanup site information was obtained from the State Water Resources Control Board's GeoTracker database, which contains records for sites that impact, or have the potential to impact, groundwater quality. Water wells within and adjacent to the AoR are discussed in Section 2.7.7 of this document.

40 CFR 146.82(a)(2) requires that the application includes a map showing the injection wells, the AoR, and the below list of items and these are shown on the indicated maps where present:

- Existing injection wells, producing wells, abandoned wells, plugged wells or dry holes, deep stratigraphic boreholes (**Figure 2.2-1**).
- Surface bodies of water, springs, mines (surface and subsurface), quarries, State, Tribal, and Territory boundaries, roads and other pertinent surface features (**Figure 2.2-9**).

- State- or EPA-approved subsurface cleanup sites (**Figure 2.2-10**).
- Water wells (Figure 2.7-7; see Section 2.7)
- **Figure 2.2-11** is a compilation of the above data including index numbers to well names. Referenced index number are listed in **Table 2.2-1** and **Table 2.2-2**.

2.3 Faults and Fractures [40 CFR 146.82(a)(3)(ii)]

A combination of 2D and 3D seismic and well control were used to define the structure [redacted]

[redacted]

2.4 Injection and Confining Zone Details [40 CFR 146.82(a)(3)(iii)]

2.4.1 <u>Mineralogy</u>

Some quantitative mineralogy information exists within the AoR boundary from the [redacted] Mineralogy data will be acquired across all the zones of interest as part of pre-operational testing. Several wells outside the AoR have mineralogy over the formations of interest, and that data is presented below. The locations of wells used for mineralogy are shown in **Figure 2.2-2**, and the mineralogy data is posted in **Table 2.4-1**.

2.4.1.1 Upper Confining Zone

Mineralogy data is available for the upper confining zone from three wells in [redacted] has Fourier-transform infrared spectroscopy (FTIR) data, while the other two wells have x-ray diffraction (XRD) data. Nine samples show an average of 29% total clay, with mixed-layer illite/smectite being the dominant species, and kaolinite and chlorite still prevalent. They also contain 32% quartz, 39% plagioclase and potassium feldspar, minimal pyrite, and less than 1% calcite and dolomite.

2.4.1.2 Upper Injection Zone

Mineralogy data is available for the Upper Injection Zone in the form of XRD data from the [redacted] within the AoR. Reservoir sand from six samples within this well averages 32% quartz, 21% plagioclase and potassium feldspar, and 18% total clay. The primary clay minerals are kaolinite, chlorite and mixed layer illite/smectite. Calcite & dolomite were not detected in any of the samples.

2.4.1.3 Internal Barrier

Mineralogy data is available for the internal barrier zone from the [redacted] well. A mix of XRD and FTIR data on nine samples show an average of 46% total clay, with mixed layer illite/smectite being the dominant species, and kaolinite and chlorite still prevalent. They also contain 23% quartz, 29% plagioclase and potassium feldspar, 2% pyrite, and 1% calcite and dolomite.

2.4.1.4 Lower Injection Zone

Mineralogy data is available for the Lower Injection Zone in the form of XRD data from the [redacted] well within the AoR. Reservoir sand from three samples within this well averages 40% quartz, 9% plagioclase and potassium feldspar, and 14% total clay. The primary clay minerals are kaolinite, chlorite, and mixed-layer illite/smectite.

Mineralogy data is available from within the AoR for the Lower Injection Zone from XRD data in the [redacted] Reservoir sand from 29 samples within these wells averages 54% quartz, 26% plagioclase and potassium feldspar, and 11% total clay. The primary clay minerals are kaolinite, chlorite, and mixed-layer illite/smectite. Calcite and dolomite were detected in several samples, which are interpreted to be calcite-cemented sandstone and grain replacement based on thin-section analysis of samples [redacted]

2.4.1.5 [redacted]

Mineralogy data is available for the [redacted] in the form of XRD data from the [redacted] Twenty-two samples show an average of 41% total clay, with chlorite being the dominant species, with illite/mica and smectite common. They also contain 25% quartz, 26% plagioclase and potassium feldspar, 2% pyrite, and less than 1% calcite and dolomite. Two samples show calcite cementation.

2.4.1.6 [redacted]

Mineralogy data is available for the [redacted] in the form of XRD data from the [redacted] Ten samples show an average of 47% total clay, with chlorite being the dominant species, with illite/mica and smectite common. They also contain 22% quartz, 27% plagioclase and potassium feldspar, 1% pyrite, and less than 1% calcite and dolomite.

2.4.2 Porosity and Permeability

Wireline log data was acquired with measurements that include but are not limited to spontaneous potential (SP), natural gamma ray, borehole caliper, compressional sonic, resistivity, as well as neutron porosity and bulk density. Whole core was also cut in the Upper Injection Zone and overlying [redacted]

Formation porosity is determined one of two ways: from bulk density using 2.65 grams per cubic centimeter (g/cc) matrix density as calibrated from core grain density and core porosity data, or from compressional sonic using 55.5 microseconds per foot (µsec/ft) matrix slowness and the Wyllie time-average equation. See **Table 2.4-2** for explanation of which equations were used in each zone.

Clay volume is determined by SP and is calibrated to core data. Log-derived permeability is determined by applying a core-based transform that utilizes capillary pressure porosity and permeability along with clay values from XRD or FTIR. Core data from two wells with 13 data points was used to develop a permeability transform. An example of the transform from core data is illustrated in **Figure 2.4-1**.

Comparison of the permeability transform to log-generated permeability (Timur-Coates method) from a nuclear magnetic resonance (NMR) log in the [redacted]

2.4.2.1 Upper Confining Zone

The average porosity of the upper confining zone is 28.5%, based on 10 wells with porosity logs and 3,155 individual logging data points. See **Figure 2.4-3** for location of wells used for porosity and permeability averaging. The geometric average permeability of the upper confining zone is 0.33 millidarcies (mD), based on the [redacted] NMR permeability from the Timur-Coates method.

Core data is available for the upper confining zone from the [redacted] The cited report states that the vertical permeability for the upper confining zone is between 0.04-0.06 mD based on two different analysis methods for samples from the [redacted] This is lower than the permeability from the NMR log in [redacted] and confirms that the upper confining zone has good sealing potential

2.4.2.2 Upper Injection Zone

The average porosity for the Upper Injection Zone is 32.2%, based on 38 wells with porosity logs and 33,891 individual logging data points. The geometric average permeability for the Upper Injection Zone is 216 mD, based on 38 wells with porosity logs and 33,768 individual logging data points. This is in agreement with the NMR permeability in the [redacted] which had a geometric mean of 225 mD for the upper injection zone. Twenty-one core data points from [redacted] (see **Figure 2.2-2** for well location) are from the upper injection zone. Permeability was measured and is in agreement with the log averages (see **Table 2.4-3**).

Core data is available for the upper injection zone from the [redacted] The cited report states that the upper injection zone has an average porosity of 25% and a horizontal permeability of 807 mD based on 162 samples in the [redacted] The horizontal permeability is very similar to the average of the core data in **Table 2.4-3**, which has an average of 780 mD. Vertical permeability measurements from that well showed an average Kv/Kh ratio of 0.8, which is similar to data from [redacted], which shows an average Kv/Kh ratio of 0.74.

2.4.2.3 Internal Barrier

The average porosity of the internal barrier zone is 25.5%, based on 23 wells with porosity logs and 9,854 individual logging data points. The geometric average permeability of the internal barrier zone is 1.3 mD, based on the [redacted] NMR permeability from the Timur-Coates method.

2.4.2.4 Lower Injection Zone

The average porosity of the Lower Injection Zone is 25.5%, based on 21 wells with porosity logs and 12,798 individual logging data points. The geometric average permeability of the Lower Injection Zone is 52 mD, based on 20 wells with porosity logs and 11,602 individual logging data points. This is in agreement with the NMR permeability in [redacted] which had a geometric mean of 53 mD for the lower injection zone. Five core data points from [redacted] are from the lower injection zone. Permeability was measured and is in agreement with the log averages (see **Table 2.4-4**).

2.4.3 Injection and Confining Zone Capillary Pressure

Capillary pressure is the difference across the interface of two immiscible fluids. Capillary entry pressure is the minimum pressure required for an injected phase to overcome capillary and interfacial forces and enter the pore space containing the wetting phase.

Capillary pressure data within the project area is available from four sidewall core samples taken from [redacted] Two samples were collected from the Upper Injection Zone and two samples were collected from the Lower Injection Zone using mercury-injection capillary pressure (MICP). The capillary pressure was determined by applying CO_2-brine corrections to air-mercury test data. An interfacial tension of 480 dynes per centimeter (dynes/cm) was used for air-mercury and 30 dynes/cm was used to convert to CO_2-brine. The cosine of contact angles of 0.766 and 0.875 degrees were also used for air-mercury and CO_2-brine, respectively, based on published studies.

The report [redacted] cites caprock threshold pressure tests that were performed on samples from the upper confining zone. A delta pressure was held across three separate core samples, none of which showed any brine production at the highest delta pressure of 2,000 psi. As stated in the report, [redacted]

2.4.4 Depth and Thickness

Depth and thickness of the Upper Confining Zone, Upper Injection Zone, barrier, and Lower Injection Zone (**Table 2.4-5**) are determined by structural and isopach maps (**Figure 2.4-4** and

Figure 2.4-5) based on well data (wireline logs). Variability of thickness and depth measurements within the project AoR is caused by the following factors.

1. [redacted]
2. Structural and thickness variability within [redacted] is due to erosion [redacted]
3. Structural and thickness variability across [redacted] is due to deposition on [redacted]

2.4.5 Structure Maps

Structure maps (**Figure 2.4-4** and **Figure 2.4-5**) are provided to indicate a depth to formation adequate for supercritical-state injection.

2.4.6 Isopach Maps

SP logs from surrounding gas wells were used to identify sandstones. Negative millivolt (mV) deflections on these logs, relative to a baseline response in the enclosing shales, define the sandstones. These logs were baseline-shifted to 0 mV. Due to the log vintage variability, there is an effect on quality which creates a degree of subjectivity within the gross sand, however this will not have a material impact on the maps.

