Carbon TerraVault IV
Class VI Permit Application
Narrative Report

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

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Document Version History

Version	Revision Date	File Name	Description of Change
1	4/24/2023	Att A – CTV IV Narr_v1	Original Submission
2	6/13/2023	Att A – CTV IV Narr_v2	Edits to address EPA comments dated 5/25/2023: Section 2.2 and Figures
3	6/27/2023	Att A – CTV IV Narr_v3	Added Figure 2-2-11

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

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 eight CO_2 geologic sequestration wells at the project area located in Sacramento 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] (Upper Injection Zone) at [redacted] on average for [redacted] for a total of [redacted] (MMT), and in the [redacted] (Lower Injection Zone) at [redacted] on average for [redacted] for a total of [redacted] Taking both injection zones, [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 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 IV (CTV IV) storage site is located in the [redacted] The project is comprised of eight injectors, surface facilities, and monitoring wells. This supporting documentation applies to the eight 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
715 P Street, MS 1804,
Sacramento, CA 95814
(916) 203-7734

2. CA Senate District 6
Senator Roger Niello
2200A Douglas Boulevard – Suite 100
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(916) 772-0589

3. CA Assembly District 9
Assemblyman Heath Flora
578 North Wilma Avenue – Suite B
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(209) 948-7479

4. Sacramento County District 5
Supervisor – Pat Hume
700 H Street – Suite 2450
Sacramento, CA 95814
(916) 874-5465

5. Sacramento County Planning and Environmental Review
Director – Todd Smith
827 7th Street, Room 225
Sacramento, CA 95814
(916) 874-6141

6. Sacramento County Council of Governments
Executive Director – James Corless
1415 L Street
Sacramento, CA 95814
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7. Region 9 Environmental Protection Agency
75 Hawthorne Street
San Francisco, CA 94105
(415) 947-8000

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 IV storage site is [redacted]

2.1.2 Geology Overview

The CTV IV 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, that contains a steep western flank and a broad, shallow eastern flank, spans approximately 240 miles in length and 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 migrational event 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, that became named the Great Valley, 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 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 Nevadas, that make up the eastern boundary, are a result of a chain of ancient volcanos.

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 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 approximately [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]

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) 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 and the area of the structural framework that was built from these seismic surveys. Also shown are the seismic well ties made to the 2D data. Available three-dimensional (3D) seismic data to the west of the area were used to confirm the seismic horizons that were interpreted back to additional well ties. The 3D data were also used as the basis for phase and time matching the 2D seismic lines so that the surfaces were mapped on a consistent datum. The 2D 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]
- [redacted]

Due to the shallower sedimentary section [redacted] to use as the base of this model and to map any basement involved faulting seen in the data. 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 on a 3,000 by 3,000 foot cell basis due to the distance between the 2D lines. Alongside this mapping was the interpretation of any faulting in the area which is discussed further in Section 2.3 (Faults and Fracture) of this document.

The gridded time maps and a sub-set of the highest quality well ties and associated velocity data are 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 create the following depth grids for input in to the geologic and plume growth models:

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

2.2.2 Stratigraphy

[redacted]

[redacted]

2.2.2.1 [redacted] *(Lower Confining 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]

Five injectors will inject into the Lower Injection Zone sands as shown above in **Figure 2.2-6**. A total of eight injectors are required for the combined Upper and Lower Injection Zones (**Figure 2.2-7**).

2.2.2.3 [redacted] *(Internal Barrier)*

The [redacted] is a regional [redacted] West of the project area, [redacted] Due to its [redacted]

2.2.2.4 [redacted] *(Upper Injection Zone)*

The [redacted] Deposited as [redacted] In the [redacted]

Three injectors will inject into the Upper Injection Zone sands as shown in **Figure 2.2-8**. A total of eight injectors are required for the combined Upper and Lower Injection Zones (**Figure 2.2-7**).

2.2.2.5 [redacted] *(Upper Confining Zone)*

The [redacted] and acts as the Upper Confining Zone for the storage project. [redacted]

[redacted] serves as the sealing facies above the Upper and Lower Injection Zones and will prevent the upward migration of CO_2 from the storage reservoirs, thus protecting USDWs.

2.2.2.6 [redacted] *(Dissipation Zone)*

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

2.2.2.7 [redacted] *(Secondary Confining Zone)*

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, 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]

The project AoR is in Sacramento County. [redacted]

[redacted] This cleanup site information was obtained from the State Water Resources Control Boards̓ 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 maps showing the injection wells, the AoR, and the list of items below:

- Existing injection wells, producing wells, abandoned wells, plugged wells or dry holes, deep stratigraphic boreholes. **Figure 2.2-1** displays abandoned oil and gas wells in the AoR. All abandoned wells were dry holes, and there are no injection or producing wells in the AoR.
- Surface bodies of water, springs, mines (surface and subsurface), quarries, State, Tribal, and Territory boundaries, roads and other pertinent surface features are shown on **Figure 2.2-9** where present.
- State- or EPA-approved subsurface cleanup sites are displayed on **Figure 2.2-10**.
- Water wells are shown on **Figure 2.7-6** (see Section 2.7).
- **Figure 2.2-11** is a compilation of the above data.