Variability in the thickness and depth of [redacted] sandstones will not impact confinement. CTV will utilize the thicknesses and depths shown when determining operating parameters and assessing project geomechanics.

2.5 Geomechanical and Petrophysical Information [40 CFR 146.82(a)(3)(iv)]

2.5.1 Caprock Ductility

Ductility and the unconfined compressive strength (*UCS*) of shale are two properties used to describe geomechanical behavior. Ductility refers to how much a rock can be distorted before it fractures, while the *UCS* is a reference to the resistance of a rock to distortion or fracture. Ductility generally decreases as compressive strength increases.

Ductility and rock strength calculations were performed based on the methodology and equations from Ingram & Urai (1999) and Ingram, et al. (1997). Brittleness is determined by comparing the log-derived *UCS* to an empirically derived *UCS* for a normally consolidated rock (UCS_{NC}).

$$\log UCS = -6.36 + 2.45 \log(0.86V_p - 1172) \quad (1)$$

$$\sigma' = OB_{pres} - P_p \quad (2)$$

$$UCS_{NC} = 0.5\sigma' \quad (3)$$

$$BRI = \frac{UCS}{UCS_{NC}} \quad (4)$$

Units for the *UCS* equation are *UCS* in megapascals (MPa) and V_p (compressional velocity) in meters per second (m/s). OB_{pres} is overburden pressure, P_p is pore pressure, σ' is effective overburden stress, and *BRI* is brittleness index.

If the value of *BRI* is less than 2, empirical observation shows that the risk of embrittlement is lessened, and the confining zone is sufficiently ductile to accommodate large amounts of strain without undergoing brittle failure. However, if *BRI* is greater than 2, the "risk of development of an open fracture network cutting the whole seal depends on more factors than local seal strength, and therefore the *BRI* criterion is likely to be conservative, so that a seal classified as brittle may still retain hydrocarbons" (Ingram & Urai, 1999).

2.5.1.1 Upper Confining Zone

Within the project area, 16 wells had compressional sonic data over the upper confining zone to calculate ductility, comprising 8,863 individual logging data points (pink circles in **Figure 2.2--2)**. The same 16 wells were used to calculate *UCS*, comprising 8,863 individual logging data points. The average ductility of the upper confining zone based on the mean value is 1.34. The average rock strength of the confining zone, as determined by the log-derived *UCS* equation above, is 1,589 psi.

[redacted]

2.5.1.2 Additional Barrier between Upper Injection Zone and Lowermost USDW

Additionally, ductility and rock strength were calculated over the additional barrier between the Upper Injection Zone and the lowermost USDW (see Section 2.2.2.7) and the internal barrier zone. Fifteen wells had sufficient data for the additional barrier, comprising 6,288 individual logging data points. The average ductility of the additional barrier based on the mean value is 1.43. The average rock strength of the additional barrier, as determined by the log-derived *UCS* equation above, is 1,125 psi.

2.5.1.3 Internal Barrier

Nine wells had sufficient data to calculate ductility and rock strength over the internal barrier zone, comprising 3,974 individual logging data points. The average ductility of the internal barrier zone based on the mean value is 2.0. The average rock strength of the internal barrier zone, as determined by the log-derived *UCS* equation above, is 3,088 psi.

An example calculation for the well [redacted] is shown in **Figure 2.5-1**. *UCS_CCS_VP* is the *UCS* based on the compressional velocity, *UCS_NC* is the *UCS* for a normally consolidated rock, and *BRI* is the calculated brittleness using this method. Brittleness less than 2 (representing ductile rock) is shaded red.

Within the upper confining layer, the brittleness calculation drops to a value less than 2. Additionally, the additional barrier has a brittleness value less than 2. The barrier zone also has a brittleness value less than 2. As a result of the confining layer ductility, there are no fractures that will act as conduits for fluid migration from the injection zones. This conclusion is supported by the fact that prior to discovery, the upper confining zone provided a seal to the underlying gas reservoirs of [redacted] for millions of years in several gas fields surrounding and within the project AoR.

2.5.2 Stress Field

The stress of a rock can be expressed as three principal stresses. Formation fracturing will occur when the pore pressure exceeds the least of the stresses. In this circumstance, fractures will propagate in the direction perpendicular to the least principal stress (**Figure 2.5-2**).

Stress orientations in the [redacted] have been studied using both earthquake focal mechanisms and borehole breakouts (Snee and Zoback, 2020; Mount and Suppe, 1992). The azimuth of maximum principal horizontal stress (S_{Hmax}) was estimated at N40ºE ± 10º by Mount and Suppe (1992). Data from the World Stress Map 2016 release (Heidbach et al., 2016) shows an average S_{Hmax} azimuth of N37.4ºE once several far-field earthquakes with radically different S_{Hmax} orientations are removed (**Figure 2.5-3**), which is consistent with Mount and Suppe (1992). The earthquakes in the area indicate a strike-slip/reverse-faulting regime.

Within the project AoR, there is a site-specific fracture gradient for the Upper Injection Zone, but not for the Lower Injection Zone or any of the confining zones. A step-rate test will be conducted as per the pre-operational testing plan (**Attachment I**) in the injection zones. A step-rate test (SRT) was performed in the [redacted] with a resultant fracture gradient of 0.822 psi/ft in the Upper Injection Zone. Several additional wells in the [redacted] have formation integrity tests (FIT) or leak-off tests (LOT) performed at similar depth ranges to the project injection and confining zones. Tests from seven wells average 0.82 psi/ft from tests in the depth range of [redacted] feet TVD. See **Figure 2.5-4** for the location of the wells. For the computational simulation modeling and well-performance modeling, a frac gradient of 0.76 psi/ft was assumed for now as a safety factor.

The overburden stress gradient in the injection and confining zones is 0.87 to 0.94 psi/ft. No data currently exists for the pore pressure of the confining zone. This will be determined as part of the preoperational testing.

2.6 Seismic History [40 CFR 146.82(a)(3)(v)]

2.6.1 Recent Seismicity

As discussed in prior sections, 2D and 3D seismic along with well data were used to create depth surfaces within the AoR. [redacted]

[redacted] The California Geologic Survey (CGS) has produced a Fault Activity Map which captures a compilation of mapped faults within the state. [redacted]

USGS provides an earthquake catalog tool (https://earthquake.usgs.gov/earthquakes/search/) which can be used to search for recent seismicity that could be associated with faults for movement. A search was made for earthquakes in the greater vicinity of the project area from 1900 to modern day with events of a magnitude greater than 2.5. **Figure 2.6-1** shows the results of this search. **Table 2.6-1** summarizes data taken from these events. The events were confirmed to be the same as those in the Northern California Earthquake Data Center catalog (NCEDC, 2014).

There are seventeen events [redacted]

Lund-Snee and Zoback (2020) published updated maps for crustal-stress estimates across North America. **Figure 2.6-2** shows a modified image from that work highlighting the project area. This work agrees with previous estimates of maximum horizontal stress in the region of approximately N40°E in a strike-slip to reverse-stress regime (Mount and Suppe, 1992) and is consistent with World Stress map data for the area (Heidbach et al., 2016). **Attachment C** of this application (Testing and Monitoring Plan) discusses the seismicity monitoring plan for this injection site.

2.6.2 Seismic Hazard Mitigation

[redacted]

The following is a summary of CTVs seismic hazard mitigation for CTV V:

The project has a geologic system capable of receiving and containing the volumes of CO_2 proposed to be injected.

- [redacted]
- There are no faults or fractures identified in the AoR that will impact the confinement of CO_2 injectate. [redacted]

Will be operated and monitored in a manner that will limit risk of endangerment to USDWs, including risks associated with induced seismic events.

- Injection pressure will be lower than the fracture gradient of the sequestration reservoir with a safety factor (90% of the fracture gradient).
- Injection and monitoring well pressure monitoring will ensure that pressures are beneath the fracture pressure of the sequestration reservoir and confining zone.
- A seismic monitoring program will be designed to detect events lower than seismic events that can be felt. This will ensure that operations can be modified with early warning events, before a felt seismic event.

Will be operated and monitored in a way that in the unlikely event of an induced event, risks will be quickly addressed and mitigated.

- Via monitoring and surveillance practices (pressure and seismic monitoring program), CTV personnel will be notified of events that are considered an early warning sign. Early warning signs will be addressed to ensure that more significant events do not occur.
- CTV will establish a central control center to ensure that personnel have access to the continuous data being acquired during operations.

Minimizing potential for induced seismicity and separating any events from natural to induced.

- Pressure will be monitored in each injector and sequestration-monitoring well to ensure that pressure does not exceed the fracture pressure of the reservoir or confining zone.
- Seismic monitoring program will be installed pre-injection for a period to monitor for any baseline seismicity that is not being resolved by current monitoring programs.
- Average depth of prior seismic hazard in the region based on reviewed historical seismicity has been approximately 5.0 km, which is significantly deeper than the proposed injection zones.

2.7 Hydrologic and Hydrogeologic Information [40 CFR 146.82(a)(3)(vi), 146.82(a)(5)]

The California Department of Water Resources (DWR) has defined 515 groundwater basins and subbasins within the state. [redacted]

[redacted]

[redacted]

Portions of the text below regarding hydrologic features of the area are adopted from [redacted] (2019).

2.7.1 Hydrologic Information

[redacted]

[redacted]

[redacted]

[redacted]

2.7.2 Base of Fresh Water and Base of USDWs

The owner or operator of a proposed Class VI injection must define the general vertical and lateral limits of all USDWs and their positions relative to the injection zone and confining zones. The intent of this information is to demonstrate the relationship between the proposed injection formation and any USDWs, and it will support an understanding of the water resources near the proposed injection well. A USDW is defined as an aquifer or its portion which supplies any public water system; or which contains a sufficient quantity of ground water to supply a public water system and currently supplies drinking water for human consumption; or contains fewer than 10,000 mg/L TDS; and which is not an exempted aquifer. The freshwater aquifer zone is defined by California State Water Resources Control Board Resolution 88-63 as containing less than 3,000 mg/L TDS. For the California Sustainable Groundwater Management Act (SGMA), the bottom of the groundwater basin is defined as the approximated bottom of the [redacted] 2019).

2.7.2.1 Base of Fresh Water

The base of fresh water helps define the aquifers that are used for public water supply. Local water agencies in the subbasins have participated in various studies to comply with SGMA. [redacted] Therefore, it is appropriate to consider water quality when delineating the basin bottom (DWR, 2016a).

[redacted]

2.7.2.2 Calculation of Base of Fresh Water and USDW

CTV has used geophysical logs to investigate the USDWs and the base of the USDWs. The calculation of salinity from logs used by CTV is a four-step process:

(1) converting measured density or sonic to formation porosity

The equation to convert measured density to porosity is:

$$POR = \frac{(Rhom - RHOB)}{(Rhom - Rhof)} \tag{5}$$

Parameter definitions for the equation are:

POR is formation porosity
Rhom is formation matrix density g/cc; 2.65 g/cc is used for sandstones
RHOB is calibrated bulk density taken from well-log measurements (g/cc)
Rhof is fluid density (g/cc); 1.00 g/cc is used for water-filled porosity

The equation to convert measured sonic slowness to porosity is done one of two ways.

The Raymer equation:

$$POR = -1\left(\frac{\Delta tma}{2\Delta tf} - 1\right) - \sqrt{\left(\frac{\Delta tma}{2\Delta tf} - 1\right)^2 + \frac{\Delta tma}{\Delta tlog} - 1} \quad (6)$$

Or the Wyllie time-average equation:

$$POR = \left(\frac{\Delta tlog - \Delta tma}{\Delta tf - \Delta tma}\right)\frac{1}{C_p} \quad (7)$$

Parameter definitions for the equations are:

POR is formation porosity

Δtma is formation matrix slowness (μs/ft); 55.5 μs/ft is used for sandstones

Δtf is fluid slowness (μs/ft); 189 μs/ft is used for water-filled porosity

Δtlog is formation compressional slowness from well-log measurements (μs/ft)

Cp is an empirical compaction factor which is calibrated to make sonic porosity equal to density porosity in wells that have both compressional sonic and bulk density logs

(2) calculation of apparent water resistivity using the Archie equation,

The Archie equation calculates apparent water resistivity. The equation is:

$$Rwah = \frac{POR^m R_t}{a} \quad (8)$$

Parameter definitions for the equation are:

Rwah is apparent water resistivity (ohmm)

POR is formation porosity

m is the cementation factor; 2 is the standard value

R_t is deep reading resistivity taken from well-log measurements (ohmm)

a is the Archie constant; 1 is the standard value

(3) correcting apparent water resistivity to a standard temperature

Apparent water resistivity is corrected from formation temperature to a surface temperature standard of 75 degrees Fahrenheit:

$$Rwahc = Rwah\frac{TEMP + 6.77}{75 + 6.77} \quad (9)$$

Parameter definitions for the equation are:

Rwahc is apparent water resistivity (ohmm), corrected to surface temperature

TEMP is down hole temperature based on temperature gradient (DegF)

(4) converting temperature corrected apparent water resistivity to salinity.

The following formula was used (Davis, 1988):

$$SAL\_a\_EPA = \frac{5500}{Rwahc} \tag{10}$$

Parameter definitions for the equation are:

SAL_a_EPA is salinity from corrected Rwahc (ppm)

The evaluation of electrical logs from gas exploration and production wells [redacted] indicates that the base of the USDW occurs at about 750 feet below the ground surface and is separated from the target injection reservoir by about 800 feet of sedimentary rocks, including two competent shale formations [redacted] A map of the depth to base of the USDW is shown on **Figure 2.7-5** and the base USDW is also shown on the geologic cross section in **Figure 2.2-5**.

2.7.3 Formations with USDWs

[redacted]

2.7.3.1 Younger Alluvium and [redacted]

The Younger Alluvium includes recent sediments that have been deposited [redacted] The maximum thickness of Younger Alluvium, where it exists, is 50 feet and is comprised of continental unconsolidated gravel and coarse to medium sand deposited along present stream channels [redacted] The sand and gravel deposits are highly permeable and comprise a significant avenue for percolation to underlying formations [redacted]

The maximum thickness of the [redacted] is 65 to 130 feet and is composed of mainstream arkosic sediments and associated deposits of local derivation laid down during the last major series of aggradation events in the [redacted]

[redacted] materials are similar in character to [redacted]

2.7.3.2 [redacted]

The [redacted]

2.7.3.3 [redacted]

The [redacted]

2.7.3.4 [redacted]

[redacted] described as being stream channel, alluvial, and mudflow deposits derived mainly from andesitic volcanic rocks. The [redacted] consists of two elements: (1) black volcanic sand, silt, and clay layers called [redacted] and (2) dense tuff breccia (DWR, 1974). [redacted]

[redacted]

2.7.3.5 [redacted]

[redacted]

[redacted]

2.7.3.6 [redacted]

The [redacted] has been mapped along the [redacted]

2.7.4 Geologic Cross-Sections Illustrating Formations with Base of Fresh Water

Hydrogeologic cross-section B-B' along the southern edge of the AoR (**Figures 2.7-3 and 2.7-4**) illustrates the vertical distribution of geologic formations and aquifer material that comprise the sediments that could reasonably be tapped for groundwater supply [redacted] From this data, [redacted]

- Depth of water table
- Depth and thickness of saturated fine to coarse-grained sand and gravel layers
- Depth and thickness of discrete layers of sands
- Depth and thickness of discrete clay or silt layers that locally confine groundwater
- Depth of water-bearing aquifer materials (e.g., sands and gravels) down to the base of fresh water and deeper, where available

Analysis identified significant permeable zones with high production rates and good water quality at relatively shallow depths [redacted] due to the following conditions:

- The relatively shallow depths of production wells had high specific capacity that met the water supply demand and reduced the cost associated with drilling deeper.
- The base of fresh groundwater throughout the [redacted]

- Deeper water is saline and not considered suitable for potable or agricultural use.

2.7.5 Principal Aquifer

In the SGMA regulations, principal aquifers are defined as aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems. [redacted]

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

Details on the formations are provided in Section 2.7-3

2.7.5.1 Shallow Aquifer Zone

The shallow, water-bearing zone is composed of permeable sediments from recent alluvium, [redacted] This zone is generally unconfined above the aquitards (clays/silts, including [redacted] and old soil horizons/hardpan layers; [redacted]

The depositional structure on the eastern side of the valley trough is depicted on the hydrogeologic cross-sections A-A’ and B-B’ (**Figure 2.7-4**). This structure results in the groundwater flow that follows both the dip of the beds and hydraulic head differentials. Erosional and depositional features dominate aquifer characteristics. The cross-sections also depict the aquifer thickness from 30 feet to greater than 300 feet [redacted]

2.7.5.2 Intermediate Aquifer Zone

As depicted on the hydrogeologic cross-sections A-A’ and B-B’ (**Figure 2.7-4**), sands, typically from 10 to over 60 feet thick, are found below the low permeability clay layers. The sands and gravels are developed with one relatively continuous sand unit at 350 feet bgs, within the top of the lower unit [redacted]

The aquifer characteristics are supported by the sand thickness information detailed herein for the principal aquifer. The eastern distribution of this water-bearing zone near the surface suggests unconfined groundwater conditions. Typically, this zone is found semi-confined with high-yielding wells and is considered the current primary production zone [redacted]

2.7.5.3 Deep Aquifer Zone

The water-bearing black sands of the semi-consolidated [redacted] This water-bearing zone is confined due to the thick overlying clay units, consolidation, and basin location. Semi-confined conditions are more likely to the east because of the dipping of beds and stratigraphic layer thinning and erosion of clay/silt beds. Consolidated sediments of [redacted] Recharge to these aquifer formations occurs because of the high topographic setting with increased rainfall and exposure of weathered surface and runoff from the adjacent fractured Sierran bedrock [redacted]

2.7.6 Groundwater Levels and Flow

Figure 2.7-6 shows a groundwater contour map reproduced from the [redacted] Groundwater Sustainability Plan for the fourth quarter 2017 [redacted] The horizontal groundwater flow direction for the [redacted] is typically towards areas of lower groundwater near the center of the Subbasin. The flow generally mirrors topography and is relatively consistent over time. The flow direction follows the overall east dipping gradient of the geologic formations [redacted] Higher groundwater elevations are in the foothills [redacted] and the elevations decrease following the topography. In the [redacted] Groundwater elevation is typically lower in monitoring wells with deeper screen placement, suggesting downward flow of groundwater [redacted]

2.7.7 Water Supply and Groundwater Monitoring Wells

The California State Water Resources Control Board Groundwater Ambient Monitoring Assessment Program (GAMA), the DWR, California Statewide Groundwater Elevation Monitoring (CASGEM), and other public databases were searched to identify any water supply and groundwater monitoring wells within a one-mile radius of the AoR. DWR's Water Data Library reports groundwater data collected from a variety of well types including irrigation, stock, domestic, and public supply wells. The State Water Board's GAMA Program was established in 2000 to create a comprehensive groundwater monitoring program throughout California and to increase public availability and access to groundwater quality and contamination information (State Water Board, 2018).

Over 2,000 water wells were identified within one mile of the AoR, 1,539 of which are production wells. Data provided from public databases indicate that the wells identified are completed much shallower than the proposed injection zone. A map of well locations and table of information are found in **Figure 2.7-7** (Water Well Map) and **Table 2.7-2** (Water Well Information), respectively.

The primary uses for groundwater obtained from the principal aquifer are irrigated agriculture, public supply, and rural domestic. Well-screen depth is provided for 575 of the 1,539 production wells from **Table 2.7-2**. Depths of the bottom perforated interval range from 16 to 880 feet with an average depth of 143 feet.