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

A combination of 2D 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 Mineralogy

No quantitative mineralogy information exists within the AoR boundary. 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 location of wells used for mineralogy are shown in **Figure 2.4-1**, 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, with kaolinite and chlorite still prevalent. They also contain 32% quartz, 39% plagioclase and potassium feldspar, minimal pyrite, and less than 1% calcite & dolomite.

2.4.1.2 Upper Injection Zone

Mineralogy data is available for the Upper Injection Zone in the form of XRD data from two wells outside the AoR, [redacted] Reservoir sand from five samples within these wells averages 34% quartz, 39% plagioclase and potassium feldspar, and 25% total clay. The primary clay minerals are kaolinite 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, with kaolinite and chlorite still prevalent. They also contain 23% quartz, 29% plagioclase and potassium feldspar, 2% pyrite, and 1% calcite & dolomite.

2.4.1.4 Lower Injection Zone

Mineralogy data is available for the Lower Injection Zone from XRD data in [redacted] and from [redacted] while a mix of XRD and FTIR data is available in [redacted] Reservoir sand from 30 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 & 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 Lower Confining Zone [redacted]

Mineralogy data is available for the [redacted] in the form of XRD data from [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 & dolomite. Two samples show calcite cementation.

2.4.1.6 Lower Confining Zone [redacted]

Mineralogy data is available for the [redacted] in the form of XRD data from [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 & 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.

Formation porosity is determined one of three 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 or the Raymer-Hunt equation. See **Table 2.4-2** for explanation of which equations were used in each zone.

Volume of clay 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 2.4-2**.

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

A log plot for [redacted] is included in **Figure 2.4-4**, showing the calculated model curves within the AoR.

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 2.4-5** 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. Two core data points from [redacted] (see **Figure 2.4-1** for well location) are from the Upper Confining Zone. Permeability was measured and is in agreement with the log averages (see **Table 2.4-3**).

2.4.2.2 Upper Injection Zone

The average porosity for the Upper Injection Zone is 31.4%, based on 10 wells with porosity logs and 3,117 individual logging data points. The geometric average permeability for the Upper Injection Zone is 201.2 mD, based on 10 wells with porosity logs and 3114 individual logging data points. Twenty-eight core data points from the [redacted] (see **Figure 2.4-1** for well location) are from the Upper Injection Zone. Permeability was measured and is in agreement with the log averages (see **Table 2.4-4**).

2.4.2.3 Internal Barrier

The average porosity of the internal barrier zone is 28.3%, based on 7 wells with porosity logs and 1,094 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 30.4%, based on 7 wells with porosity logs and 6685 individual logging data points. The geometric average permeability of the Lower Injection Zone is 139.7 mD, based on 7 wells with porosity logs and 6661 individual logging data points.

2.4.2.5 Lower Confining Zone [redacted]

The average porosity of the [redacted] portion of the lower confining zone is 23.5%, based on 6 wells with porosity logs and 6467 individual logging data points. The geometric average permeability is 1.1 mD, based on 6 wells with porosity logs and 6409 individual logging data points.

2.4.2.6 Lower Confining Zone [redacted]

The average porosity of the [redacted] portion of the lower confining zone is 24.3%, based on 4 wells with porosity logs and 2851 individual logging data points. The geometric average permeability is 1.1 mD, based on 4 wells with porosity logs and 2836 individual logging data points.

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.

No capillary pressure data was available for the Upper Confining Zone, barrier zone or injection zones within project area. This data will be acquired as part of pre-operational testing. The computational modeling used capillary pressure data from sidewall core samples taken from the Injection zones in [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 2.4-6 and Figure 2.4-7**) based on well data (wireline logs) and 2D seismic. Variability of thickness and depth measurements within the project AoR is due to:

1. [redacted]
2. Structural and thickness variability within the Upper Injection Zone is due to erosion [redacted]
3. Structural and thickness variability across the Lower Injection Zone is due to deposition on [redacted]

2.4.5 Structure Maps

Structure maps (**Figure 2.4-6 and Figure 2.4-7**) are provided to indicate a depth to formation adequate for supercritical-state injection.

2.4.6 Isopach Maps

SP logs from surrounding 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 the [redacted] Upper Injection Zone sandstones, and Lower Injection Zone sandstones will not impact confinement. CTV will utilize the thickness 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 unconfined compressive strength (*UCS*) vs. an empirically derived UCS for a normally consolidated rock (UCS_{NC}).

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

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

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

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

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, nine wells had compressional sonic data over the Upper Confining Zone to calculate ductility, comprising 2,656 individual logging data points (see pink squares in **Figure 2.4-1)**. The same nine wells were used to calculate UCS, comprising 2,655 individual logging data points. The average ductility of the Upper Confining Zone based on the mean value is 0.96. The average rock strength of the confining zone, as determined by the log derived *UCS* equation above, is 713 pounds per square inch (psi). This is supported by the fact that prior to discovery the Upper Confining Zone provided a seal to the underlying gas reservoirs of the [redacted]

2.5.1.2 Secondary Confining Zone

Additionally, ductility and rock strength were calculated over the Secondary Confining Zone and the internal barrier zone. Ten wells had sufficient data for the Secondary Confining Zone, comprising 4,276 individual logging data points. The average ductility of the Secondary Confining Zone based on the mean value is 1.05. The average rock strength of the Secondary Confining Zone, as determined by the log derived *UCS* equation above, is 571 psi.