2.8 Geochemistry [40 CFR 146.82(a)(6)]

2.8.1 <u>Formation Geochemistry</u>

All formation geochemistry information is presented in the mineralogy section (section 2.4.1).

2.8.2 <u>Fluid Geochemistry</u>

Three water samples from the storage zones exist within the AoR and from surrounding gas fields in close proximity to the AoR(see **Figure 2.8-1** for well locations).

2.8.2.1 Upper Injection Zone

For the Upper Injection Zone, the [redacted] was sampled in 2013 from within the AoR. The measurement of TDS for the sample is 14,000 mg/L. The complete water chemistry is shown in **Figure 2.8-2**.

The well [redacted] was sampled in [redacted] The measurement of TDS for the sample is 13,889.4 mg/L. The complete water chemistry is shown in **Figure 2.8-3**.

Salinity calculations were also performed on logs from wells within the AoR, and these showed TDS in the Upper Injection Zone being approximately 13,000 to 18,000 ppm. A conservative TDS of 14,000 ppm was used for the computational model.

Historically, [redacted]
Analytical results from natural gas sample collected within the Upper Injection Zone within the boundaries of the AoR from [redacted] indicates that the gas comprises nearly 92 percent methane and 8 percent nitrogen with trace amounts of ethane, propane and carbon dioxide (Medeiros, M., et al., 2018).

2.8.2.2 Lower Injection Zone

For the Lower Injection Zone, the well [redacted] was sampled in [redacted] The measurement of TDS for the sample is 14,415 mg/L. The complete water chemistry is shown in **Figure 2.8-4**.

Salinity calculations were also performed on logs from wells within the AoR, and these showed TDS in the Lower Injection Zone being approximately 13,000 to 18,000 ppm. A conservative TDS of 14,000 ppm was used for the computational model.

No gas production is present within the Lower Injection Zone within the boundaries of the AoR, so no hydrocarbon analysis is available.

2.8.3 Fluid-Rock Reactions

2.8.3.1 Upper Confining Zone

There is no fluid geochemistry analysis for the upper confining zone. The shale will only provide fluid for analysis if stimulated. However, given the low permeability of the rock and the low carbonate content, the upper confining zone is not expected to be impacted by the CO_2 injectate.

2.8.3.2 Upper Injection Zone

Mineralogy and formation fluid interactions have been assessed for the Upper Injection Zone. The following applies to potential reactions associated with the CO_2 injectate:

1. The Upper Injection Zone has a negligible quantity of carbonate minerals and is instead dominated by quartz and feldspar. These minerals are stable in the presence of CO_2 and carbonic acid, and any dissolution or changes that occur will be on grain surfaces.

2. The water within the Upper Injection Zone contains minimal calcium and magnesium cations, which would be expected to react with the CO_2 to form calcium-bearing minerals in the pore space. Also, the salinity being less than 30,000 ppm will reduce the "salting out" effect seen in higher salinity brine under the presence of CO_2.

2.8.3.3 Internal Barrier

There is no fluid geochemistry analysis for the internal barrier zone. The shale will only provide fluid for analysis if stimulated. However, given the low permeability of the rock and the low carbonate content, the internal barrier is not expected to be impacted by the CO_2 injectate.

2.8.3.4 Lower Injection Zone

Mineralogy and formation fluid interactions have been assessed for the Lower Injection Zone. The following applies to potential reactions associated with the CO_2 injectate:

1. The Lower Injection Zone generally has a negligible quantity of carbonate minerals and is instead dominated by quartz and feldspar. These minerals are stable in the presence of CO_2 and carbonic acid, and any dissolution or changes that occur will be on grain surfaces. The few intervals that do have higher concentrations of carbonate minerals are very thin, tight streaks caused by calcite cementing of sands. Dissolution of these will only result in the reduction of vertical permeability barriers within the formation.

2. The water within the Lower Injection Zone contains minimal calcium and magnesium cations, which would be expected to react with the CO_2 to form calcium-bearing minerals in the pore space. Also, the salinity being less than 30,000 ppm will reduce the "salting out" effect seen in higher salinity brine under the presence of CO_2.

2.8.3.5 Geochemical Modeling

Using fluid geochemistry data for the injection zones, and the available mineralogy data for the injection zones and confining zones, geochemical modeling was conducted using PHREEQC (ph-REdox- Equilibrium), the USGS geochemical modeling software, to evaluate the compatibility of the injectates being considered for the project with formation rocks and fluid.

The PHREEQC software was used to evaluate the behavior of minerals and changes in aqueous chemistry and mineralogy over the life of the project, and to identify major potential reactions that may affect injection or containment.

Based on the geochemical modeling, the injection of CO_2 at the CTV V site does not cause significant reactions that will affect injection or containment. Detailed methodology and results can be found in **Appendix 3** submitted with this application.

2.9 Other Information (Including Surface Air and/or Soil Gas Data, if Applicable)

No additional information necessary.

2.10 Site Suitability [40 CFR 146.83]

[redacted]

[redacted]

[redacted]

[redacted]

3.0 AoR and Corrective Action

CTV's AoR and Corrective Action Plan (**Attachment B**) pursuant to 40 CFR 146.82(a)(4), 40 CFR 146.82(a)(13) and 146.84(b), and 40 CFR 146.84(c) describes the process, software, and results to establish the AoR, and the wells that require corrective action.

AoR and Corrective Action GSDT Submissions
GSDT Module: AoR and Corrective Action ***Tab(s):*** All applicable tabs Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☒ Tabulation of all wells within AoR that penetrate confining zone ***[40 CFR 146.82(a)(4)]*** ☒ AoR and Corrective Action Plan *[40 CFR 146.82(a)(13) and 146.84(b)]* ☒ Computational modeling details ***[40 CFR 146.84(c)]***

4.0 Financial Responsibility

CTV's Financial Responsibility demonstration pursuant to 140 CFR 146.82(a)(14) and 40 CFR 146.85 (**Attachment H**) is met with a line of credit for Injection Well Plugging and Post-Injection Site Care and Site Closure and insurance to cover Emergency and Remedial Responses.

Financial Responsibility GSDT Submissions
GSDT Module: Financial Responsibility Demonstration ***Tab(s):*** Cost Estimate tab and all applicable financial instrument tabs Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☒ Demonstration of financial responsibility ***[40 CFR 146.82(a)(14) and 146.85]***

5.0 Injection and Monitoring Well Construction

CTV plans to drill six new injectors for the CTV V storage project. New injection wells are planned and designed specifically for CO_2 sequestration purposes. [redacted]

All planned new wells will be constructed with components that are compatible with the injectate and formation fluids encountered such that corrosion rates and cumulative corrosion over the duration of the project are acceptable. The proposed well materials will be confirmed based on actual CO_2 composition such that material strength is sufficient to withstand all loads encountered throughout the life of the well with an acceptable safety factor incorporated into the design. Casing points will be verified by trained geologists using real-time drilling data such as logging while drilling (LWD) and mud logs to ensure non-endangerment of USDW. Due to the depth of the base of the lowermost USDW, an intermediate casing string will be utilized to isolate the USDW. Cementing design, additives, and placement procedures will be sufficient to ensure isolation of the injection zone and protection of the USDW using cementing materials that are compatible with injectate, formation fluids, and subsurface pressure and temperature conditions.

[redacted]

These conditions are not extreme, and CTV has extensive experience successfully constructing, operating, working over, and plugging wells in depleted reservoirs.

Appendix 5: Injection and Monitoring Well Schematics provides casing diagram figures for all injection and monitoring wells, with construction specifications and anticipated completion details in graphical and/or tabular format.

5.1 Proposed Stimulation Program [40 CFR 146.82(a)(9)]

There are no proposed stimulation programs currently.

5.2 Construction Procedures [40 CFR 146.82(a)(12)]

CTV has created Construction and Plugging documents for each project well pursuant to 40 CFR 146.82(a)(8). Each **Attachment G**: Well Construction and Plugging Plan document includes well construction information based on requirements defined within 40 CFR 146.82. The relevant attachments are:

- Attachment G1: [redacted] Construction and Plugging Plan
- Attachment G2: [redacted] Construction and Plugging Plan
- Attachment G3: [redacted] Construction and Plugging Plan
- Attachment G4: [redacted] Construction and Plugging Plan
- Attachment G5: [redacted] Construction and Plugging Plan
- Attachment G6: [redacted] Construction and Plugging Plan

6.0 <u>Pre-Operational Logging and Testing</u>

CTV has indicated a proposed pre-operational logging and testing plan throughout the application documentation pursuant to 40 CFR 146.82(a)(8). Each **Attachment G**: Well Construction and Plugging Plan document (listed in Section 5.2) includes logging and testing plans for each individual project well based on requirements defined within 40 CFR 146.87.

Pre-Operational Logging and Testing GSDT Submissions
GSDT Module: Pre-Operational Testing ***Tab(s):*** Welcome tab Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☒ Proposed pre-operational testing program ***[40 CFR 146.82(a)(8) and 146.87]***

7.0 <u>Well Operation</u>

7.1 Operational Procedures [40 CFR 146.82(a)(10)]

The Operational Procedures for all injectors associated with the project are detailed in **Appendix 4** (Operational Procedures) document attached with this application.

7.2 Proposed Carbon Dioxide Stream [40 CFR 146.82(a)(7)(iii) and (iv)]

CTV is planning to construct a carbon capture and sequestration "hub" project (*i.e.*, a project that collects CO_2 from multiple sources over time and injects the CO_2 stream(s) via Class VI UIC permitted injection well(s)). Therefore, CTV is currently considering multiple sources of anthropogenic CO_2 for the project. Potential sources include capture from existing and potential future industrial sources in the Sacramento Valley area, as well as Direct Air Capture (DAC). CTV would expect the CO_2 stream to be sampled at the transfer point from the source and between the final compression stage and the wellhead. Samples will be analyzed according to the analytical methods described in the "**Appendix 10**: QASP" (Table 4) document and the Testing and Monitoring Plan (**Attachment C,** see Table 1).