2.5.1.3 Internal Barrier

Seven wells had sufficient data to calculate ductility and rock strength over the barrier zone, comprising 1,094 individual logging data points. The average ductility of the internal barrier zone based on the mean value is 1.81. The average rock strength of the internal barrier zone, as determined by the log derived UCS equation above, is 1,745 psi.

An example calculation for the [redacted] is shown in **Figure 2.5-1**. UCS_CCS_VP is the UCS_NC 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 two (representing ductile rock) is shaded red.

Within the upper confining layer, the brittleness calculation drops to a value less than two. Additionally, the secondary confining layer has a brittleness value less than two. The barrier zone also has a brittleness value less than two. As a result of the confining layer ductility, there are no fractures that will act as conduits for fluid migration from the injection zones.

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 no site-specific fracture pressure or fracture gradient for the injection zones. A step rate test will be conducted as per the pre-operational testing plan (Attachment I) in the injection zones. However, several wells in the [redacted] have formation integrity tests (FIT) performed at similar depth ranges to the project injection and confining zones. Tests from nine wells average 0.76 psi/ft from tests in the depth range of [redacted] TVD. See **Figure 2.5-4** for location of wells. For the computational simulation modeling and well performance modeling, a frac gradient of 0.76 psi/ft was assumed for now.

The overburden stress gradient in the injection and confining zones is 0.87-0.90 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

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

[redacted]

The United States Geologic Survey (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 1850 to modern day with events of a magnitude greater than two and a half. **Figure 2.6-1** shows the results of this search. **Table 2.6-1** summarizes some of the data taken from these events. The events were confirmed to be the same as those in the Northern California Earthquake Data Center (NCEDC, 2014) catalog.

There are two historical earthquakes cataloged in the area. [redacted] As discussed by the authors, [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 IV:

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. Injection pressure will be lower than the fracture gradients of the sequestration reservoir with a safety factor (90% of the fracture gradients).
- 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 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 5.0km. 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 with the state. [redacted]

[redacted]

[redacted] the AoR and vicinity will be referred to as the project area.

2.7.1 Hydrologic Information

[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 total dissolved solids; and which is not an exempted aquifer. For the California Sustainable Groundwater Management Act (SGMA), the bottom of the groundwater basin is defined as the approximated bottom of the Ione Formation, which represents the contact between the continental and marine deposits, or the base of fresh groundwater, whichever is highest in elevation (EKI, 2021).

2.7.2.1 Base of Fresh Water

The base of fresh water (BFW) helps define the aquifers that are used for public water supply. Local water agencies in [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:

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

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:

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

Or the Wyllie time-average equation:

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

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:

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

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:

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

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):

$$SAL\_a\_EPA = \frac{5500}{Rwahc} \quad (10)$$

Parameter definitions for the equation are:
SAL_a_EPA is salinity from corrected Rwahc (ppm)

The base of the USDW is illustrated on the geologic Cross Section A-A' (**Figure 2.2-5**) at a measured depth of between 2,000 ft and 3,000 ft within the project AoR. A map of the depth to base of the lowermost USDW is shown on **Figure 2.7-3**.

2.7.3 Formations with USDWs

[redacted]

2.7.3.1 Younger Alluvium

The Younger Alluvium includes recent sediments that have been deposited [redacted] The maximum thickness of Younger Alluvium, where it exists, is 100 feet and is comprised of unconsolidated silt, fine- to medium-grained sand, and gravel (DWR, 2003). The sand and gravel deposits are highly permeable and can yield significant quantities of water to wells (DWR, 2003). These deposits also provide important areas for groundwater recharge (EKI, 2021).

2.7.3.2 Older Alluvium

The Older Alluvium is comprised mostly of the [redacted] The [redacted] consists of loose to moderately compacted sand, silt, and gravel with discontinuous clay lenses. [redacted]

[redacted]

2.7.3.3 [redacted]

The [redacted] consists of two elements: (1) black volcanic sand, silt, and clay layers [redacted] and (2) dense tuff breccia (DWR, 1974). [redacted]

2.7.3.4 [redacted]

The [redacted] is of volcanic origin and contains greenish clay members along with volcanic ejecta (DWR, 1974). [redacted]

2.7.3.5 Ione Formation

The [redacted] in the project area. [redacted]

[redacted] or the base of fresh groundwater, whichever is highest in elevation (EKI, 2021).

2.7.3.6 [redacted]

The upper Paleogene and Neogene sequence begins with the [redacted] which represents fluvial deposits that blanket the entire southern [redacted] Undifferentiated sediments above [redacted] contain approximately less than 10,000 milligrams per liter (mg/l) total dissolved solids (TDS) water and represent the USDW in the project AoR.