For the purposes of geochemical modeling, CO_2 plume modeling, AoR determination, and well design, two major types of injectate compositions were considered based on the source.

- Injectate 1: a potential injectate stream composition from DAC or a pre-combustion source (such as a blue hydrogen facility that produces hydrogen using steam methane reforming process) or a post-combustion source (such as a natural gas-fired power plant or steam generator). The primary impurity in the injectate is nitrogen.
- Injectate 2: a potential injectate stream composition from a biofuel capture source (such as a biodiesel plant that produces biodiesel from a biologic source feedstock) or from an oil and gas refinery. The primary impurity in the injectate is light end hydrocarbons (methane and ethane).

The compositions for these two injectates are shown in **Table 7.2-1**, and are based on engineering design studies and literature.

For geochemical and plume modeling scenarios, these injectate compositions were simplified to a 4-component system, shown in **Table 7.2-2** and then normalized for use in the modeling. The 4-component simplified compositions cover 99.9% by mass of Injectate 1 and 2 and cover particular impurities of concern (H_2S and SO_2). The estimated properties of the injectates at downhole conditions are specified in **Table 7.2-3**.

The anticipated injection temperature at the wellhead is 90 to 130° F.

No corrosion is expected in the absence of free-phase water provided that the entrained water is kept in solution with the CO_2. This is ensured by maintaining a [redacted] injectate specification limit, and this specification will be a condition of custody transfer at the capture facility. For transport through pipelines, which typically use standard alloy pipeline materials, this specification is critical to the mechanical integrity of the pipeline network, and out of specification product will be immediately rejected. Therefore, all product transported through pipeline to the injection wellhead is expected to be dry-phase CO_2 with no free-phase water present.

Injectate water solubility will vary with depth and time as temperature and pressures change. The water specification is conservative to ensure water solubility across super-critical operating ranges. CRA tubing will be used in the injection wells to mitigate any potential corrosion impact should free-phase water from the reservoir become present in the wellbore, such as during shut-in events when formation liquids, if present, could backflow into the wellbore. CTV may further optimize the maximum water content specification prior to injection based on technical analysis.

8.0 Testing and Monitoring

CTV's Testing and Monitoring plan (**Attachment C**) pursuant to 40 CFR 146.82 (a) (15) and 40 CFR 146.90 describes the strategies for testing and monitoring to ensure protection of the USDW, injection well mechanical integrity, and plume monitoring.

Testing and Monitoring GSDT Submissions
GSDT Module: Project Plan Submissions ***Tab(s):*** Testing and Monitoring tab Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☒ Testing and Monitoring Plan [40 CFR 146.82(a)(15) and 146.90]

9.0 Injection Well Plugging

CTV's Injection Well Plugging Plan pursuant to 40 CFR 146.92 (**Attachment G**) describes the process, materials, and methodology for injection well plugging.

Injection Well Plugging GSDT Submissions
GSDT Module: Project Plan Submissions ***Tab(s):*** Injection Well Plugging tab Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☒ Injection Well Plugging Plan [40 CFR 146.82(a)(16) and 146.92(b)]

10.0 Post-Injection Site Care (PISC) and Site Closure

CTV has developed a Post-Injection Site Care and Site Closure Plan (**Attachment E**) pursuant to 40 CFR 146.93 (a) to define post-injection testing and monitoring.

CTV is proposing an alternative PISC timeframe as described in **Attachment E**.

PISC and Site Closure GSDT Submissions
GSDT Module: Project Plan Submissions ***Tab(s):*** PISC and Site Closure tab Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☒ PISC and Site Closure Plan [40 CFR 146.82(a)(17) and 146.93(a)]
GSDT Module: Alternative PISC Timeframe Demonstration ***Tab(s):*** All tabs (only if an alternative PISC timeframe is requested) Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☒ Alternative PISC timeframe demonstration ***[40 CFR 146.82(a)(18) and 146.93(c)]***

11.0 Emergency and Remedial Response

CTV's Emergency and Remedial Response Plan (**Attachment F**) pursuant to 40 CFR 164.94 describes the process and response to emergencies to ensure USDW protection.

Emergency and Remedial Response GSDT Submissions
GSDT Module: Project Plan Submissions ***Tab(s):*** Emergency and Remedial Response tab Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☒ Emergency and Remedial Response Plan *[40 CFR 146.82(a)(19) and 146.94(a)]*

12.0 Injection Depth Waiver and Aquifer Exemption Expansion

No depth waiver or Aquifer Exemption expansion is being requested as part of this application

Injection Depth Waiver and Aquifer Exemption Expansion GSDT Submissions
GSDT Module: Injection Depth Waivers and Aquifer Exemption Expansions ***Tab(s):*** All applicable tabs Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☐ Injection Depth Waiver supplemental report ***[40 CFR 146.82(d) and 146.95(a)]*** ☐ Aquifer exemption expansion request and data ***[40 CFR 146.4(d) and 144.7(d)]***

13.0 References

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FIGURES

[redacted]

Figure 2.1-1. Location map of the project AoR (red) in relation to the [redacted] CO_2 plume boundaries shown for the Upper Injection Zone (green) and Lower Injection Zone (blue).

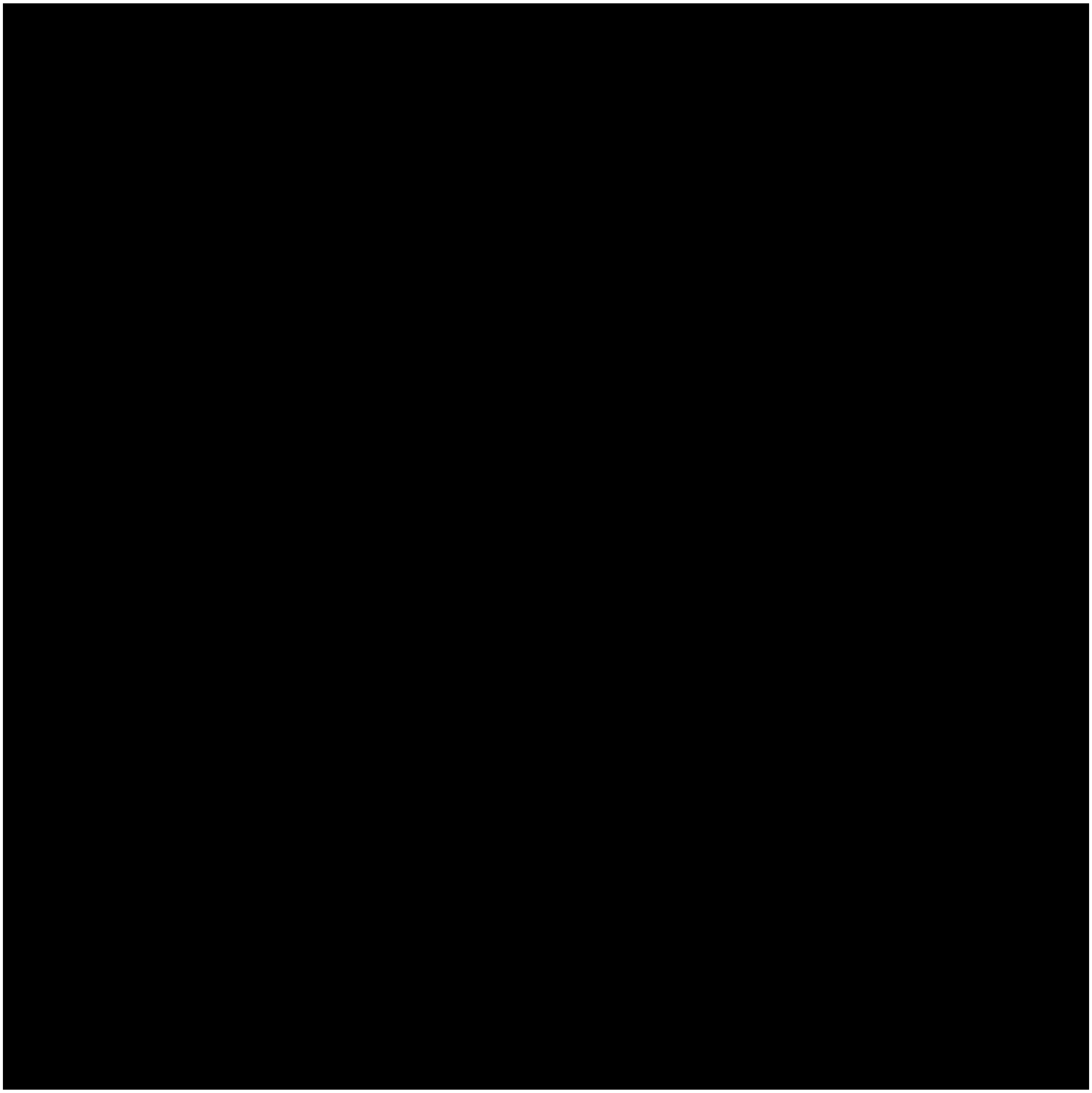

Figure 2.1-2. Location map of California modified from (Beyer, 1988) & (Sullivan, 2012). The Sacramento Basin regional study area is outlined by a dashed black line. B – Bakersfield; F – Fresno; R – Redding.

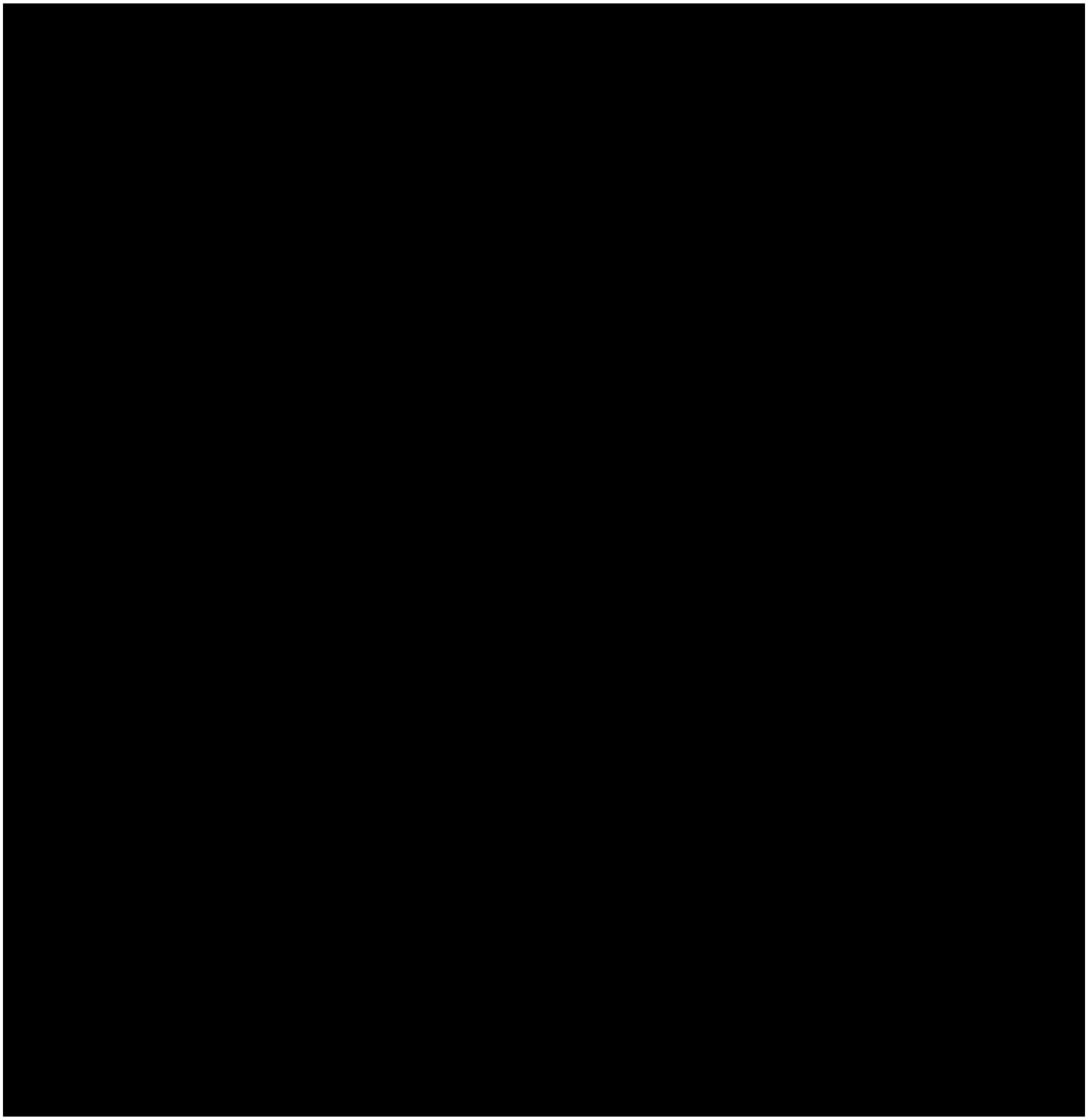

Figure 2.1-3. Migrational position of the Mendocino triple junction (Connection point of the Gorda, North American and Pacific plates) on the west and migrational position of Sierran arc volcanism in the east (Graham, 1984). The figure indicates space-time relations of major continental-margin tectonic events in California during the Miocene.

[redacted]

Figure 2.1-4. Schematic W-E cross-section of California, highlighting the [redacted] as a continental margin during late Mesozoic. The oceanic Farallon plate was forced below the west coast of the North American continental plate.

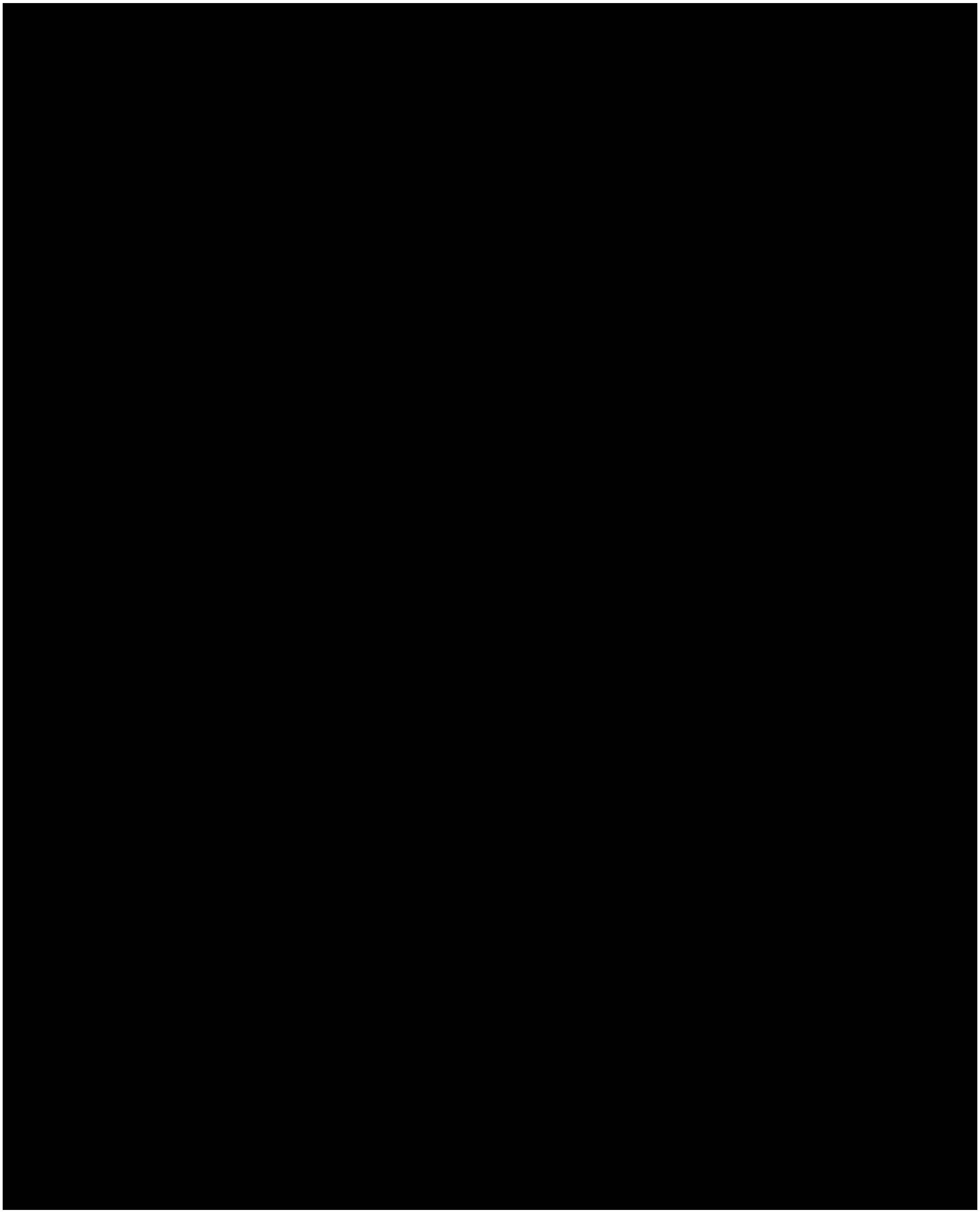

Figure 2.1-5. Evolutionary stages showing the history of the arc-trench system of California from Jurassic (A) to Neogene (E) (modified from Beyer, 1988).

[redacted]

Figure 2.1-6. Schematic west to east cross section in the [redacted]

[redacted]

Figure 2.1-7a. [redacted] isopach map for the greater Lower Injection Zone project area. Wells shown as orange dots on the map have open-hole logs.

[redacted]

Figure 2.1-7b. [redacted] isopach map for the greater Upper Injection Zone project area. Wells shown as orange dots on the map have open-hole logs.

[redacted]

Figure 2.2-1. Existing oil/gas wells and injector well locations in the AoR.

[redacted]

Figure 2.2-2. Wells drilled in the project area with porosity data are shown in gray, wells with core are shown in green and wells used for ductility calculation are shown in pink.

[redacted]

Figure 2.2-3. Type well showing average rock properties for the confining zones and injection zones within the project AoR.

Figure 2.2-4. Summary map and area of seismic data used to build the structural model. The overlapping 3D seismic surveys used to build the structural model were acquired between 1997 and 1999. The single 2D seismic line used was acquired in 1981. California gas fields are shown in red for reference.

[redacted]

Figure 2.2-5. Cross section showing stratigraphy and lateral continuity of major formations across the AoR.

[redacted]

Figure 2.2-6. Lower Injection Zone structure and thickness maps.

[redacted]

Figure 2.2-7. Injection well location map for the project area. The injection wells can be separated into two groups: Lower Injection Zone: [redacted] and Upper Injection Zone: [redacted]

[redacted]

Figure 2.2-8. Upper Injection Zone structure and thickness maps.

[redacted]

Figure 2.2-9. Map of the AoR and surface features in the project area. Mine and quarries from Conservation Division of Mine Reclamation (DMR) & U.S. Geological Survey (USGS). No springs or tribal lands are identified near AoR.