2.7.4 Geologic Cross Sections Illustrating Formations with USDWs

Geologic Cross Section B-B' (**Figure 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] **Figure 2.7-1** shows the location of the cross section. The cross-section was constructed by [redacted] based on the following information sources:

- Water wells that were proximal to the cross-section lines, the perforated/screened interval (when known), and generalized lithologic information from well completion reports, supplemental boring logs including sediment color and depth intervals (e.g., clay, silt, fine sand, sand, gravel, volcanic material);
- Surficial geology informed by [redacted]
- Subsurface formation depths by or modified from pre-existing cross-sections [redacted]
- [redacted]
- [redacted]
- Geophysical survey results [redacted]
- Base of fresh groundwater as mapped by [redacted] in **Figure 2.7-2**
- Fall 2018 groundwater elevations as mapped in **Figure 2.7-5**.

[redacted] Surficial geology along the cross-section is primarily recent alluvium ('Qal'). [redacted]

[redacted]

[redacted] Based on ETS results, there is an inferred clay layer at the interface [redacted] Most production wells in proximity to [redacted]

Base of fresh groundwater is shallowest in [redacted]

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]

2.7.5.1 Upper Aquifer Zone

The upper zone of the principal aquifer is unconfined and consists of alluvium that extends approximately [redacted] below the ground surface (SCGA, 2012; DWR, 2003). Quaternary deposits consist of flood basin deposits, dredge tailings, alluvium and stream channel deposits. Pliocene to Pleistocene-age deposits consist of compacted sand, silt and gravel (DWR, 2004; Marchand and Allwardt, 1981). Permeable sand and gravel deposits are typically enclosed by less permeable silt and clay, resulting in a network of tabular water-bearing zones (DWR, 1974).

2.7.5.2 Lower Aquifer Zone

[redacted]

2.7.6 Groundwater Levels and Flow

Despite a trend towards drier conditions and increasing population, groundwater levels in the [redacted] The recent increase in groundwater levels has been mostly attributed to a blend of conjunctive use projects (i.e., the combined use of groundwater and surface water sources), construction of diversion facilities, urban conservation plans, and changes in use of previous agricultural land. [redacted] Groundwater levels within this area have fluctuated within each year due to seasonal recharge and use variations; over a year or series of years due to short-term droughts and wet periods; and over decades due to changes in land and water use or longer-term hydrologic conditions. (LWA, W&C, 2021).

Groundwater contour maps provide information on groundwater elevations across [redacted] A contour map displays this information by interpolating groundwater data between monitoring sites and plotting a contour line at locations of equal elevation. The elevation contours are then used to identify groundwater flow directions and to calculate the gradient of horizontal flow (LWA, W&C, 2021).

[redacted] The enhanced integrated groundwater and surface water simulation capabilities afforded by [redacted] were intended to assist in a broad range of water management activities in [redacted] was built on the Integrated Water Flow Model (IWFM) framework, which is specifically designated in Sustainable Groundwater Management Act (SGMA) Groundwater Sustainability Plans (GSP) regulations. [redacted]

Simulated groundwater level contours and observed values for calibration wells are shown in **Figure 2.7-5**, for fall 2018 (Woodard & Curran, 2021). The highest groundwater elevations are along the eastern side of the area. The lowest water elevations are in the [redacted]

[redacted] This map illustrates the flow directions, which are generally westward. [redacted] do not have known structural restrictions to groundwater flow. [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 increase public availability and access to groundwater quality and contamination information (State Water Board, 2018).

Over 160 water wells were identified within one mile of the projected surface. 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 2.7-6** (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. [redacted] Irrigation wells are the most frequent type of production wells, comprising 20% of all wells. Public supply wells represent about 10% of the wells in [redacted] and rural domestic wells represent about 15% of the wells [redacted]

[redacted]

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

2.8.1 Formation Geochemistry

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

2.8.2 Fluid Geochemistry

No water samples from the storage zones exist within the AoR, so samples from surrounding gas fields in close proximity to the AoR have been used (see **Figure 2.8-1** for well locations).

For the Upper Injection Zone, the well [redacted] was sampled in [redacted] The measurement of total dissolved solids (TDS) for the sample is 13,889.4 mg/L. The complete water chemistry is shown in **Figure 2.8-2**.

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 – 18,000 ppm. A conservative TDS of 13,889 ppm was used for the computational model.

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

2.8.2.1 Lower Injection Zone

For the Lower Injection Zone, the well [redacted] was sampled in [redacted] The measurement of total dissolved solids (TDS) for the sample is 14,415 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 Lower Injection Zone being approximately 13,000 – 18,000 ppm. A conservative TDS of 14,415 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.

2.8.2.2 Lower Confining Zone

For the [redacted] was sampled in [redacted] The measurement of total dissolved solids (TDS) for the sample is 16,000 mg/L. The complete water chemistry is shown in **Figure 2.8-4**.

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 Lower Confining Zone [redacted]

Mineralogy and formation fluid interactions have been assessed for the [redacted] The following applies to potential reactions associated with the CO_2 injectate:

1. The [redacted] 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 cementation.

2. The water within the [redacted] contains minimal calcium and magnesium cations, which would be expected to react with 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.

2.8.3.6 Lower Confining Zone [redacted]

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

2.8.3.7 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 IV 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]

CTV's estimated storage for the project is [redacted] MMT of CO_2. This was arrived through computational modeling presented in Attachment B.

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 eight new injectors for the CTV IV 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 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 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
- Attachment G7: [redacted] Construction and Plugging Plan
- Attachment G8: [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 Well Operation

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 8: QASP" (Table4) 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: is 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: is 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 & 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 – 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 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 <u>Post-Injection Site Care (PISC) and Site Closure</u>

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 <u>Emergency and Remedial Response</u>

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).

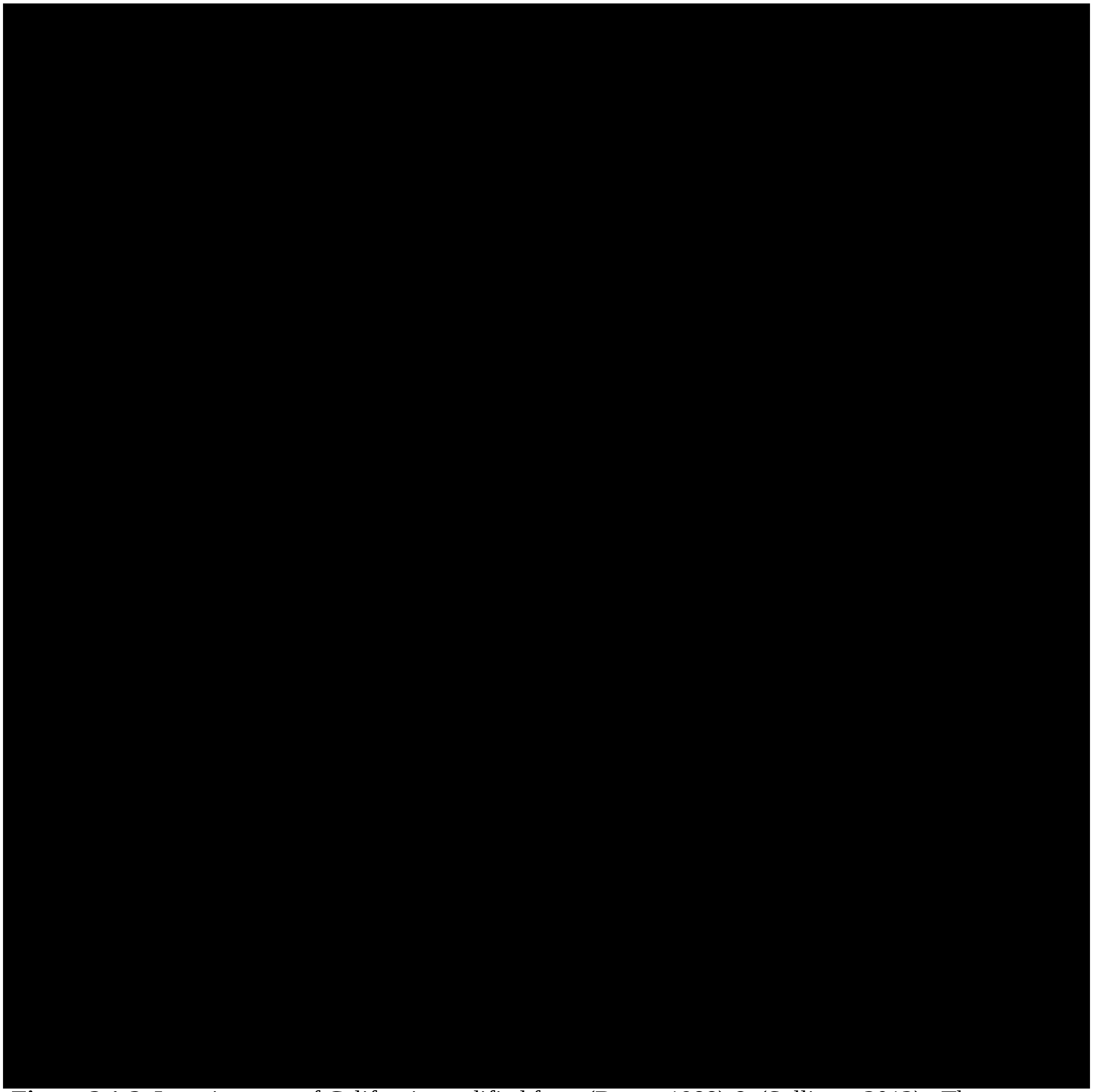

Figure 2.1-2. Location map of California modified from (Beyer, 1988) & (Sullivan, 2012). The Sacramento Basin regional study area is outlined by a dashed black line. B – Bakersfield; F – Fresno; R – Redding.