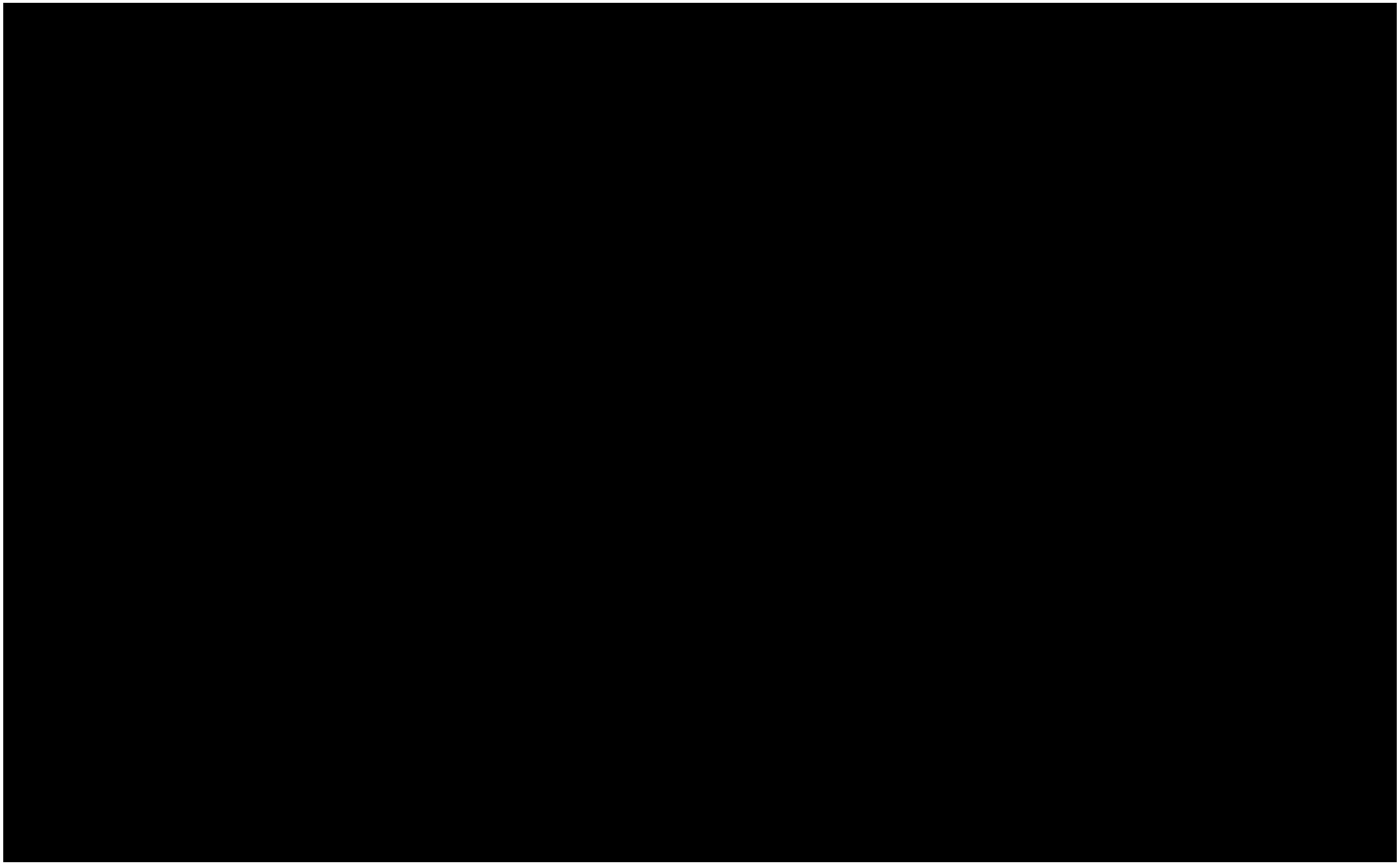

Figure 2.2-10. State- or EPA-approved subsurface cleanup sites (source: State Water Resources Control Board GeoTracker online database).

[redacted]

Figure 2.2-11. Summary map of the AoR, oil or gas wells, water wells, State- or EPA-approved subsurface cleanup sites, and surface features in the project area. Mine and quarries from Conservation Division of Mine Reclamation (DMR) & U.S. Geological Survey (USGS). Water wells from California Division of Drinking Water (DWR) and Groundwater Ambient Monitoring and Assessment (GAMA) program. No springs or tribal lands are identified near AoR. Active wells include: Gas Storage and Observation wells. Plugged wells include: Core holes, Dry Gas, Down Hole, Gas, and Gas Storage wells. Idle wells include: Dry Gas, Gas Storage, and Observation wells

[redacted]

Figure 2.3-1: Reference map for normal fault traces within proximity of the AoR. The traces are shown at the [redacted] and highlight the up and down thrown sides of the faults.

[redacted]

Figure 2.3-2. Generalized structural section through the interpreted normal fault identified on 3D seismic data that intersects the western edge of the AoR. This style of faulting is typical for the area with a throw of approximately 100 feet at the [redacted]

[redacted]

Figure 2.3-3. Generalized structural section through the interpreted normal fault identified on 3D seismic data within the eastern portion of the AoR. This style of faulting is typical for the area with a throw of approximately 50 feet at the [redacted]

[redacted]

Figure 2.3-4. Fault activity map from the California Geologic Survey which shows no mapped faults within and beyond the project AoR. (https://maps.conservation.ca.gov/cgs/fam/)

[redacted]

Figure 2.4-1. Permeability transform for [redacted]

[redacted]

Figure 2.4-2. Example log from the [redacted] The last track shows a comparison of the permeability calculated from the transform (black) shown in **Figure 2.4-1** to permeability calculated from an NMR log (green) and rotary sidewall core permeability (red dots). Track 1: Correlation and caliper logs. Track 2: Measured depth. Track 3: Vertical depth and vertical subsea depth. Track 4: Zones. Track 5: Resistivity. Track 6: Compressional sonic, density, and neutron logs. Track 7: NMR total porosity and bound fluid. Track 8: Volume of clay. Track 9: Porosity calculated from density and NMR total porosity (green). Track 10: Permeability calculated using permeability transform and NMR Timur-Coates permeability (green).

[redacted]

Figure 2.4-3. Map of wells with porosity and permeability data.

[redacted]

Figure 2.4-4. Thickness and structure maps for Upper Confining Zone, Upper Injection Zone

[redacted]

Figure 2.4-5. Thickness and structure maps for Barrier and Lower Injection Zone.

[redacted]

Figure 2.5-1. Unconfined compressive strength and ductility calculations for well [redacted] The ductility is less than two for all of the upper confining zone, secondary confining zone, and the internal barrier. Track 1: Correlation logs. Track 2: Measured depth. Track 3: Vertical depth and vertical subsea depth. Track 4: Zones. Track 5: Resistivity. Track 6: Density and neutron logs. Track 7: Density and compressional sonic logs. Track 8: Volume of clay. Track 9: Porosity calculated from density. Track 10: Water saturation. Track 11: Permeability. Track 12: Caliper. Track 13: Overburden pressure and hydrostatic pore pressure. Track 14: UCS and UCS_NC. Track 15: Brittleness.

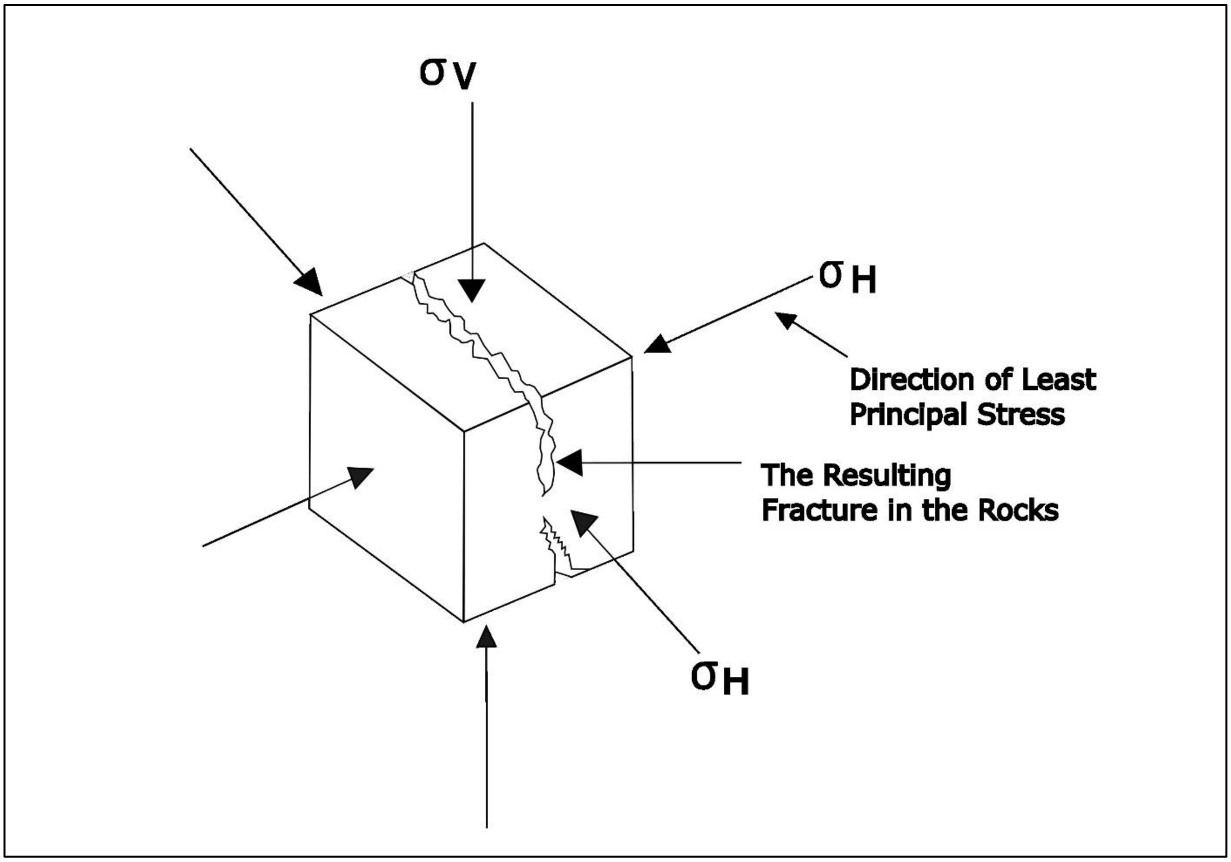

Figure 2.5-2: Stress diagram showing the three principal stresses and the fracturing that will occur perpendicular to the minimum principal stress.

[redacted]

Figure 2.5-3: World Stress Map output showing S_{Hmax} azimuth indicators and earthquake faulting styles in the [redacted] (Heidbach et al., 2016). In red is the outline of the project AoR. The background coloring represents topography.

[redacted]

Figure 2.5-4. Map showing the location of wells with formation integrity tests (FIT).

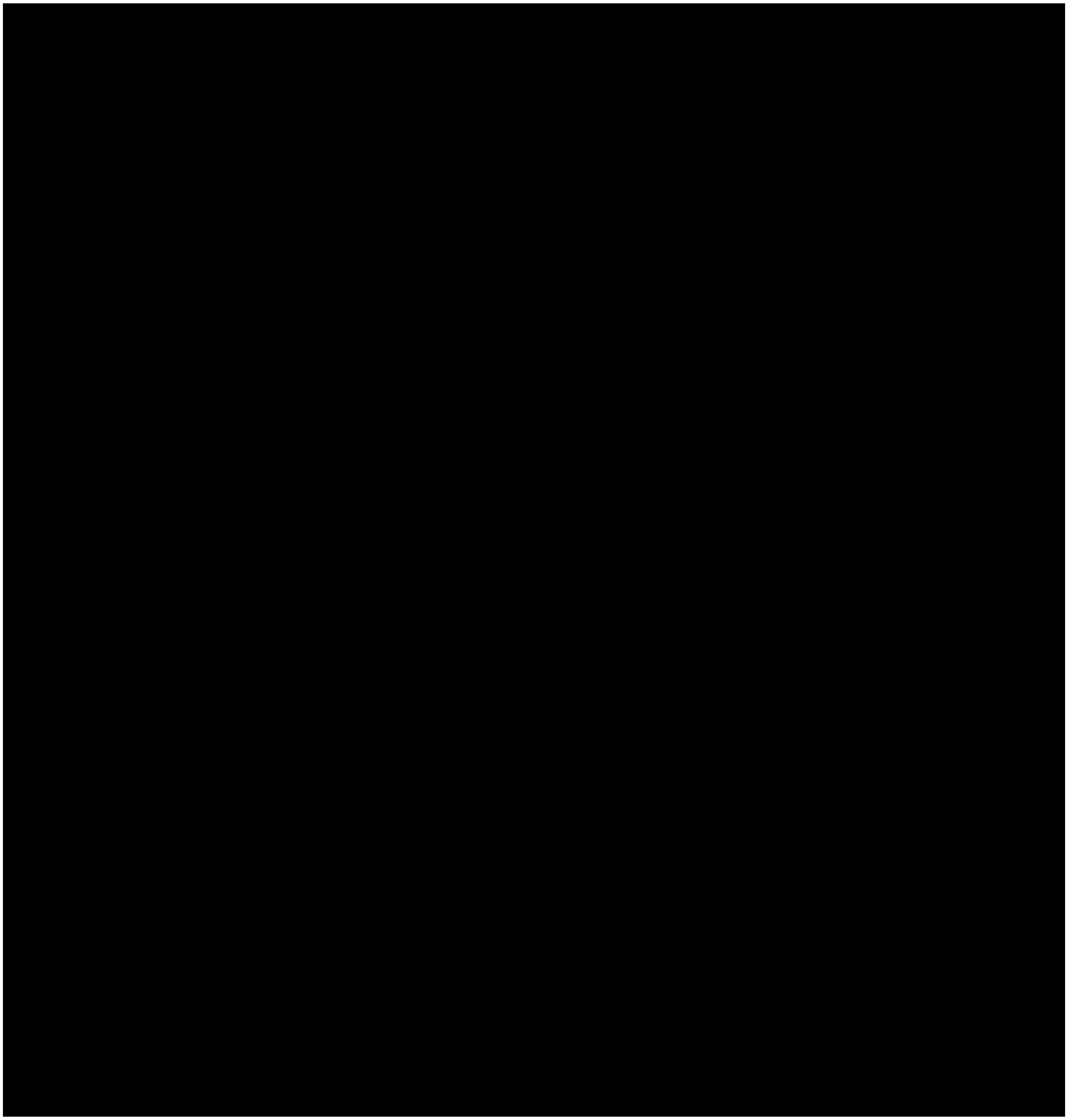

Figure 2.6-1. Historical earthquakes from the USGS catalog tool for the greater area. Data from these events are compiled in **Table 2.6-1**. (https://earthquake.usgs.gov/earthquakes/search/)

[redacted]

Figure 2.6-2. Image modified from Lund-Snee and Zoback (2020) showing relative stress magnitudes across California. Red star indicates the CTV V site area.

[redacted]

Figure 2.7-1 Map of the project AoR, groundwater subbasins, the surrounding areas

[redacted]

Figure 2.7-2. Elevation (meters below land surface) of the Estimated Base of Fresh Water (2,000 mg/L TDS) from [redacted]

[redacted]

Figure 2.7-3 Base of fresh water map [redacted]

[redacted]

Figure 2.7-4 Geologic Cross Section B-B' showing Base of Fresh Water [redacted]

[redacted]

Figure 2.7-5 Depth to the base of the lowermost USDW based on the calculation of salinity from logs from AoR.

[redacted]

Figure 2.7-6 Groundwater level contours, 4th Quarter 2017 [redacted]

[redacted]

Figure 2.7-7 Water well location map.

[redacted]

Figure 2.8-1: Map of wells with water samples.

[redacted]

Figure 2.8-2: Water geochemistry for [redacted] (Upper Injection Zone in AoR).

[redacted]

Figure 2.8-3: Water geochemistry for [redacted] Upper Injection Zone outside of the AoR).

[redacted]

Figure 2.8-4: Water geochemistry for [redacted] (Lower Injection Zone outside of the AoR).

[redacted]

Figure 2.10-1. Lateral dispersion and development of CO_2 plumes through time and confinement under the Upper Confining Zone.

[redacted]

Figure 5.0-1. Map showing the location of injection wells and monitoring wells.

TABLES

Table 2.2-1 Reference list of Water Supply Wells in the AoR

[redacted]

Table 2.2-1 Reference list of Water Supply Wells in the AoR

[redacted]

Table 2.2-1 Reference list of Water Supply Wells in the AoR

[redacted]

Table 2.2-1 Reference list of Water Supply Wells in the AoR

[redacted]

Table 2.2-1 Reference list of Water Supply Wells in the AoR

[redacted]

Table 2.2-1 Reference list of Water Supply Wells in the AoR

[redacted]

Table 2.4-1. Formation mineralogy from x-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) in eight wells

[redacted]

[redacted]

[redacted]

Table 2.4-2. Sonic porosity equations by zone

[redacted]

Table 2.4-3. Core samples from in the Upper Injection Zone

[redacted]

Table 2.4-4. Core samples from in the Lower Injection Zone

[redacted]

Table 2.4-5. [redacted] gross thickness and depth within the project AoR

Zone	Formation	Property	Low	High	Mean
Upper Confining Zone	[redacted]	Thickness (feet)	72	1,361	530
		Depth (TVD)	4,154	5,670	4,778
Upper Injection Zone	[redacted]	Thickness (feet)	18	1,902	963
		Depth (TVD)	4,427	6,975	5,433
Internal Barrier	[redacted]	Thickness (feet)	58	269	146
		Depth (TVD)	5,328	7,164	6,396
Lower Injection Zone	[redacted]	Thickness (feet)	760	2,660	1,401
		Depth (TVD)	5,399	7,286	6,507

Table 2.6-1. Data from USGS earthquake catalog for faults in the greater region of the project

[redacted]

Table 2.7-1. Stratigraphic Information

[redacted]

Table 2.7-2 Water Well Information

[redacted]

Table 2.7-2 Water Well Information

[redacted]

Table 2.7-2 Water Well Information

[redacted]

Table 2.7-2 Water Well Information

[redacted]

Table 2.7-2 Water Well Information

[redacted]

Table 2.7-2 Water Well Information

[redacted]

Table 2.7-2 Water Well Information

[redacted]

Table 2.7-2 Water Well Information

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Table 2.7-2 Water Well Information

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Table 2.7-2 Water Well Information

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Table 2.7-2 Water Well Information

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Table 2.7-2 Water Well Information

[redacted]

Table 2.7-2 Water Well Information

[redacted]

Table 2.7-2 Water Well Information

[redacted]

Table 2.7-2 Water Well Information

[redacted]

Table 2.7-2 Water Well Information

[redacted]

Notes:
1= All depths are based on feet below ground surface
WCR= Department of Water Resources Well Completion Report
LAT= Latitide
LONG= Longitude
T= Township
R= Range
S= Section
APN= Assessor Parcel Number
NA= Data is not available or not applicable
GAMA= State Water Board's GAMA website
[redacted] Well is included in both the GAMMA and DWR database

Table 7.2-1. Injectate compositions

Component	Injectate 1 (Mass %)	Injectate 2 (Mass %)
CO_2	99.21%	99.88%
H_2	0.05%	0.01%
N_2	0.64%	0.00%
H_2O	0.02%	0.00%
CO	0.03%	0.00%
Ar	0.03%	0.00%
O_2	0.00%	0.00%
SO_2+SO_3	0.00%	0.00%
H_2S	0.00%	0.01%
CH_4	0.00%	0.04%
NOx	0.00%	0.00%
NH_3	0.00%	0.00%
C_2H_6	0.00%	0.05%
Ethylene	0.00%	0.00%
Total	100.00%	100.00%

Table 7.2-2. Simplified four component composition for Injectate 1 and Injectate 2

Injectate 1	
Component	**Mass %**
CO_2	99.213%
N_2	0.643%
SO_2+SO_3	0.003%
H_2S	0.001%

Injectate 2	
Component	**Mass %**
CO_2	99.884%
CH_4	0.039%
C_2H_6	0.053%
H_2S	0.014%

Table 7.2-3. Injectate properties range over project life at downhole conditions for Injectate 1 and Injectate 2

Injectate property at downhole conditions	Injectate 1	Injectate 2
Viscosity, cp	0.022 – 0.054	0.022 – 0.056
Density, lb/ft^3	9.1 - 40.6	9.1 – 41.5
Compressibility factor, Z	0.81 - 0.67	0.80 – 0.66