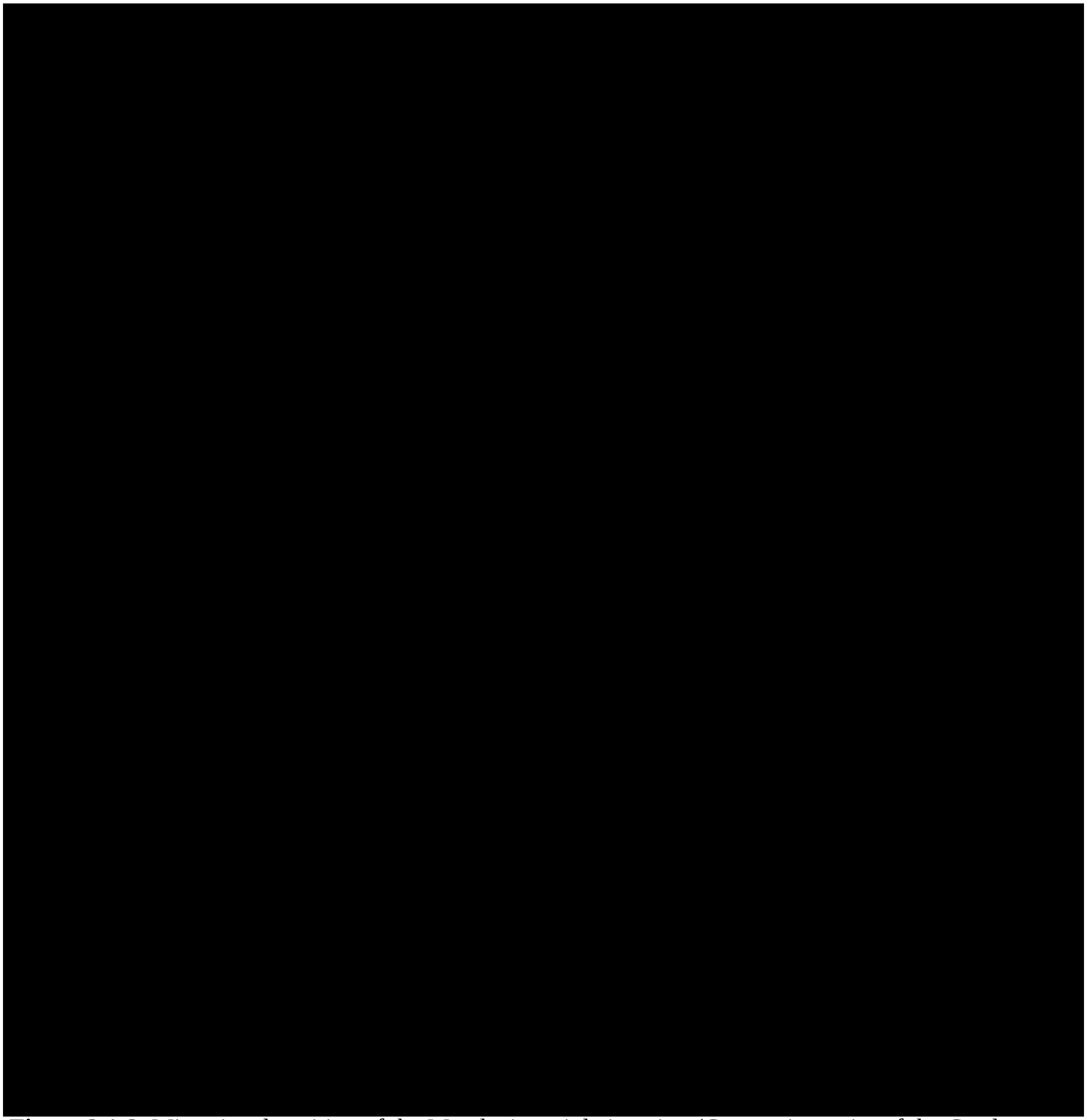

Figure 2.1-3. Migrational position of the Mendocino triple junction (Connection point of the Gorda, North American and Pacific plates) on the west and migrational position of Sierran arc volcanism in the east (Graham, 1984). The figure indicates space-time relations of major continental-margin tectonic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

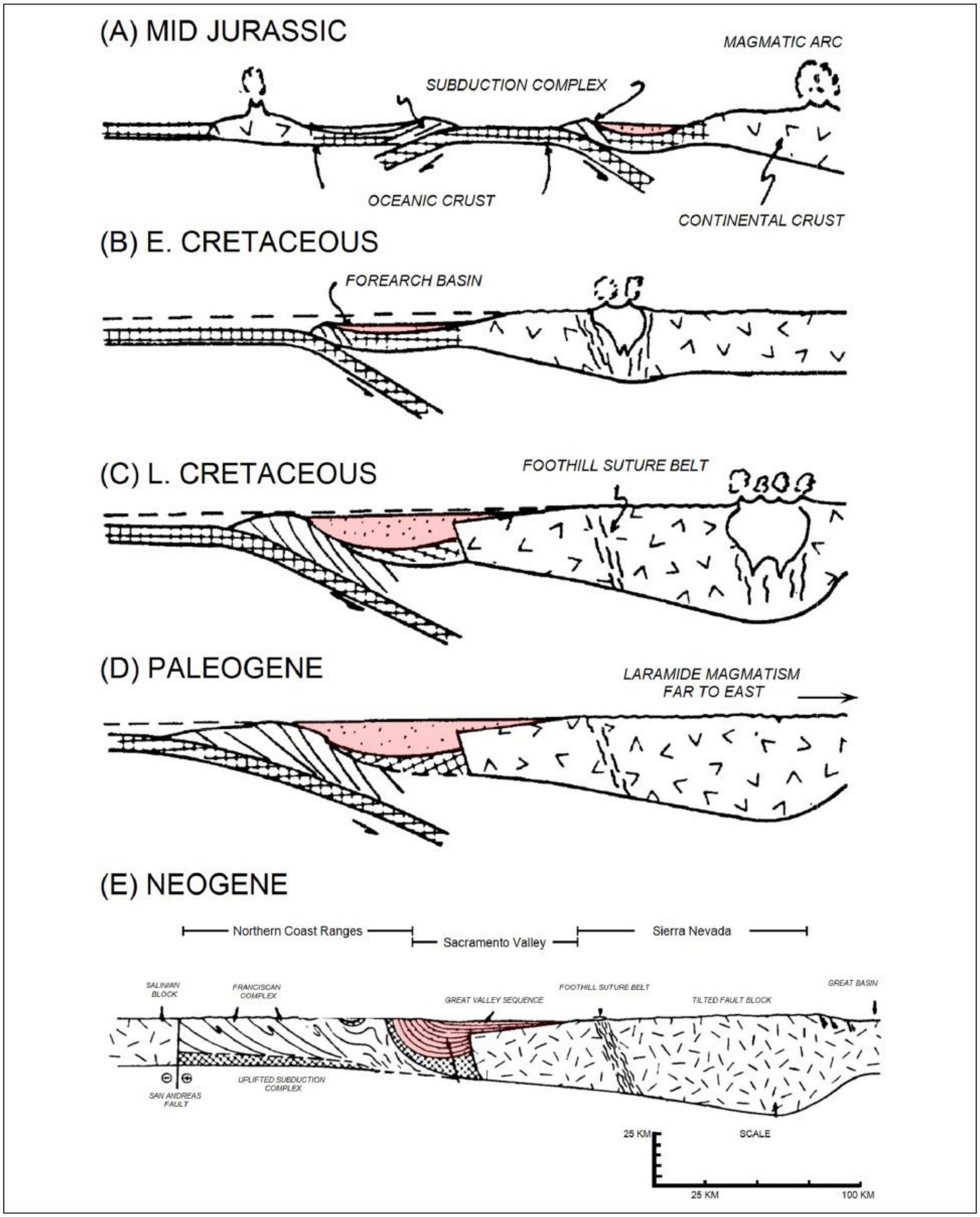

Figure 2.1-5. Evolutionary stages showing the history of the arc-trench system of California from Jurassic (A) to Neogene (E) (modified from Beyer, 1988).

[redacted]

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

[redacted]

Figure 2.1-7. [redacted] isopach map for the greater project area. Wells shown as orange dots on the map penetrate the [redacted] and 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 black, 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.

[redacted]

Figure 2.2-4. Summary map and area of seismic data used to build the structural model. The 2D seismic used to build the structural model were acquired between 1974 and 1987. California gas fields are shown 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.

[redacted]

Figure 2.2-10. State- or EPA-approved subsurface cleanup sites. Source: California State Water Resources Control Board GeoTracker website.

[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.

[redacted]

Figure 2.3-1. Generalized structural section through normal fault identified on 2D seismic data. The fault does not continue through the [redacted] Injection zone. Inset map shows 2D data in pink, CO_2 boundaries in blue and project AoR in red. The approximate location of the fault is indicated by the black arrow outside of the plumes.

[redacted]

Figure 2.3-2. 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. Map showing location of wells relative to the AoR.

[redacted]

Figure 2.4-2. Permeability transform for [redacted]

[redacted]

Figure 2.4-3. Example log from [redacted] The last track shows a comparison of the permeability calculated from the transform (black) shown in **Figure 2.4-2** 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 2.4-4. Log plot for [redacted] showing the log curves used as inputs into calculations of clay volume, porosity and permeability, and their outputs. 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, neutron, and density logs. Track 7: Volume of clay. Track 8: Porosity calculated from log curves. Track 9: Permeability calculated using transform.

[redacted]

Figure 2.4-5. Map of wells with porosity and permeability data.

[redacted]

Figure 2.4-6. Thickness and structure maps for Upper Confining Zone, Upper Injection Zone

[redacted]

Figure 2.4-7. Thickness and structure maps for Barrier and Lower Injection Zone.

[redacted]

Figure 2.5-1. Unconfined compressive strength and ductility calculations for [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.

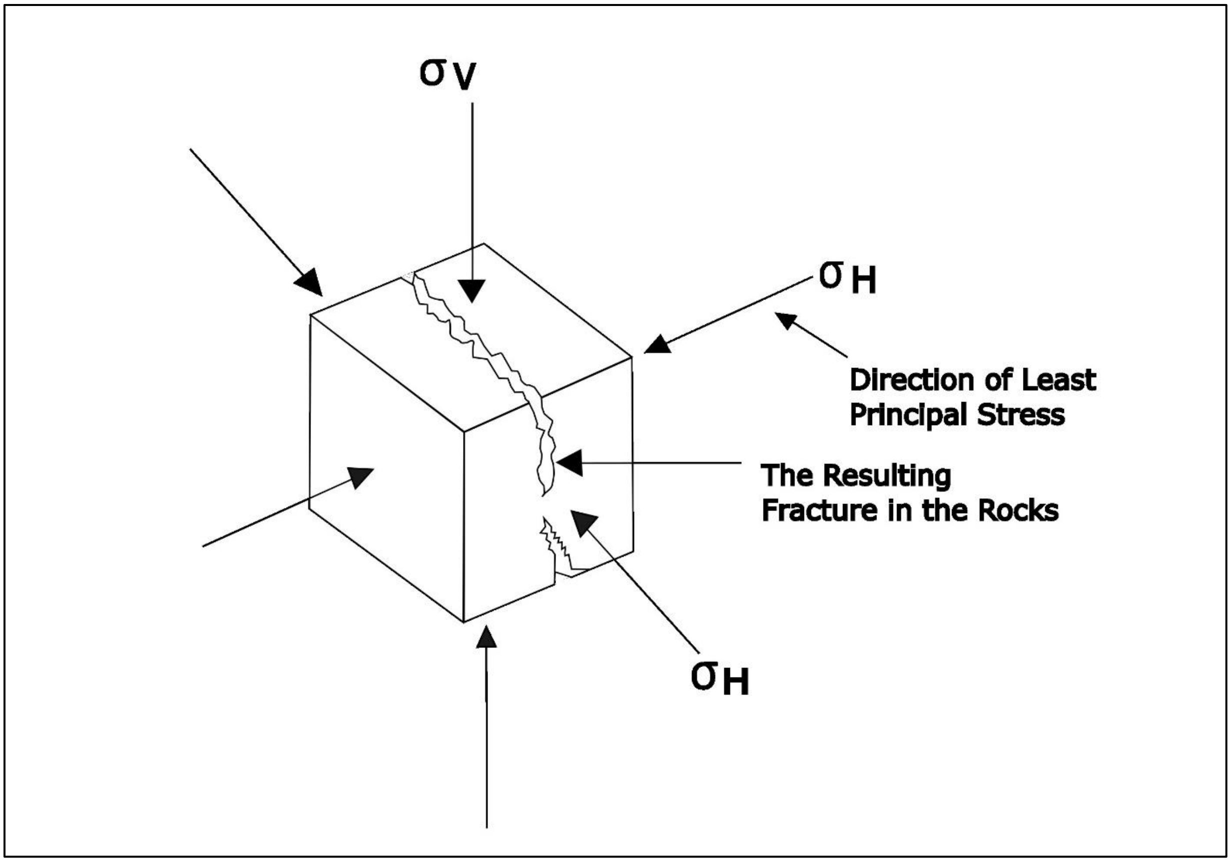

Figure 2.5-2: Stress diagram showing the three principal stresses and the fracturing that will occur perpendicular to the minimum principal stress.

[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).

In the project AoR there is no site-specific fracture pressure or fracture gradient for the upper confining zone. A step rate test will be conducted as per the pre-operational testing plan for the upper confining zone. In the interim, CTV is making the assumption that the upper confining zone will have a similar fracture gradient as the injection zones.

[redacted]

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**.

[redacted]

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

[redacted]

Figure 2.7-1 Map of the project AoR, groundwater subbasins, the surrounding areas, and cross section B-B' location.

[redacted]

Figure 2.7-2 Base of fresh water map.

[redacted]

Figure 2.7-3 Depth to base of the lowermost USDW (feet) based on the calculation of salinity from logs within the AoR.

[redacted]

Figure 2.7-4 Geologic Cross Section B-B'. The location of the B cross section is illustrated on Figure 2.7.1.

[redacted]

Figure 2.7-5 Groundwater level contours and observed values for calibration wells for [redacted] model, fall 2018.

[redacted]

Figure 2.7-6 Water well location map.

[redacted]

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

[redacted]

Figure 2.8-2: Water geochemistry for [redacted]

[redacted]

Figure 2.8-3: Water geochemistry for [redacted]

[redacted]

Figure 2.8-4: Water geochemistry for [redacted]

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

[redacted]

[redacted]

[redacted]

Table 2.4-2. Sonic porosity equations by zone

[redacted]

Table 2.4-3. Core samples from [redacted] in the upper confining zone

[redacted]

Table 2.4-4. Core samples from [redacted] in the upper 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)	192	325	245
		Depth (TVD)	2,067	3,832	3,057
Upper Injection Zone	[redacted]	Thickness (feet)	133	995	412
		Depth (TVD)	2,325	4,083	3,300
Internal Barrier	[redacted]	Thickness (feet)	71	161	107
		Depth (TVD)	2,492	4,939	3,720
Lower Injection Zone	[redacted]	Thickness (feet)	1,062	1,931	1,418
		Depth (TVD)	2,609	5,071	3,826

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]

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

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